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 2011

Natural Resource Data Series NPS/NCCN/NRDS—2013/462

ON THE COVER
Snow still covers the Sunrise Visitor Center on June 20, 2011.
Photograph by: Mount Rainier National Park

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March 2013

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 (http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Lofgren, R. A., B. Baccus, M. Larrabee, and M. Huff. 2013. North Coast and Cascades Network climate monitoring report: Mount Rainier National Park; water year 2011. Natural Resource Data Series NPS/NCCN/NRDS—2013/462. National Park Service, Fort Collins, Colorado.

NPS 105/120185, March 2013

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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 Mount Rainier National Park during the 2011 water year, and is part of a set of climate summary reports from six 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 Weather and 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 (1971-2000) 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.

Daily and monthly air temperature, precipitation and snowpack for the eight park weather stations are presented in individual appendices. Each appendix includes comparisons to the period of record, which varies by station. Highlights of important weather events and maintenance issues from each site are also noted.

Weather data collected in Water Year 2011 indicated that this year was cooler than normal with slightly above normal precipitation. Overall, conditions were characterized by a notably cool and wet spring, followed by a colder than normal summer. Snowpack remained near normal during winter only to build in the wetter, cooler late spring and summer to above normal conditions that persisted into late summer, breaking the record for the maximum snow depth at Paradise for eight consecutive days in August.

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 Weather and Avalanche Center – High Elevation Weather Stations
- Western Regional Climate Center
- National Climate Data Center

The NPS would also like to thank the Office of the Washington State Climatologist for their regional and statewide weather and climate summaries.

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 Weather and 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., 1971-2000), and are concerned with the distribution of data within limits of common occurrence.

Fall: The National Weather Service defines fall as the months of September, October and November.

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.

Spring: The National Weather Service defines spring as the months of March, April and May.

Summer: The National Weather Service defines summer as the months of June, July, and August.

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 2011 is the 12-month period beginning October 1, 2010 and ending September 30, 2011. 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).

Winter: The National Weather Service defines winter as the months of December, January and February.

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 dependent 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). Disturbance events such as forest fires, windstorms, and floods are strongly related to climate (Littell and Gwozdz 2011). 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 weather 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 2011 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; and, detailed climate data recorded from each weather station are presented in Appendices A to G.

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.

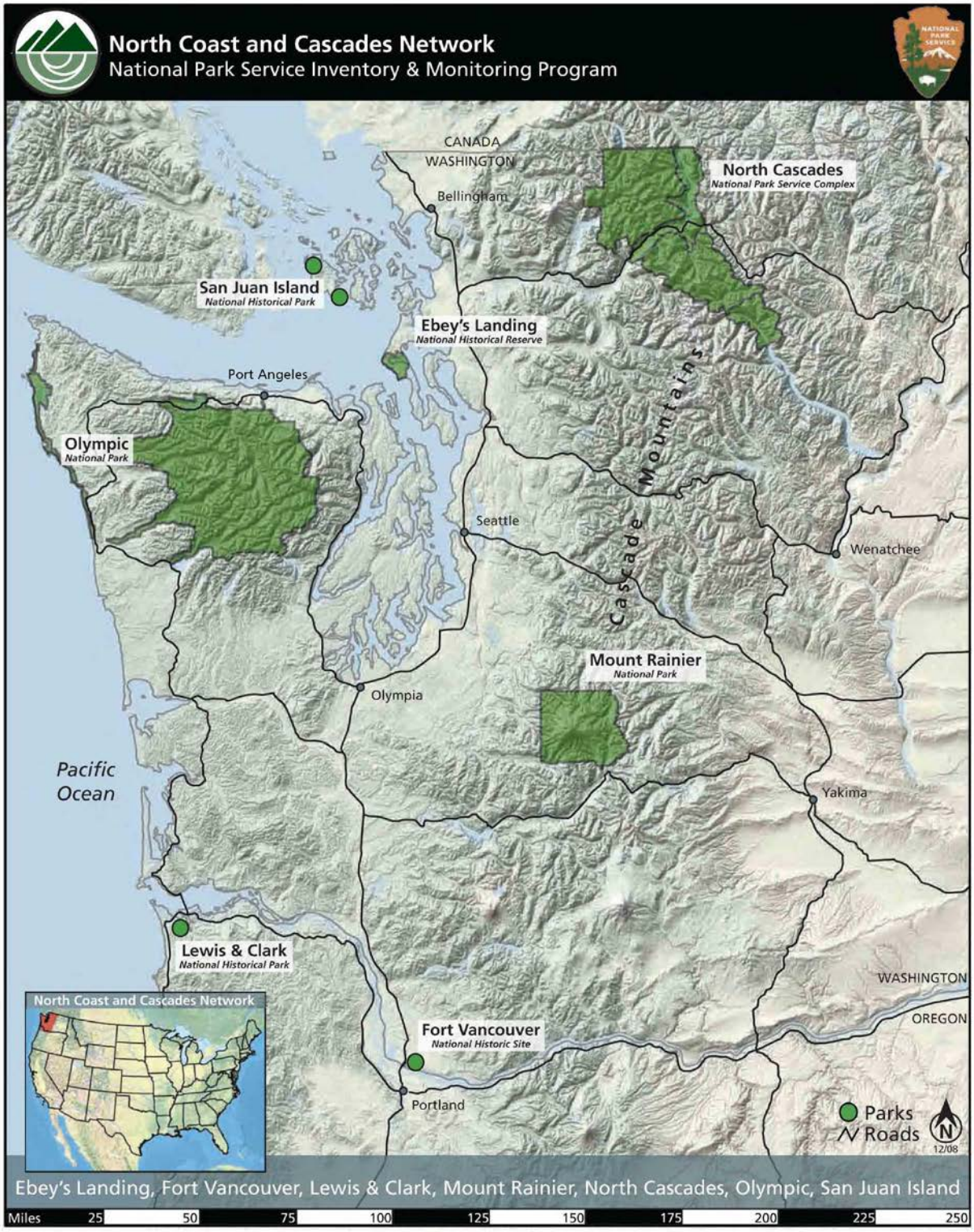

Figure 1. North Coast and Cascades Network parks (NCCN).

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 High Elevation	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	5400	Subalpine	1916 to Present
Paradise	SNOTEL	Southwest	5120	Subalpine	1981 to Present
Sunrise High Elevation	NPS	Northeast	6420	Subalpine	2004 to Present

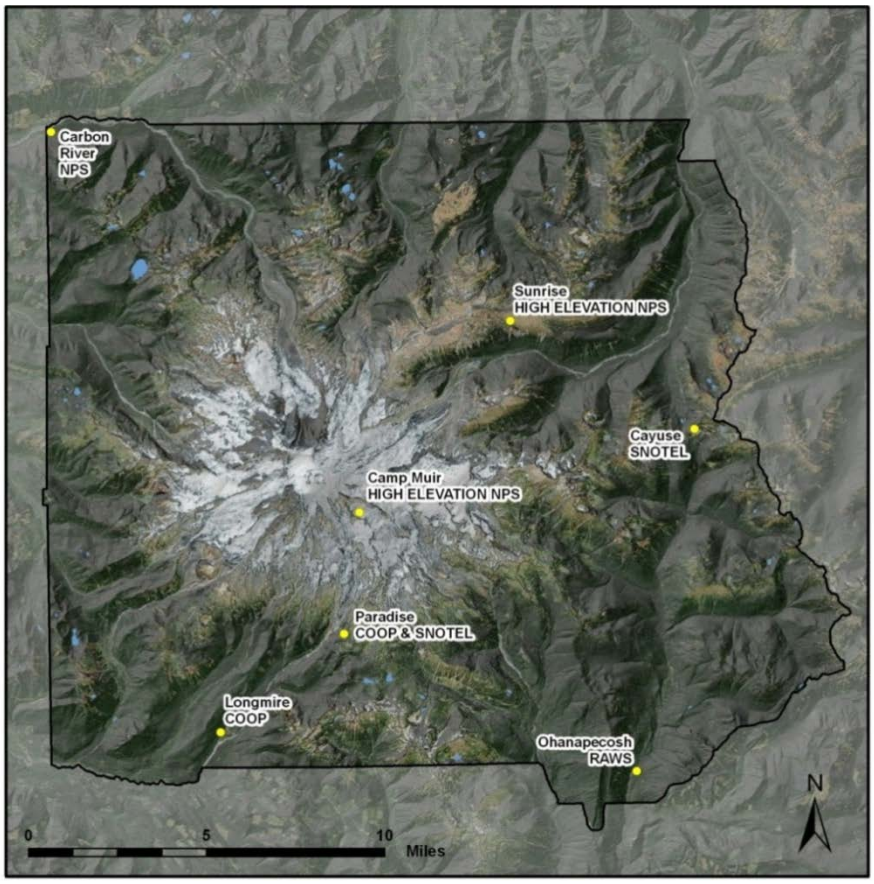

Figure 2. Location of weather stations referenced in this report. The Paradise SNOTEL and Paradise COOP stations are in two separate locations within the same general area.

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; X 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 High Elevation	NPS-High Elevation[1]	**X**	X					X	**X**		
Carbon River	NPS[1]	**X**	X	**X**	**X**					X	X
Cayuse Pass	NRCS-SNOTEL[2]	**X**		**X**	**X**		**X**			X	X
Longmire	NWS COOP[3]	**X**		**X**	**X**	**X**					
Ohanapecosh	NIFC-RAWS[4]	**X**	X	**X**				X	X		
Paradise	NWS COOP[3]	**X**		**X**	**X**	X					
Paradise	NRCS-SNOTEL[2]	**X**		**X**	**X**		**X**			X	X
Sunrise High Elevation	NPS-High Elevation[1]	**X**	X	**X**	**X**			X	X	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. Soil temperature and moisture sensors were added on 9/1/2011.

[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 Quality

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

Precipitation data are missing from the Sunrise High Elevation weather station during all months due to malfunction of the precipitation gauge. Power limitations restrict the use of a heated tipping bucket at Sunrise, and heavy winter precipitation and low temperatures have tested the limits of the existing precipitation system. Alternative methods to capture year round precipitation at Sunrise are being evaluated.

Gaps exist in the Ohanapecosh RAWS precipitation data from November-May due to failure of the heated precipitation gauge and loss of power. Temperature data is missing from November-January due to loss of power. Power was restored in mid-January and the precipitation gauge was replaced with a non-heating tipping bucket in May. Due to continued power issues at Ohanapecosh during the winter months resulting in loss of data, a NPS station was installed in October, 2011 to ensure future year round data collection. A Campbell Scientific CS705 Precipitation Adapter was purchased for the new NPS Ohanapecosh station non-heated tipping bucket winter to capture winter precipitation, and was tested in Water Year 2012.

The wind speed sensor at the Camp Muir High Elevation station is not heated and can become ice encrusted during cold, wet conditions. Data gaps represent periods when wind speed recorded zero for more than three hours. These data were removed for analysis purposes. High (out of range) temperature spikes occurred at Camp Muir from August 21 to August 25. The five days of data were omitted from the August monthly summary.

October monthly precipitation at Longmire is an anomaly when compared to all other weather station data within the park. Recorded data indicates Longmire was only 68% of normal for the month of October while weather stations at Carbon, Ohanapecosh, Paradise, and Cayuse reported 123%, 115%, 168%, and 136% of normal, respectively. Only two days of precipitation data are missing at Longmire for the month of October (24^{th} and 25^{th}), however significant precipitation occurred during this time frame that was not captured at the Longmire station (3.1 inches at Carbon, 3.0 inches at Ohanapecosh, and 3.5 inches at Paradise). Based on these values, 3.0 inches of precipitation was added to Longmire from October 24 to 25, bringing Longmire to 107% of normal for the month of October.

Nine days of precipitation data in June are missing from the Paradise COOP station. These data were replaced with precipitation values, totaling 0.5 inches, from the nearby Paradise SNOTEL.

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 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 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 2 and 3. 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.

The appendices are divided by individual weather station and present daily data for precipitation, temperature, and snowfall or snow water equivalent when available, as well as average, maximum, minimum temperatures and total precipitation for each month. Maximum wind speeds are provided for the Camp Muir High Elevation station. While the main report compares Water Year 2011 with the 30-year climate normal, the appendices compare 2011 with the period of record. Detailed discussion of maintenance issues or data concerns associated with each specific station is also presented.

Results

Temperature

For Water Year 2011, mean annual temperatures for Longmire and Paradise were 1.5°F and 1.6°F below the 30-year climate normal, respectively (Table 3). Above normal temperatures were recorded at all stations in October (Table 3, Figures 4 and 5). Overall, temperatures were colder than normal in November due to a cold air mass that arrived towards the end of the month. The coldest daily temperatures at all stations for the year were recorded during this time with Paradise breaking the record for both the coldest daily maximum (3°F) and minimum (-4°F) recorded on November 24 (Appendix A-G) for the period of record (1916-2011). Temperatures in December returned to near normal throughout the park. In January, average temperatures ranged from near normal to above normal before an extended period of below normal temperatures at all stations that lasted from February through July (Table 3, Figures 4 and 5).

April provided the most extreme example with average temperatures 6.9°F below normal at Paradise and 4.9ºF at Longmire, the second and fifth coldest average temperature in April on record at Paradise (1916-2011) and Longmire (1909-2011). The cold pattern continued in May: average temperature ranked second coldest on record at Paradise and eight coldest at Longmire. According to climate division data from the National Climatic Data Center (NCDC), the mean Washington statewide temperature for April through June was the second coldest in a record extending back to 1895 (NOAA 2011a, OWSC 2011a). Below normal average monthly temperatures were recorded for six straight months (February - July) at Paradise and Longmire stations, averaging 4.6ºF and 3.5ºF below normal, respectively during this period. The cooler temperatures were apparent in delayed spring phenology of many tree species, a high elevation winter snowpack preserved throughout most of the summer, and a late ice-out of mountain lakes (Figure 3). Average temperature returned to near normal in August and above normal in September (Table 3, Figures 4 and 5). Average monthly temperature in September ranked as the ninth warmest on record at Paradise (1916-2011).

Figure 3. Ice still covers Eunice Lake and with snow present in the surrounding basin on July 23, 2011. Due to the deep snowpack and below normal spring and summer temperatures, the lake did not thaw until August 10, 2011, several weeks later than the seven year period of record.

Table 3. Average monthly air temperatures (°F) from weather stations within Mount Rainier National Park in Water Year 2011.

Season	Month & Year	Camp Muir High Elevation NPS	Carbon River NPS	Cayuse Pass SNOTEL	Longmire NWS COOP	Ohanapecosh RAWS	Paradise NWS COOP	Sunrise High Elevation NPS
Fall	October 2010	28.5	45.3	43.0	46.3	47.0	43.5	39.6
	November 2010	15.2	36.5	30.0	33.2	----[a]	29.6	27.2
Winter	December 2010	11.0	35.4	27.6	31.0	----[a]	26.0	26.3
	January 2011	18.0	36.6	30.1	31.2	----[a]	29.3	29.4
	February 2011	10.2	33.6	25.4	29.2	31.9	24.4	22.9
Spring	March 2011	10.4	37.1	28.5	34.5	35.2	25.8	24.9
	April 2011	11.9	37.4	29.1	36.1	36.6	26.4	25.0
	May 2011	21.8	44.5	36.1	43.3	45.4	34.1	34.2
Summer	June 2011	31.1	51.6	42.6	51.9	54.6	40.8	41.3
	July 2011	37.1	57.1	47.9	56.5	59.7	47.6	47.2
	August 2011	42.8	59.2	53.0	60.6	63.3	52.2	53.1
Fall	September 2011	40.7	56.6	53.4	58.6	59.0	53.3	52.7
	Water Year	23.2	44.2	37.2	42.7	----[a]	36.1	35.3

[a] Temperature data are missing due to power loss at the Ohanapecosh RAWS.

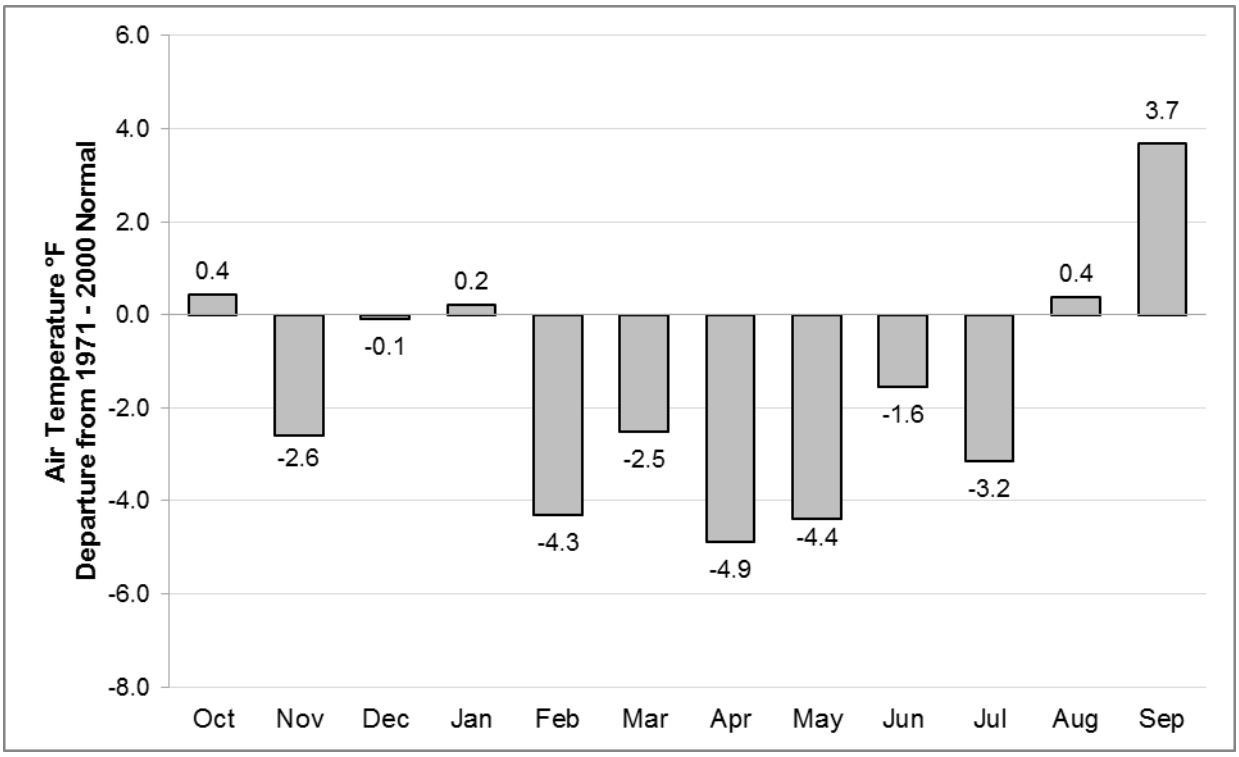

Figure 4. Comparison of average monthly temperature (°F) for Longmire (COOP) in Water Year 2011 against monthly averages for the climatological normal 1971-2000.

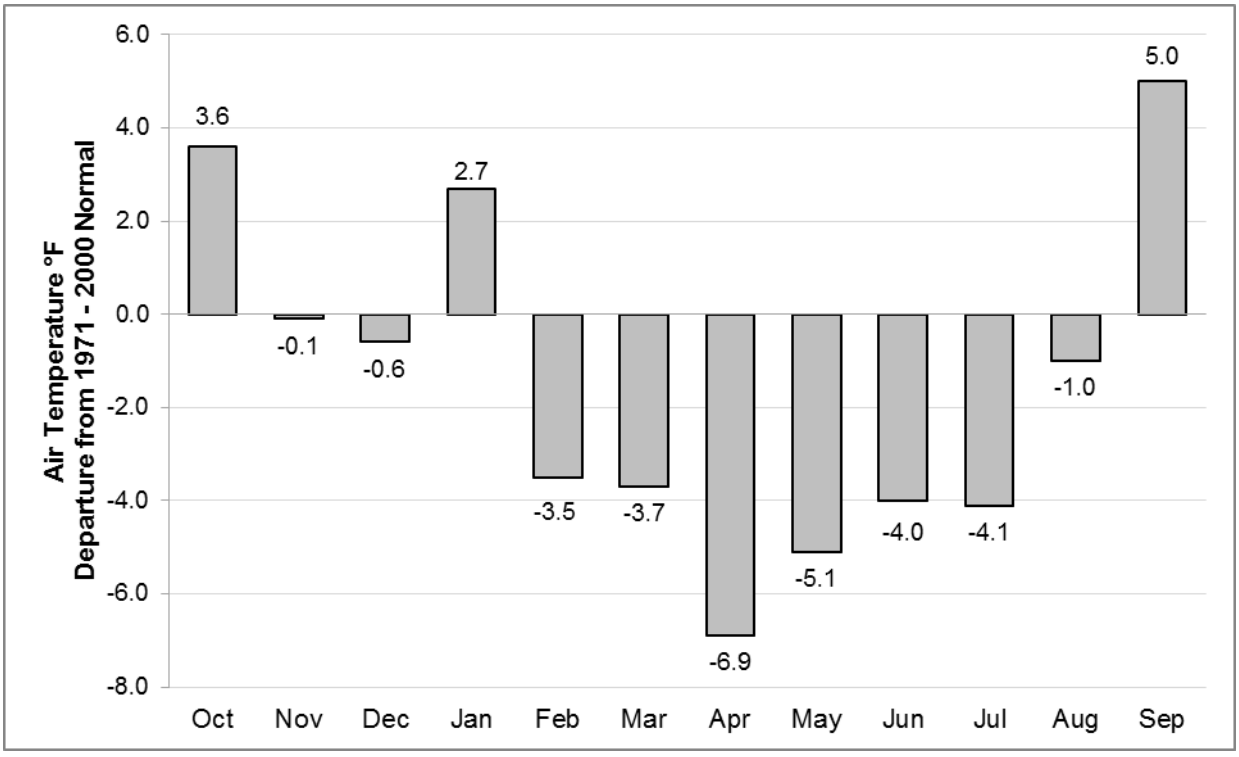

Figure 5. Comparison of average monthly temperature (°F) for Paradise (COOP) in Water Year 2011 against monthly averages for the climatological normal 1971-2000.

Precipitation

Annual precipitation was slightly above normal throughout the park for Water Year 2011. Paradise COOP received 134.2 inches, 112% of normal. Longmire COOP received 83.5[1] inches, 103% of normal. Precipitation was above normal in October followed by drier than normal conditions in November and December (Table 4, Figures 6 and 7). Precipitation during January varied across the park with Longmire recording precipitation 88% of normal and Paradise 131% of normal. Conditions in February were slightly below normal followed by an extremely wet spring. The Paradise COOP recorded 22.2 inches of rain in March, the second wettest March on record (1916-2011), only to be followed by the wettest April on record (1916-2011) with 17.3 inches recorded at Paradise.

The average statewide total precipitation for spring (March, April, and May) was the wettest in the 117-year record (NOAA 2011a). All stations within the park recorded above historic means for precipitation from March through May. June and July continued the wet pattern with most stations reporting above historic means for precipitation. The wet conditions shifted in late summer with August and September exhibiting drier than normal conditions throughout the park (Figures 6 and 7, Appendices A-G). The wettest dates of the year occurred over a six day period between March 30st and April 4th, 2010 when Paradise received 12.4 inches (Appendix F: Figure F-5) and Longmire 7.1" (Appendix D: Figure D-5) of precipitation. The highest daily precipitation was recorded on January 16 at Paradise when 5.1 inches of rain fell.

[1] Two days of precipitation data are missing from Longmire for the month of October (24-25). Based on comparisons with weather stations adjacent to Longmire and throughout the park, 3.0 inches of precipitation were added to the October data.

Table 4. Total monthly precipitation (inches) from weather stations within Mount Rainier National Park in Water Year 2011.

Season	Month & Year	Carbon River NPS	Cayuse Pass SNOTEL	Longmire NWS COOP	Ohanapecosh RAWS	Paradise NWS COOP	Sunrise High Elevation NPS
Fall	October 2010	8.3	6.9	7.5[a]	7.3	14.3	----[d]
	November 2010	11.1	11.8	11.1	----[b]	14.9	----[d]
Winter	December 2010	8.4	14.1	10.3	----[b]	15.1	----[d]
	January 2011	12.3	11.6	9.9	----[b]	23.8	----[d]
	February 2011	4.5	9.5	7.9	----[b]	9.5	----[d]
Spring	March 2011	10.6	24.8	13.1	----[b]	22.2	----[d]
	April 2011	9.6	13.6	8.0	----[b]	19.0	----[d]
	May 2011	7.5	6.9	5.3	----[b]	5.9	----[d]
Summer	June 2011	6.1	2.5	4.5	1.7	4.5[c]	----[d]
	July 2011	2.4	1.0	2.8	0.7	1.7	----[d]
	August 2011	0.1	0.0	0.2	0.1	0.2	----[d]
Fall	September 2011	2.3	2.2	2.9	2.3	3.1	----[d]
	Water Year	83.2	104.9	83.5	----[b]	134.2	----[d]

[a] Two days of precipitation data are missing from Longmire for the month of October (24-25). Based on comparisons with weather stations adjacent to Longmire and throughout the park, 3.0 inches of precipitation were added to the October data.

[b] Precipitation data are missing due to power loss and equipment malfunction.

[c] Nine days of precipitation data, totaling 0.5 inches, were estimated from the Paradise SNOTEL due to missing data at the Paradise COOP station.

[d] Precipitation data are missing due to equipment malfunction.

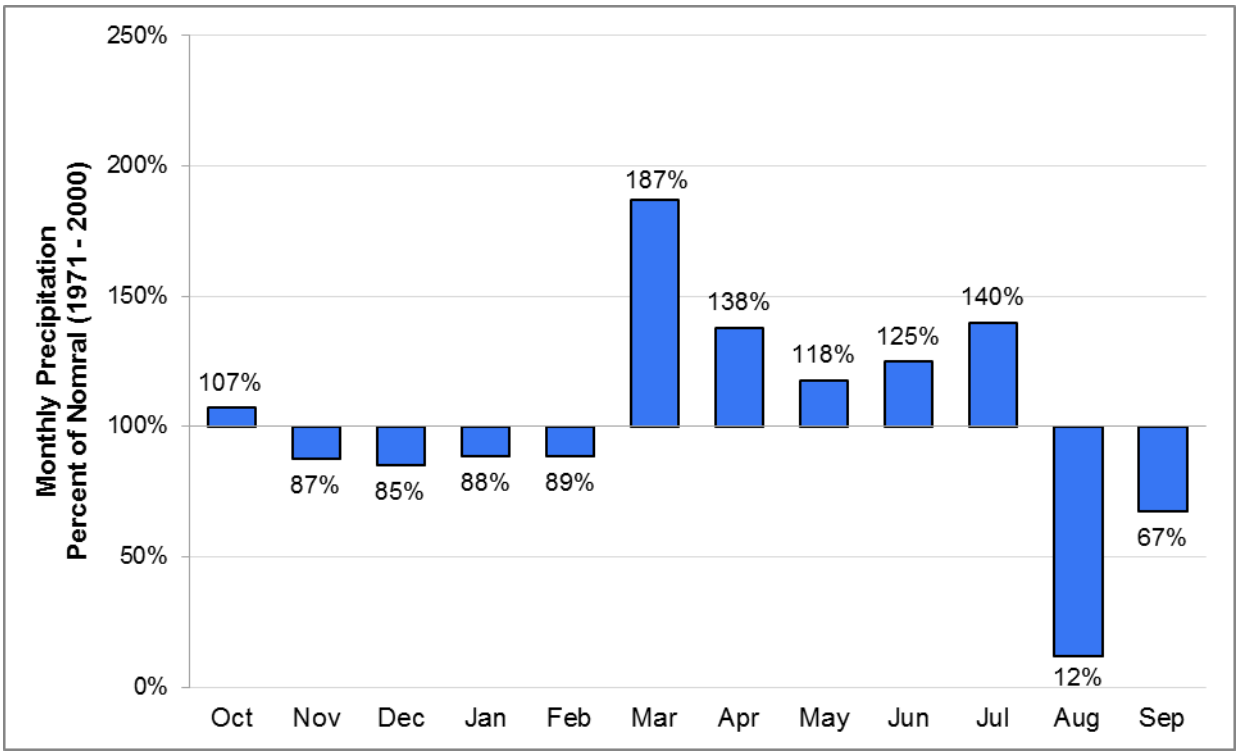

Figure 6. Comparison of monthly total precipitation (inches) as a percent of normal at the Longmire (COOP) in Water Year 2011 against the climatological normal 1971-2000**.**

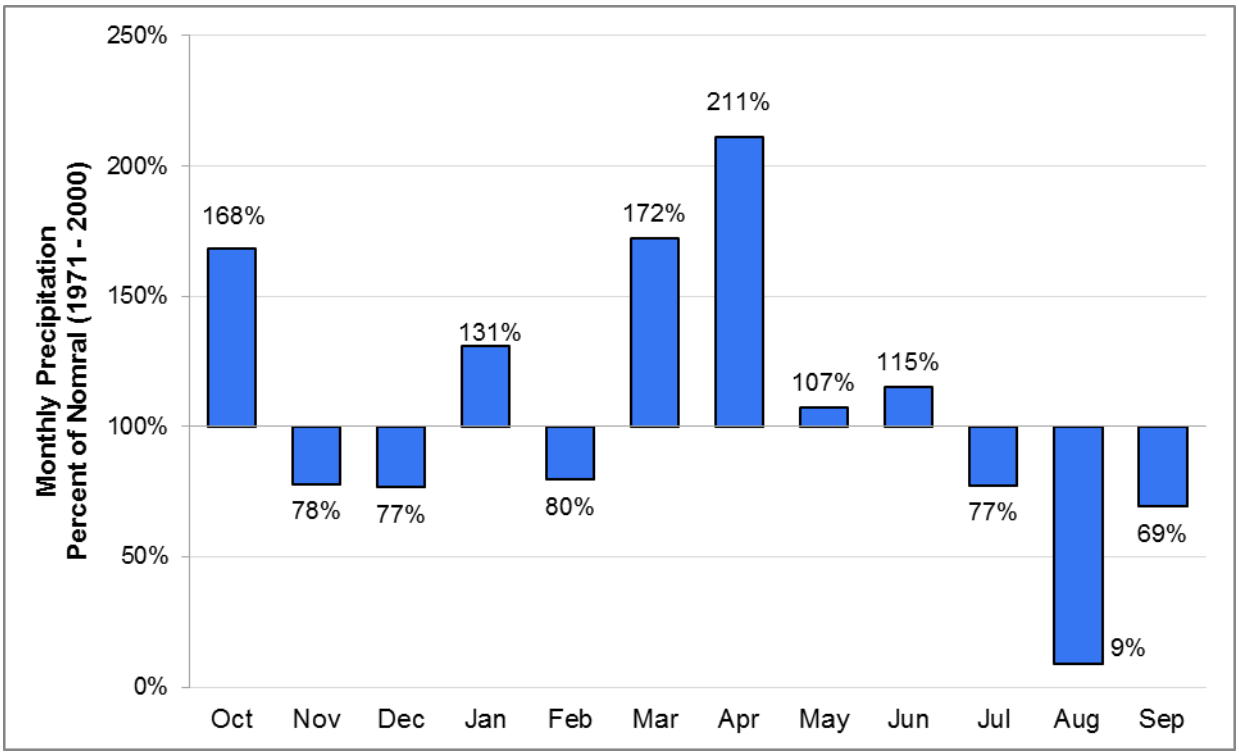

Figure 7. Comparison of total monthly precipitation (inches) as a percent of normal at the Paradise (COOP) in Water Year 2011 against the climatological normal 1971-2000.

Snow

An early season storm brought snow to upper elevations in late October causing a brief period of above normal snowpack, but quickly returned to near normal by the beginning of November. Cold temperatures towards the end of November brought low elevation snow that resulted in above normal snowpack at low and high elevations, which persisted through the end of the December (Appendix D: Figure D-8; Appendix F: Figure F-6). The snowpack remained near normal from December through mid-January at all elevations, but dropped below normal for the remainder of January and February. Snow water equivalent remained just below normal from December through the beginning of March (Figure 8).

Cold temperatures and above normal precipitation during spring and early summer months resulted in above normal snowpack and SWE beginning in March, and persisted notably late in the season (Table 4, Figure 8). At Paradise, the all-time record for the maximum snow depth was broken for eight consecutive days beginning on August 7 and ending on August 14. Snow finally melted at the Paradise COOP location on August 25, missing the record for latest snow on the ground by two days, which was set in 1974. The July first-of-month snow water equivalent measurements at Paradise was 260% of normal (Figure 8). The snowpack melted slightly earlier on the eastside of the park, with the last snow melting at the Sunrise weather station on August 3 followed closely by the Cayuse Pass SNOTEL on August 5 (Appendix C: Figure C-6; Appendix G: Figure G-3).

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 2011.

Month & Year	Cayuse Pass SNOTEL	Longmire NWS COOP	Paradise NWS COOP	Sunrise High Elevation
October 1, 2010	0.0	0.0	0.0	0.0
November 1, 2010	21.0	0.0	29.0	25.0
December 1, 2010	59.0	11.0	82.0	38.0
January 1, 2011	94.0	13.0	104.0	78.0
February 1, 2011	99.0	2.0	120.0	73.5
March 1, 2011	159.0	44.0	178.0	98.3
April 1, 2011	193.0	11.0	206.0	132.0
May 1, 2011	211.0	11.0	247.0	139.0
June 1, 2011	179.0	0.0	213.0	126.0
July 1, 2011	113.0	0.0	144.0	68.0
August 1, 2011	19.0	0.0	64.0	1.0

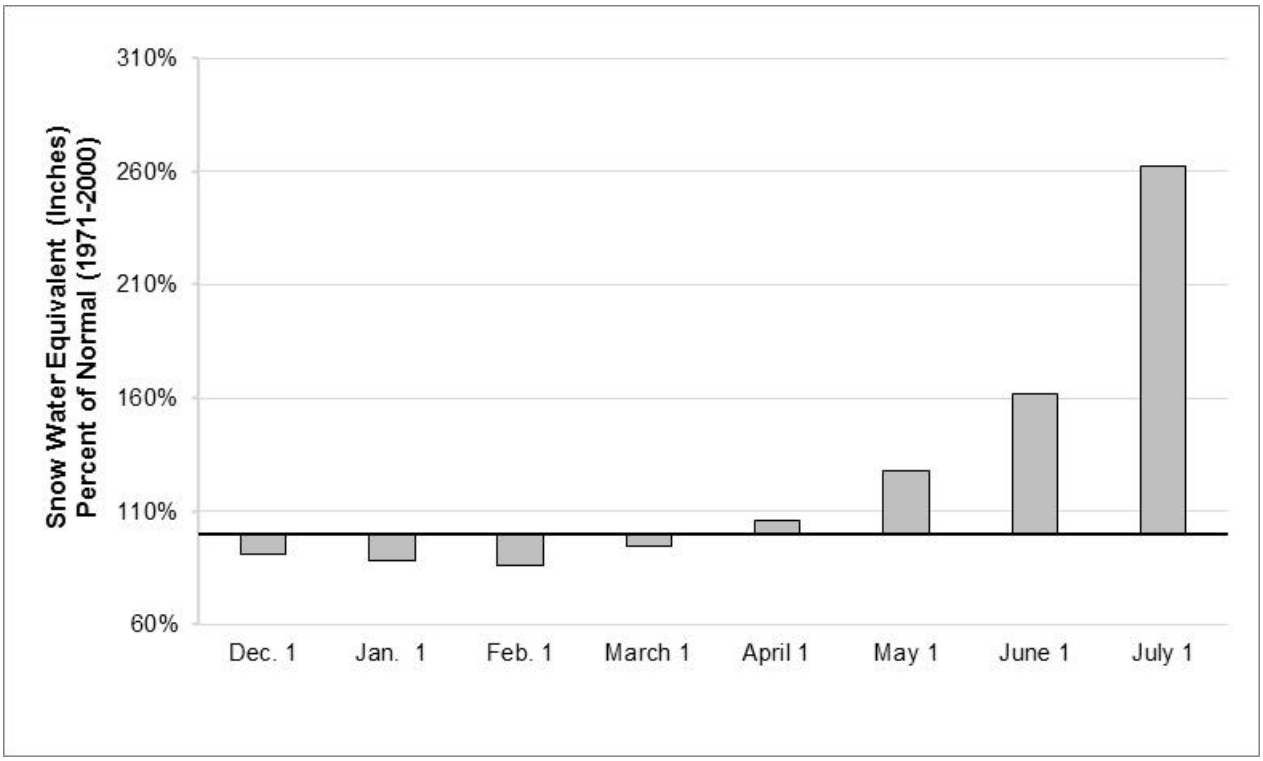

Figure 8. Comparison of snow water equivalent (inches) on the first day of each month at the Paradise Snow Course in Water Year 2011 against the climatological normal 1971-2000.

2011 Water Year in Review

Significant Weather Events and Patterns

An early season winter storm beginning on October 24 brought heavy precipitation throughout the park and significant snow to upper elevations. By October 27, Paradise recorded 44 inches of snow on the ground. November brought an unusually snowy and cold period in the latter half of the month. Temperatures dropped well below normal around the park beginning on November 20 as arctic air moved in from Canada, lasting until to November 25. Several daily records were broken throughout Washington State on November 24, many of them low temperature records (OWSC 2010). The temperatures during this period were cold enough so that any precipitation that came fell as snow at all elevations throughout the park.

Temperatures in December were near normal with slightly below average precipitation. The most notable event of the month was a warm, heavy precipitation event when upper elevation sites in the park recorded 3-4 inches of rain. This was followed by a period of heavy snow. A second warm precipitation event occurred on January 15 to 16 directed toward the west side of the park with Paradise recording almost 8 inches of rain. This mid-January rain event, observed across the Cascades, produced a widespread and persistent crust in the mountain snowpack. This crust was responsible for numerous large avalanches in 2011 which in turn created large areas of forest disturbance (Figure 9).

Figure 9. Remnants of an avalanche that occurred at Owyhigh Lakes, Mount Rainier National Park. Avalanche debris covered most of the northern portion of the lake and introduced substantial amounts of large woody debris into the lake. Photo was taken on July 19, 2011.

February marked the beginning of a long period of below normal average monthly temperatures throughout the park that would last until July. Camp Muir recorded the highest winds speeds of the year with a maximum of 155 mph on February 12, 2011. The beginning of February was generally dry, but this changed toward the end of the month; from February 22 to March 15, 2011, Paradise recorded at total of 166 inches of snowfall.

The months of March through July were cool and wet. According to the National Climatic Data Center, in Washington State, the mean statewide temperature for April through July 2011 was the second coldest in a record extending back to 1895 (NOAA 2011a, OWSC 2011a). The average statewide total precipitation for spring (March-May) was the wettest in the 117-year record (NOAA 2011b).

The cool and wet spring and early summer conditions resulted in a deep, persistent late season snowpack. Seasonal snow maximums are typically reached from March 15-April 1, but the maximum snow depth recorded at Paradise in 2011 was on April 28 with 253 inches on the ground, 151% of normal. Snow did not melt completely until August 3 at Sunrise, on the east side of the park, and August 25 at Paradise, on the west side of the park. Due to the persistent snow conditions the opening of both White River Campground and Sunrise were delayed as well as Chinook Pass on the east side of the park.

August brought notably dry conditions to the park; no station recorded more than 0.2 inches of precipitation in the month of August even though temperatures remained below normal. The pattern of the previous eight months ended in September as warmer and drier conditions occurred throughout the park. Average monthly temperature in September ranked in the warmest top ten for many locations in Washington State (OWSC 2011b).

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 rainshadow effect and prevailing southwesterly winds (Hemstrom and Franklin 1982). For Water Year 2011, precipitation at upper elevation weather stations exceeded 100 inches, with the highest recorded amount of 134.2 inches occurring on the southwest slopes at Paradise (5,400 ft.), contrasted with 104.9 inches recorded at Cayuse Pass (5,200 ft.) on the eastern slopes of Mount Rainier (Figure 10).

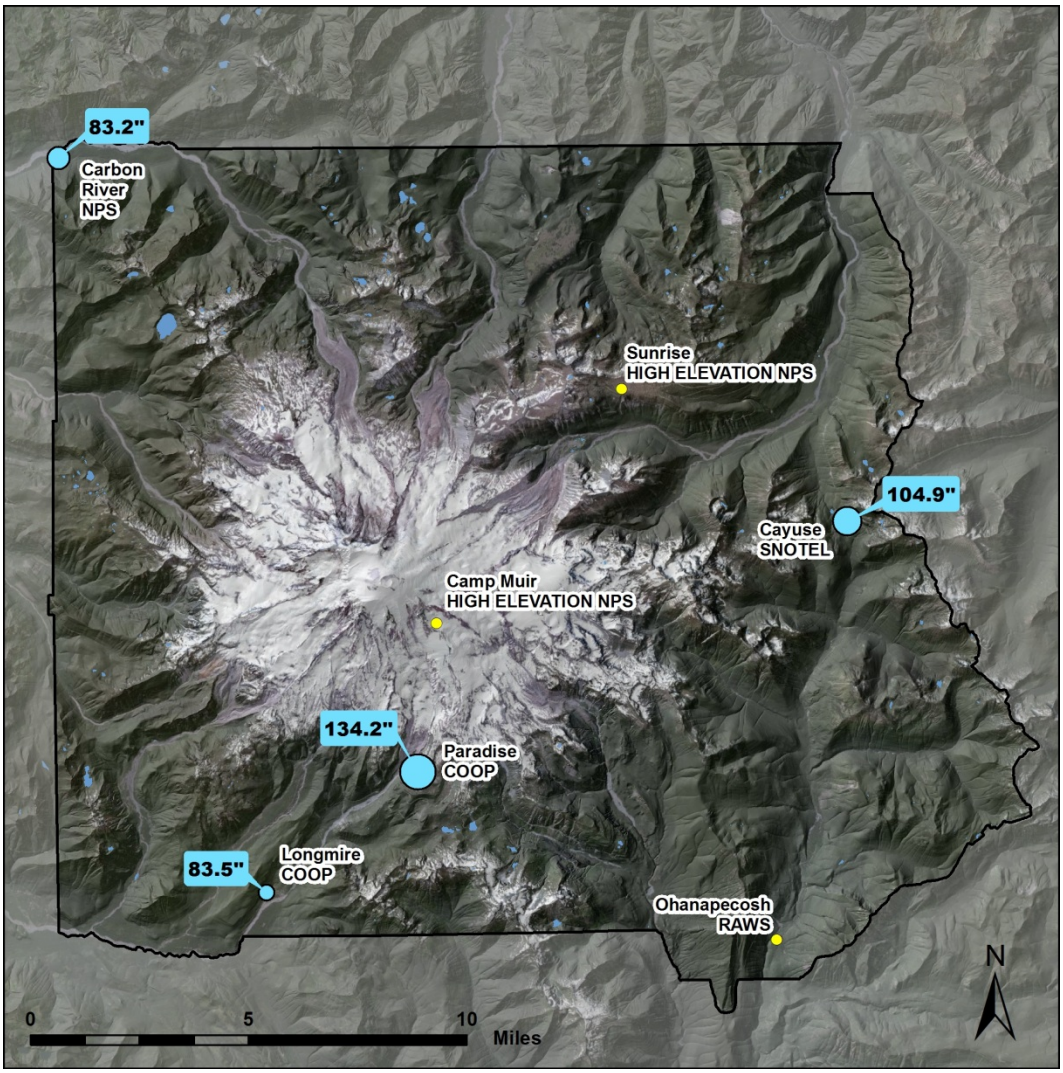

Figure 10. Total precipitation measured at weather stations located within Mount Rainier National Park during Water Year 2011. Blue circles are proportional to the total amount of precipitation measured at each site. Annual precipitation values are missing at Sunrise and Ohanapecosh due to equipment failure. Precipitation is not measured at Camp Muir due to lack of AC power, exposure to wind, and below freezing conditions.

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Appendix A: Carbon River NPS - Water Year 2011.

Daily temperatures observed at the Carbon River NPS station ranged from 7.2 to 81.3°F (Table A-2). The highest mean daily average temperature was 66.2ºF on August 21. The coldest recorded mean daily temperature was 11.8ºF on November 24 (Figure A-2). Annual precipitation totaled 83.2 inches (Table A-1, Figure A-3), 120% compared to the period of record (1906-1974). The highest daily precipitation of 2.0 inches fell on January 12 (Figure A-5). The NPS weather station was installed in February of 2008 making recent period of record comparisons unavailable for this location. However, a NWS COOP station operated year round at the Carbon River Ranger Station from 1906-1974. The period of record average for precipitation and temperature from this COOP station was used for comparison purposes. The colder and wetter than average spring reflected in the data match the trends recorded throughout the park (Figures A-1, A-3, and A-4).

Table A-1. Monthly summary data, Carbon River Station, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Precipitation (inches)
Fall	October 2010	45.3	50.9	40.7	8.3
	November 2010	36.5	40.2	32.9	11.1
Winter	December 2010	35.4	39.6	32.1	8.4
	January 2011	36.6	40.3	33.4	12.3
	February 2011	33.6	38.3	29.3	4.5
Spring	March 2011	37.1	43.3	32.7	10.6
	April 2011	37.4	43.2	32.3	9.6
	May 2011	44.5	52.2	38.0	7.5
Summer	June 2011	51.6	59.6	44.6	6.1
	July 2011	57.1	66.8	47.7	2.4
	August 2011	59.2	70.0	49.7	0.1
Fall	September 2011	56.6	66.7	48.2	2.3
	Water Year	**44.2**	**50.9**	**38.5**	**83.2**

Table A-2. Air temperature extremes, Carbon River Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 11, 2011	81.3	November 23, 2010	7.2
August 20, 2011	80.5	November 24, 2010	9.1
August 21, 2011	79.9	February 25, 2011	13.9
July 24, 2011	79.7	February 26, 2011	14.3
July 6, 2011	79.8	February 24, 2011	16.3

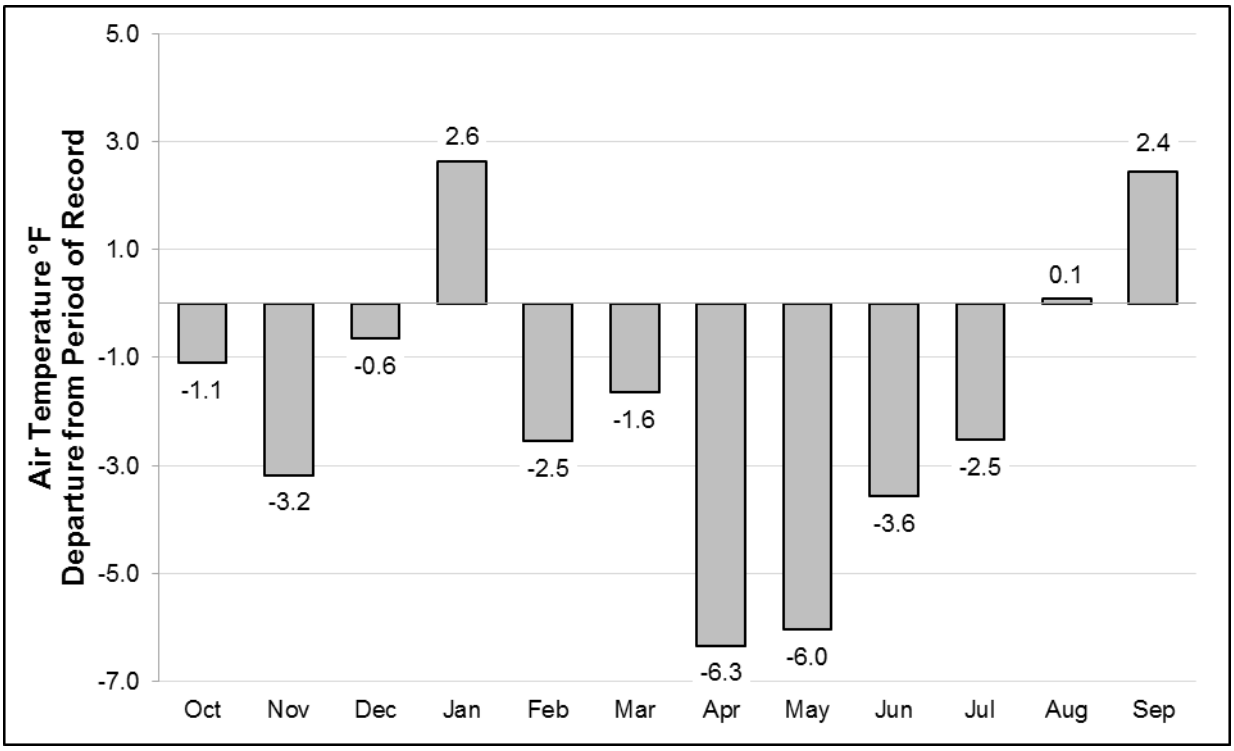

Figure A-1. Comparison of average monthly temperature (°F) for Carbon River Station in Water Year 2011 against monthly averages for the period of record (1906-1974).

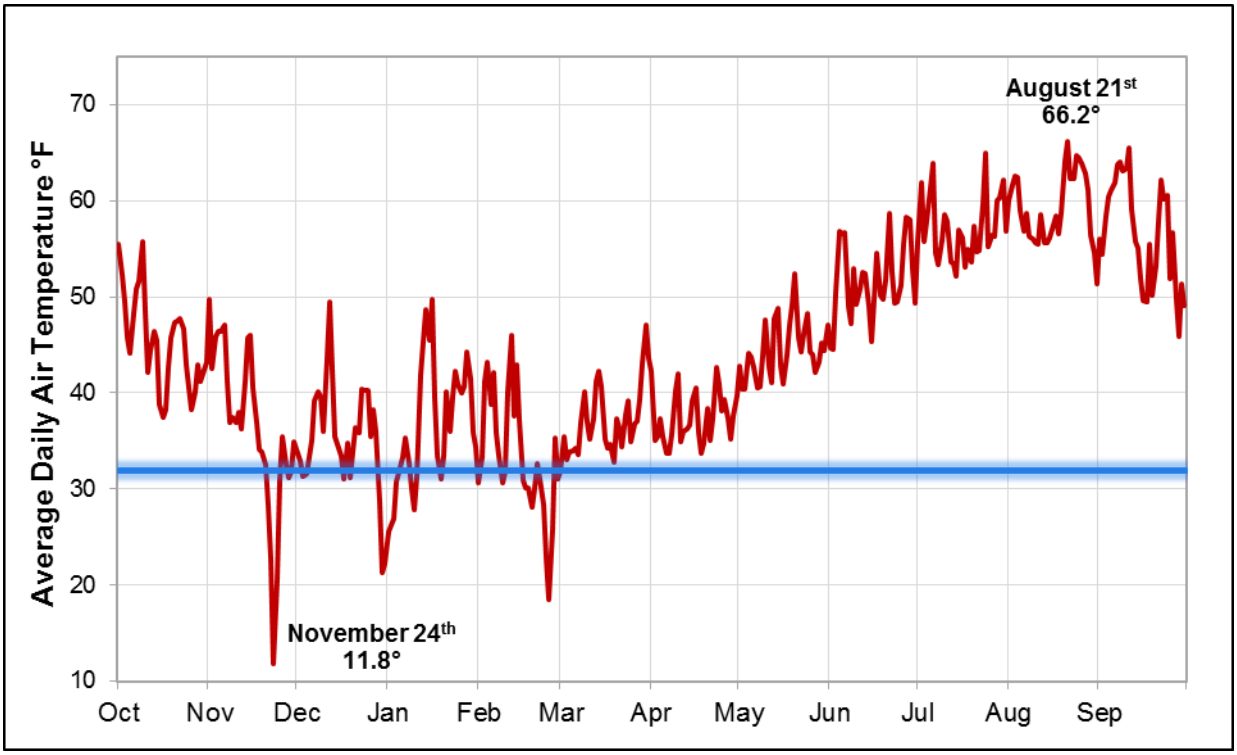

Figure A-2. Daily average air temperature (°F) at the Carbon River Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

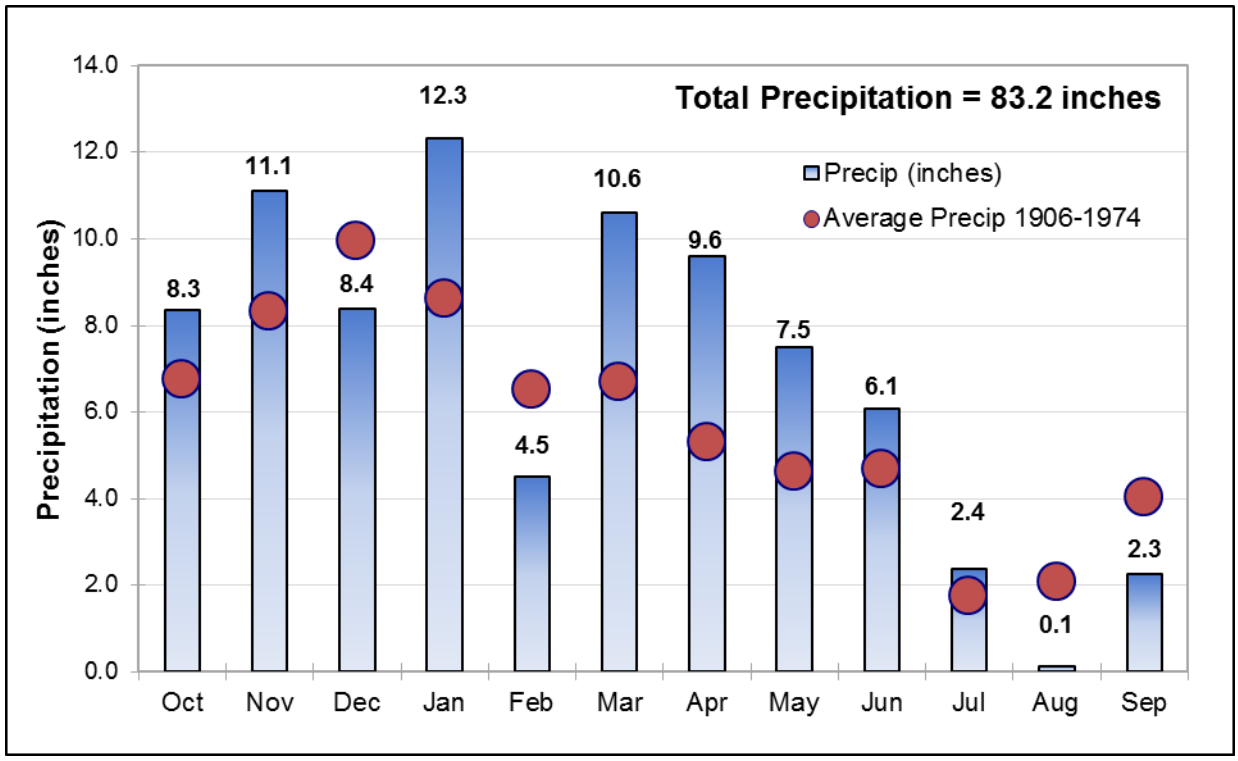

Figure A-3. Monthly precipitation (inches) at the Carbon River Station, Water Year 2011.

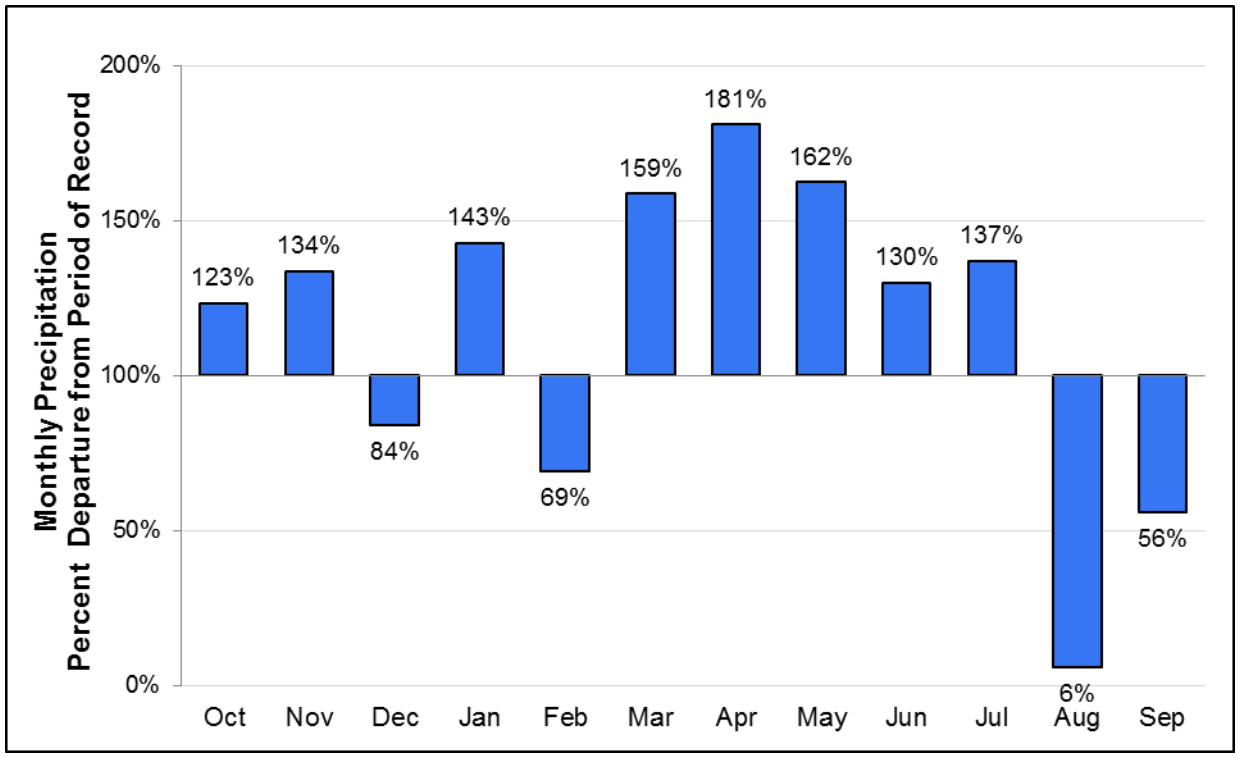

Figure A-4. Percent of average precipitation for the period of record (1906-1974) at the Carbon River Station in Water Year 2011.

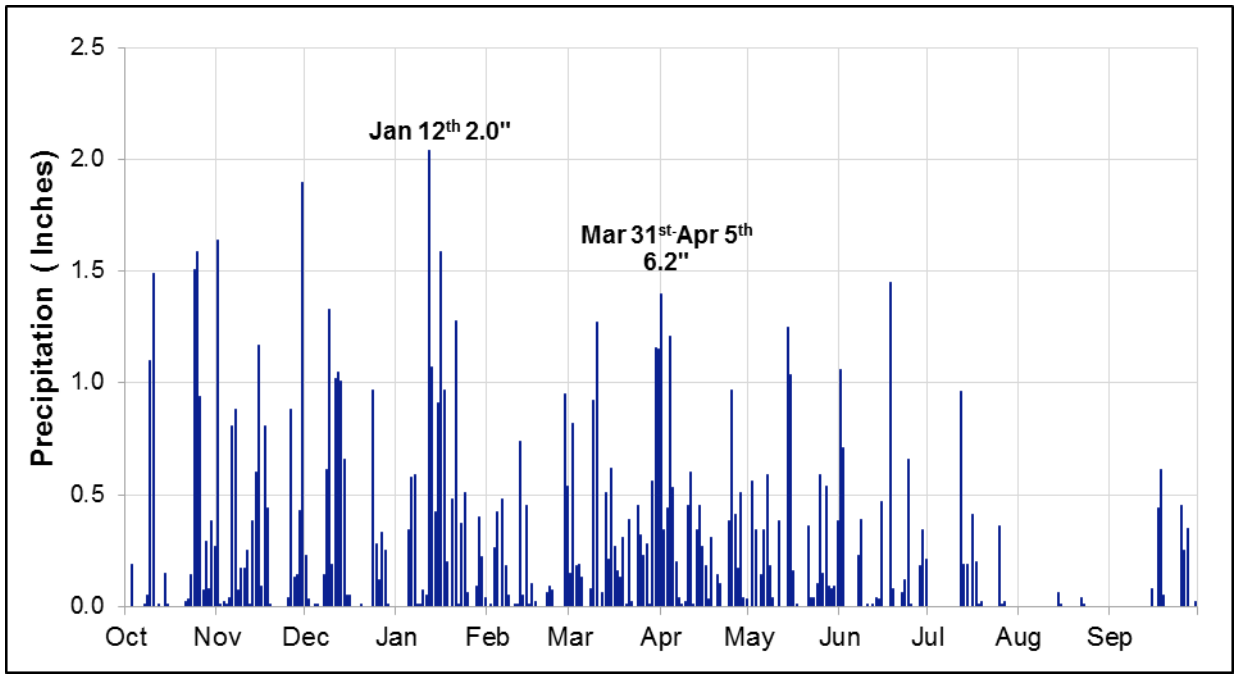

Figure A-5. Daily total precipitation (inches) at the Carbon River Station, Water Year 2011.

Appendix B: Camp Muir High Elevation - Water Year 2011.

Temperatures observed at the Camp Muir High Elevation weather station ranged from -16.9 to 61.8°F (Table B-2). The coldest recorded mean daily temperature was -9.8°F on February 24, 2010 (Figure B-1). The maximum recorded hourly wind speed was also recorded in February, measuring 154 mph (Table B-1, Figure B-2). Due to a short of record for this site, no period of record comparisons were made.

The wind speed sensor is not heated and can rime[2] during cold, wet conditions. The daily average wind speed recorded during cold wet periods, may not capture actual average wind speed due to riming events interfering with the rotation of the anemometer[3]. Data gaps represent periods when zero wind speed was recorded for more than 3 hours. These data were removed from this analysis. Unexplained high temperature spikes of 80-100°F were observed from August 21 to 25, 2011, causing these days to be removed from the monthly summary. A maximum temperature of 60.8°F was recorded for August, but it is possible the actual August maximum temperature was not captured due the malfunction of the temperature sensor. The temperature sensor was replaced on August 25, 2011.

Table B-1. Monthly summary data, Camp Muir High Elevation Station, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Maximum Wind Speed (mph)[2]
Fall	October 2010	28.5	34.3	23.8	83.9
	November 2010	15.2	20.3	9.6	111.0
Winter	December 2010	11.0	15.5	6.3	----[3]
	January 2011	18.0	23.6	12.9	108.6
	February 2011	10.2	16.3	4.6	154.7
Spring	March 2011	10.4	16.7	5.3	117.6
	April 2011	11.9	20.9	4.9	85.3
	May 2011	21.8	29.8	15.4	82.3
Summer	June 2011	31.1	38.7	25.6	64.7
	July 2011	37.1	42.3	32.7	71.4
	August 2011	42.8[1]	48.4[1]	38.0	48.6
Fall	September 2011	40.7	45.8	36.0	104.8
	Water Year	**23.2**	**29.4**	**17.9**	**154.7**

[1] Five days of temperature data are missing due to equipment error. Average mean air temperature and mean maximum daily temperature may actually be higher than indicated.

[2] Wind speed and direction sensors are not heated and can rime during cold, wet conditions. Data represent recorded maximum hourly wind speed, but may not capture actual maximum wind events due to riming events.

[3]No wind speed values above zero were recorded for the month of December indicating a prolonged rime event.

[2] Rime is a coating of ice that forms when the water droplets in fog freeze to the outer surfaces of objects. High elevation features such as trees and rocks are often covered with a thick glaze of this tenacious material.

[3] An anemometer is an instrument which measures wind speeds. Wind forces metal cups to spin on an axis. The rate of this rotation is translated into wind speeds.

Table B-2. Air temperature extremes, Camp Muir High Elevation Station, Water Year 2011.

Date	Max Air Temp °F[1]	Date	Min Air Temp °F
September 12, 2011	61.8	November 23, 2010	-16.9
August 28, 2011	60.8	November 22, 2010	-14.1
September 3, 2011	57.8	February 24, 2011	-13.2
August 6, 2011	57.6	February 25, 2011	-11.8
August 5, 2011	57.3	December 30, 2011	-8.9

[1] Five days of temperature data are missing in August due to equipment error. Maximum air temperatures may have been higher than indicated.

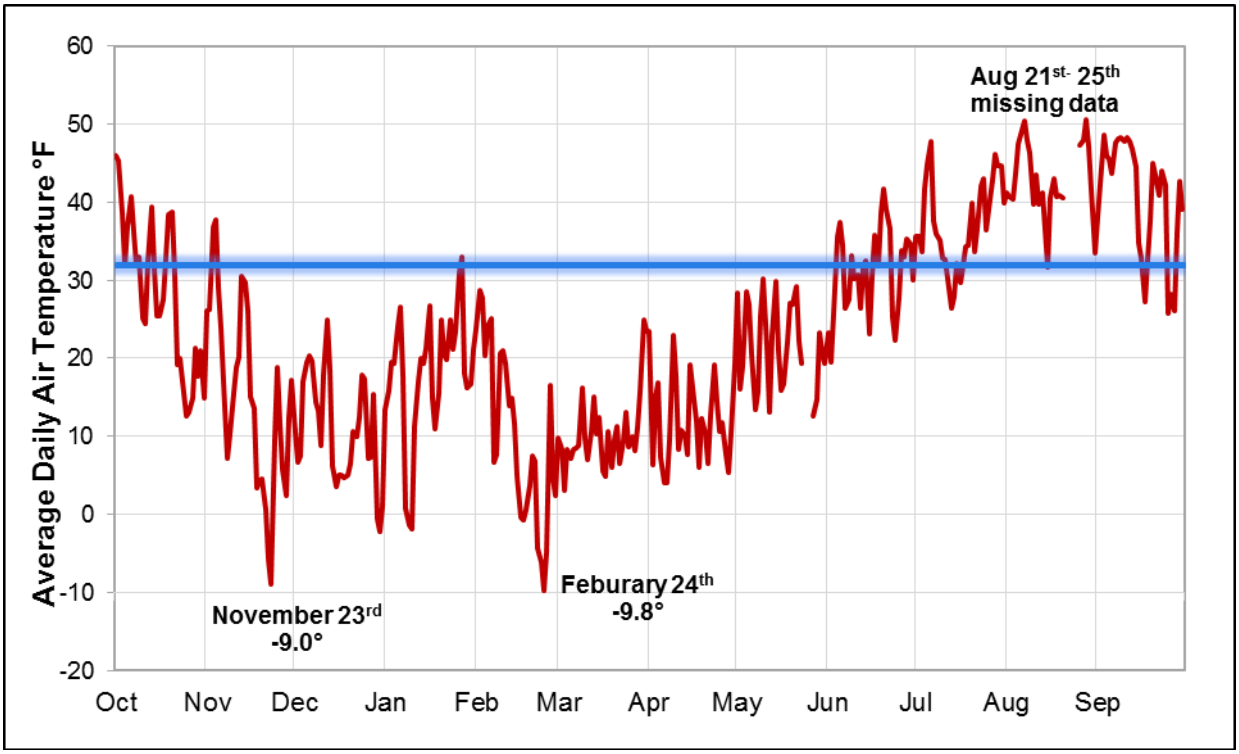

Figure B-1. Daily average air temperature (°F) at the Camp Muir High Elevation Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

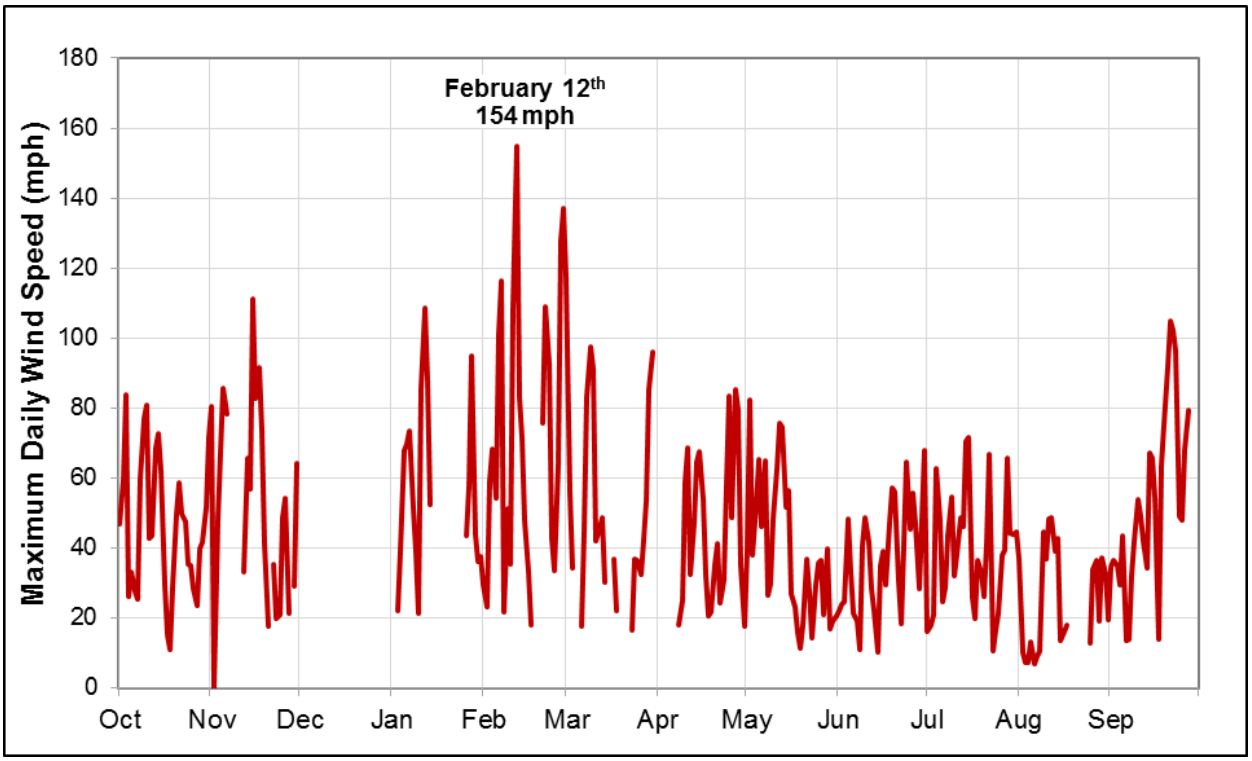

Figure B-2. Maximum daily wind speed (mph) recorded at the Camp Muir High Elevation Station, Water Year 2011. Wind speed sensor is not heated and can rime during cold, wet conditions. Data represents recorded daily average wind speed, but may not capture actual average wind speed due to riming events. Data gaps represent periods when wind speed recorded zero for more than 3 hours. These data were not included in the analysis.

Appendix C: Cayuse Pass SNOTEL - Water Year 2011.

Temperatures observed at the Cayuse Pass SNOTEL station ranged from -1.0 to 80.0°F (Table C-2). The coldest average daily temperature recorded was 4°F on November 24, 2010. The warmest average daily temperature was 70°F on September 11, 2011 (Figure C-1). Total annual precipitation was 104.9 inches with 24.8 inches falling in the month of March (Table C-1, Figure C-2). The highest daily precipitation value was recorded on January 13 and April 2, 2011 (Figure C-3). Snow water equivalent reached its peak on May 9, with 86.9 inches on the ground (Figure C-4). Snowpack began accumulating on October 25, 2010 and melted August 5, 2011, persisting for 285 days, 37 days longer than Water Year 2010.

Due to a short of record for this site, no period of record comparisons were made.

Table C-1. Monthly summary data, Cayuse Pass SNOTEL, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Precipitation (inches)
Fall	October 2010	43.0	49.4	37.6	6.9
	November 2010	30.0	35.0	26.1	11.8
Winter	December 2010	27.6	32.5	24.7	14.1
	January 2011	30.1	34.8	26.0	11.6
	February 2011	25.4	31.3	20.6	9.5
Spring	March 2011	28.5	33.6	24.1	24.8
	April 2011	29.1	35.5	24.2	13.6
	May 2011	36.1	43.1	30.3	6.9
Summer	June 2011	42.6	50.9	37.0	2.5
	July 2011	47.9	56.8	41.6	1.0
	August 2011	53.0	64.0	46.1	0.0
Fall	September 2011	53.4	62.0	42.4	2.2
	Water Year	**37.2**	**44.2**	**31.7**	**104.9**

Table C-2. Air temperature extremes, Cayuse Pass SNOTEL, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 12, 2011	80.0	November 24, 2010	-1.0
September 8, 2011	79.0	November 25, 2010	-1.0
September 11, 2011	79.0	February 26, 2011	3.0
August 29, 2011	77.0	February 25, 2011	4.0
September 9, 2011	75.0	February 27, 2011	6.0

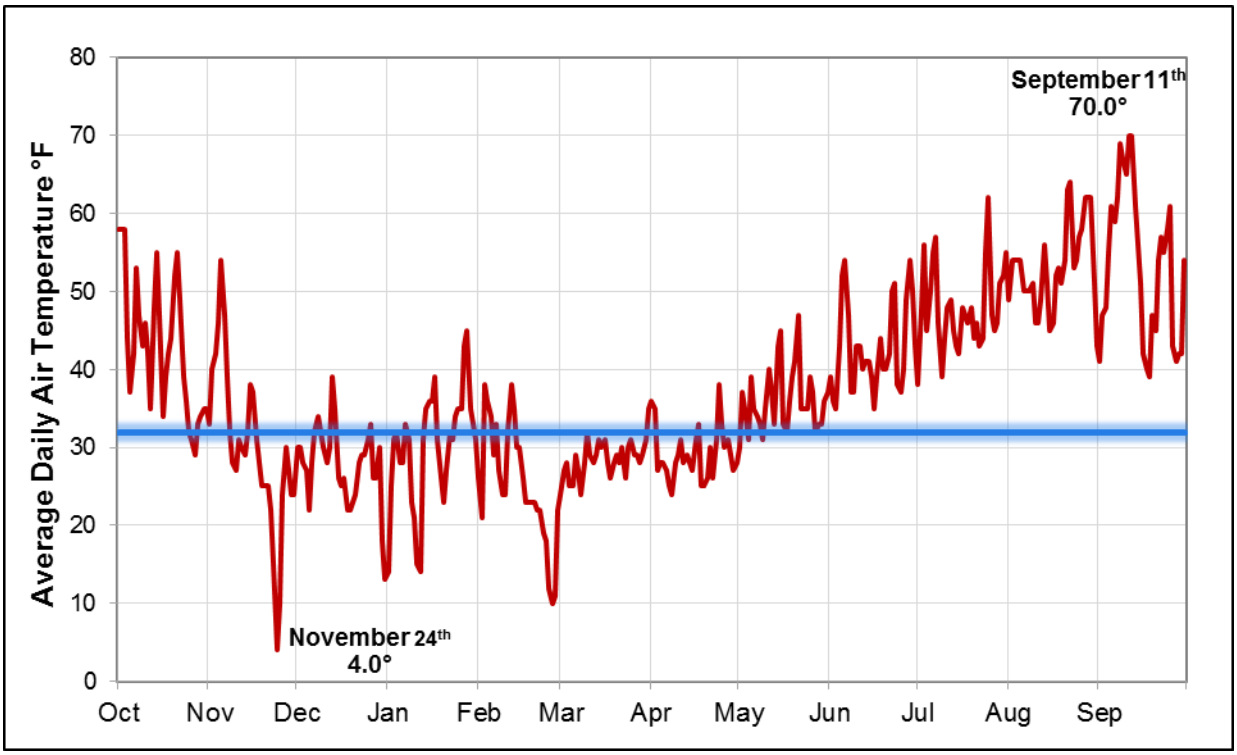

Figure C-1. Daily average air temperature (°F) at the Cayuse Pass SNOTEL, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

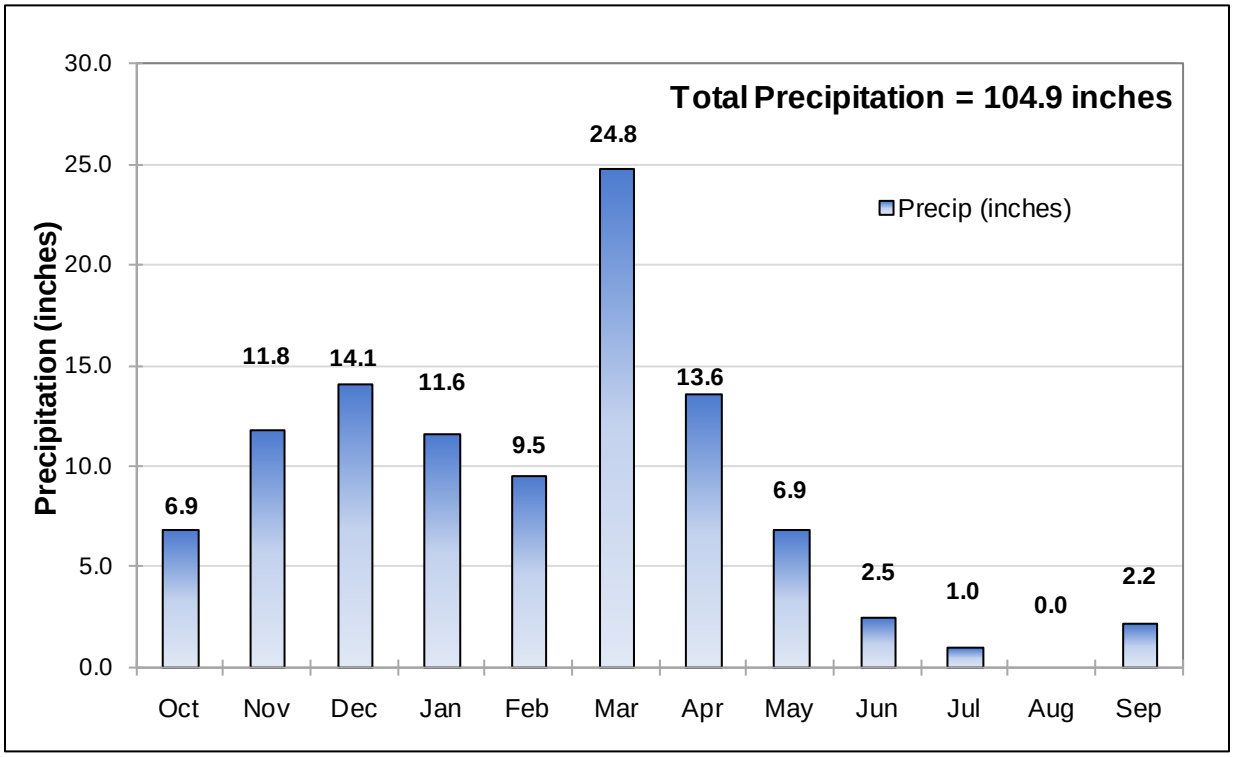

Figure C-2. Monthly total precipitation (inches) at the Cayuse Pass SNOTEL, Water Year 2011.

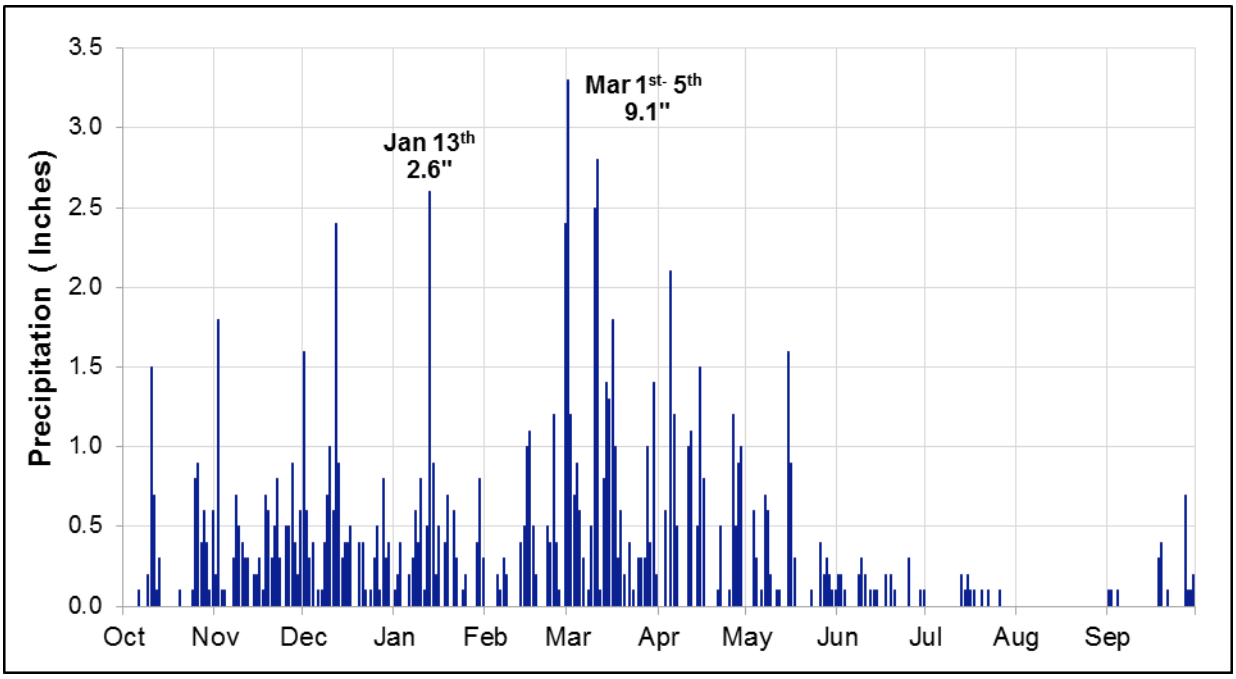

Figure C-3. Daily total precipitation (inches) at the Cayuse Pass SNOTEL, Water Year 2011.

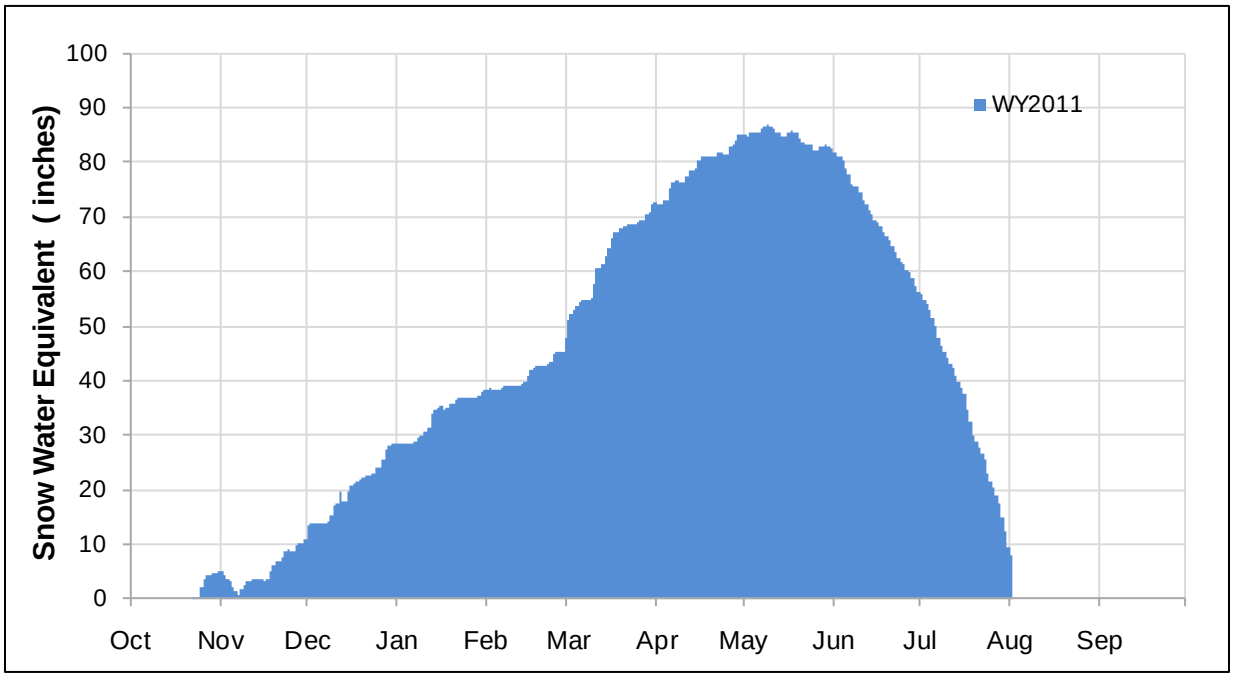

Figure C-4. Daily snow water equivalent (inches) at the Cayuse Pass SNOTEL, Water Year 2011.

Appendix D: Longmire COOP - Water Year 2011.

Temperatures observed at the Longmire COOP station ranged from -1.0 to 92.0°F (Table D-2). Monthly average temperature departures from the period of record average (1909-2010) were notably cool with the month of September the only significant exception, measuring 3.3°F above average (Figure D-1). April provided the most extreme example with temperatures -4.9ºF at Longmire, which ranks April as the fifth coldest at Longmire (1909-2010). The coldest day was November 24, 2010 and the hottest day was on September 8, 2011 (Figure D-2). Annual precipitation totaled 80.5 inches, 104% compared to the period of record (Figure D-3). Monthly precipitation values from October to February were slightly below average followed by five months of above average precipitation (Figure D-4). The wettest period was March 30 to April 3, 2010 when 7.1 inches of precipitation fell (Figure D-5). The 2011 water year began and ended with above normal snowpack with a period of below normal conditions in mid-winter (January and February) due to below average precipitation during this period (Figure D-6). The snowpack peaked on March 1 with 44 inches of snow on the ground and persisted until May 7, 2011.

Table D-1. Monthly summary data, Longmire COOP Station, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Precipitation (inches)
Fall	October 2010	46.3	56.9	35.8	7.5[1]
	November 2010	33.2	40.2	26.2	11.1
Winter	December 2010	31.0	36.5	25.6	10.3
	January 2011	31.1	36.3	25.9	9.9
	February 2011	29.2	35.6	22.8	7.9
Spring	March 2011	34.5	40.3	28.6	13.1
	April 2011	36.1	42.6	29.7	8.0
	May 2011	43.3	52.4	33.8	5.3
Summer	June 2011	51.9	62.2	41.5	4.5
	July 2011	56.5	69.4	43.8	2.8
	August 2011	60.6	74.6	46.5	0.2
Fall	September 2011	58.6	72.0	44.7	2.9
	Water Year	**42.7**	**51.6**	**33.7**	**80.5**[1]

[1] Two days of precipitation data are missing from Longmire for the month of October (24-25). Based on comparisons with weather stations adjacent to Longmire and throughout the park, 3.0" of precipitation were added to the October data.

Table D-2. Air temperature extremes, Longmire COOP Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 8, 2011	92.0	November 24, 2010	-1.0
August 21, 2011	79.0	November 25, 2010	0.0
September 5, 2011	88.0	February 25, 2011	4.0
August 22, 2011	87.0	February 26, 2011	5.0
September 11, 2011	87.0	December 31, 2011	8.0

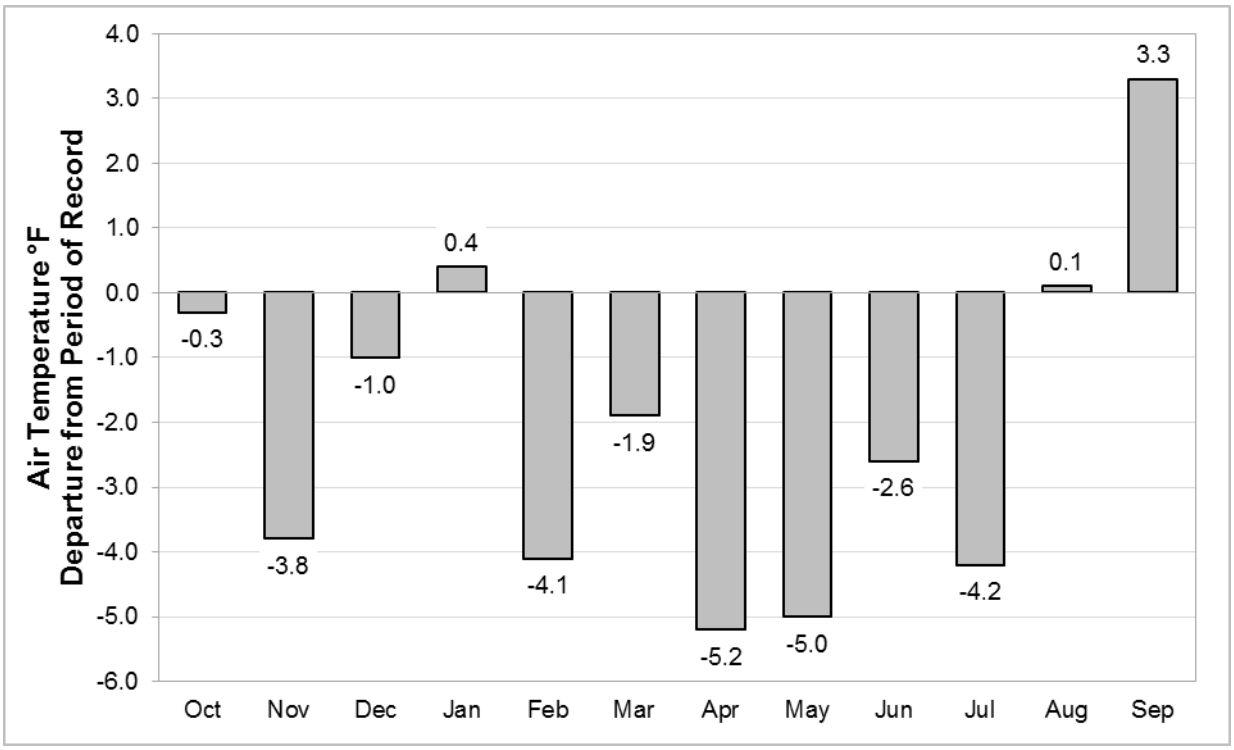

Figure D-1. Comparison of average monthly temperature (°F) for the Longmire COOP Station in Water Year 2011 against monthly averages for the period of record (1909-2010).

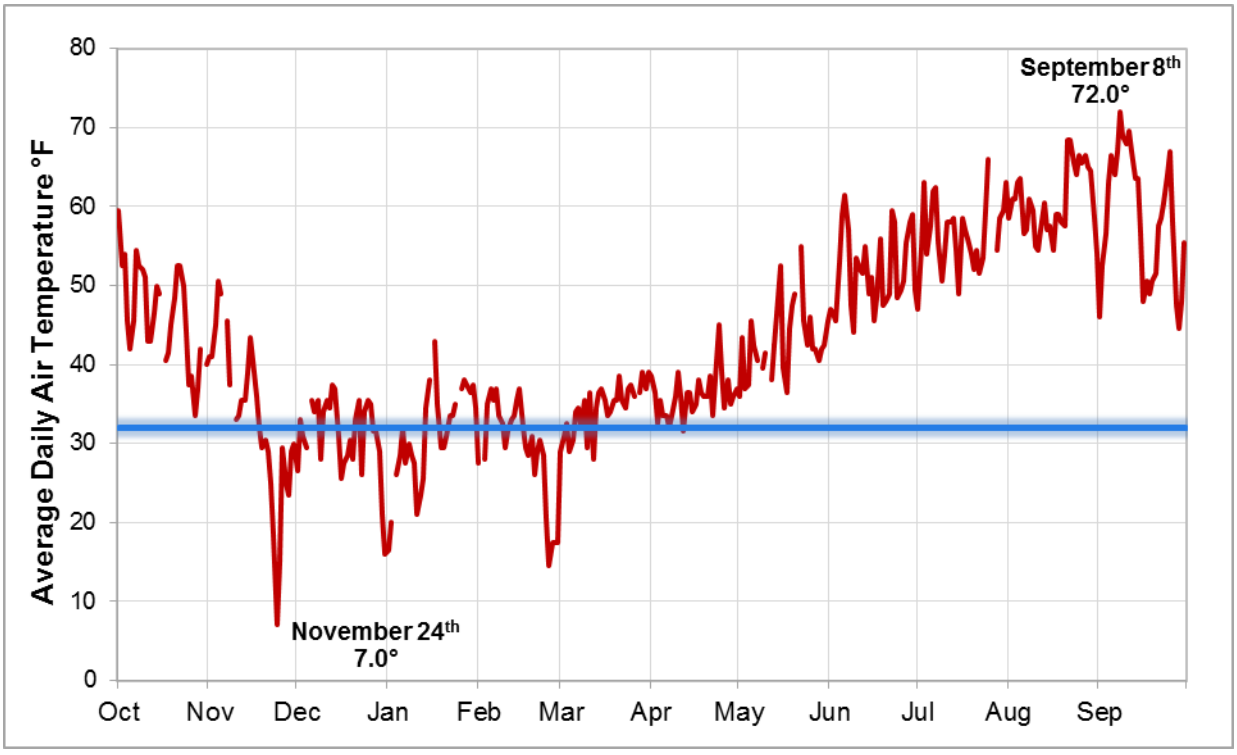

Figure D-2. Daily average air temperature (°F) values at the Longmire COOP Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

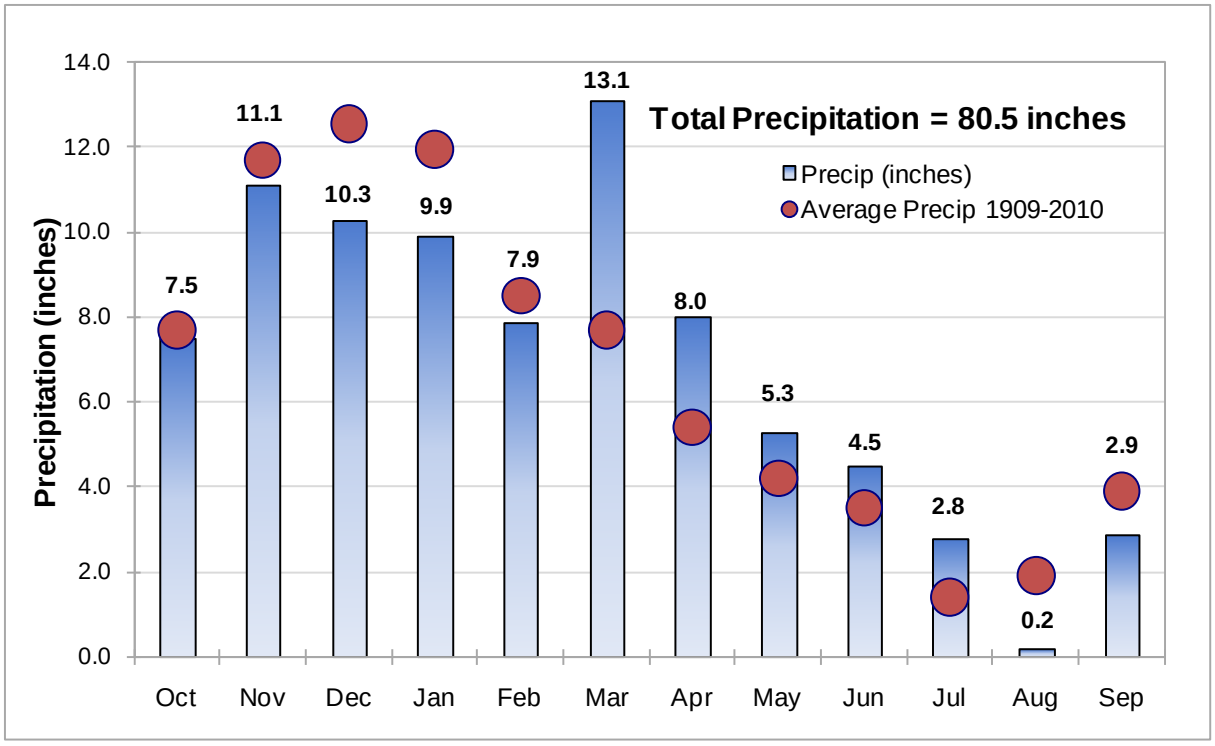

Figure D-3. Monthly precipitation (inches) at the Longmire COOP Station, Water Year 2011, compared to the monthly averages for the period of record (1909-2010).

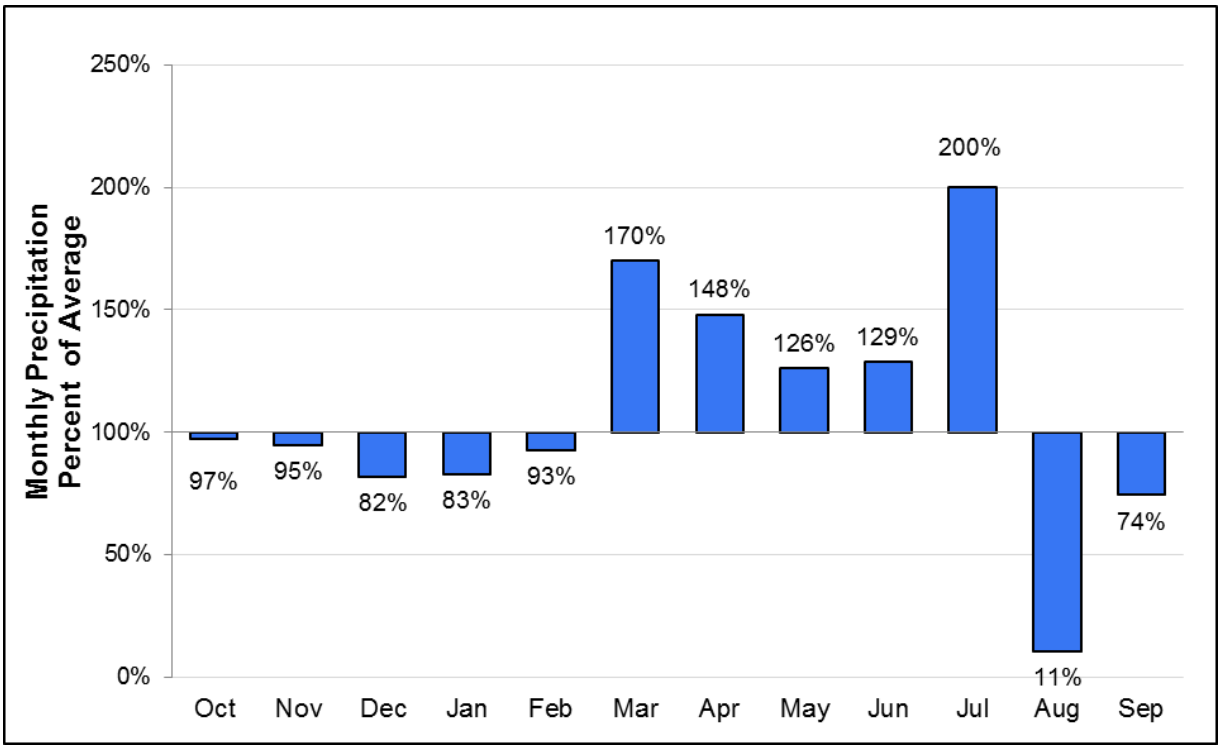

Figure D-4. Percent of average for period of record (1909-2010) for precipitation at the Longmire COOP Station in Water Year 2011.

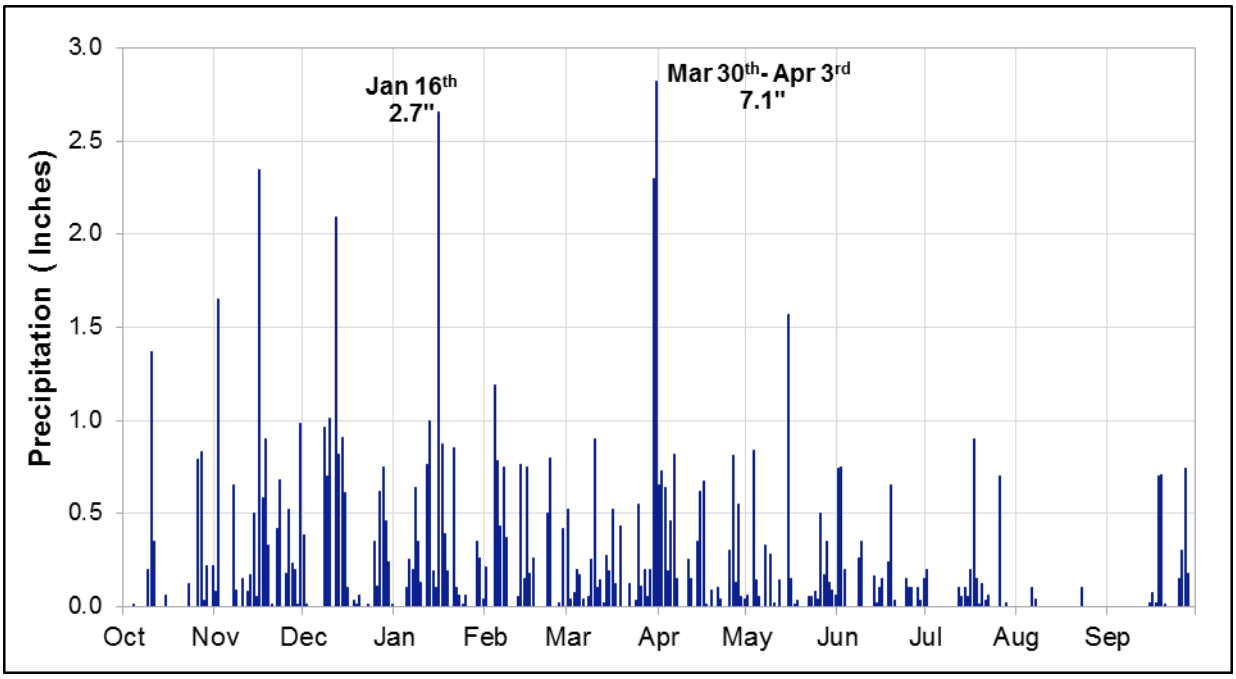

Figure D-5. Daily total precipitation (inches) at the Longmire COOP Station, Water Year 2011.

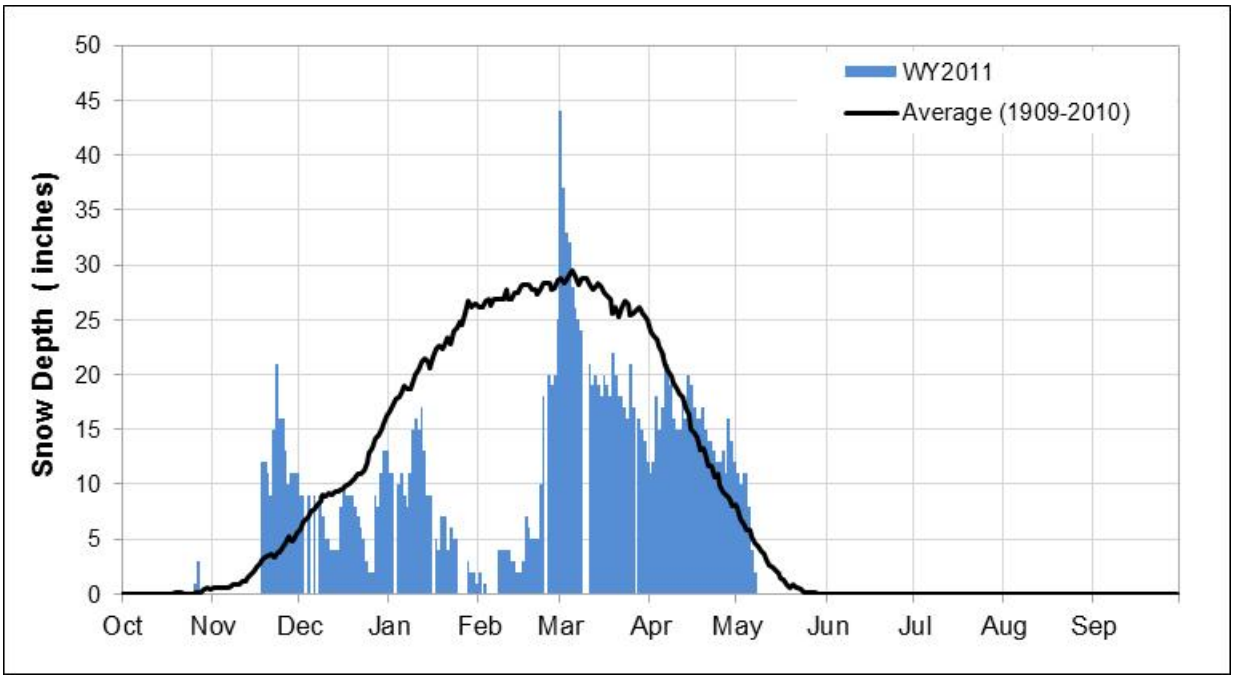

Figure D-6. Daily snow depth (inches) at the Longmire COOP Station, Water Year 2011, compared to the period of record daily average (1909-2010).

Appendix E: Ohanapecosh RAWS - Water Year 2011.

Due to intermittent power outages at Ohanapecosh since installation, data collection has been sporadic during the winter months. Therefore, no reliable period of record comparisons can be made. However, a NWS COOP station operated year round at Ohanapecosh from 1926-2001, which has consistent precipitation records. This period of record average for precipitation from the COOP station was used for comparison purposes. Temperature records are not available from the NWS COOP station. A new station, requiring less power to operate, was purchased for installation at Ohanapecosh to ensure year round data collection.

The maximum air temperature observed at the Ohanapecosh RAWS station was 98.0°F recorded on September 7 (Table E-2). The highest average daily air temperature for the park was recorded at Ohanapecosh on September 11 (Figure E-2). Temperatures from February through July reflected similar conditions to the rest of the park, with cooler than average conditions (Figure E-1).

Table E-1. Monthly summary data, Ohanapecosh RAWS Station, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Precipitation (inches)
Fall	October 2010	47.0	57.1	40.2	7.3
	November 2010	----[a]	----[a]	---[a]	----[a]
Winter	December 2010	----[a]	----[a]	----[a]	----[a]
	January 2011	----[a]	----[a]	----[a]	----[a]
	February 2011	31.9	37.5	27.9	----[b]
Spring	March 2011	35.2	42.3	31.9	----[b]
	April 2011	36.6	45.0	32.0	----[b]
	May 2011	45.4	57.4	37.6	----[b]
Summer	June 2011	54.6	68.4	45.2	1.7
	July 2011	59.7	76.2	48.2	0.7
	August 2011	63.3	81.5	51.3	0.1
Fall	September 2011	59.0	75.7	48.6	2.3
	Water Year	**----[a]**	**----[a]**	**----[a]**	**----[a,b]**

[a] Temperature and precipitation data are missing due to power loss.

[b] Precipitation data are missing due to equipment error.

Table E-2. Air temperature extremes, Ohanapecosh RAWS Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 7, 2011	98.0	----[a]	----[a]
September 10, 2011	96.0	----[a]	----[a]
September 11, 2011	96.0	----[a]	----[a]
August 20, 2011	95.0	----[a]	----[a]
July 24, 2011	94.0	----[a]	----[a]

[a] Minimum air temperatures are missing due to equipment error.

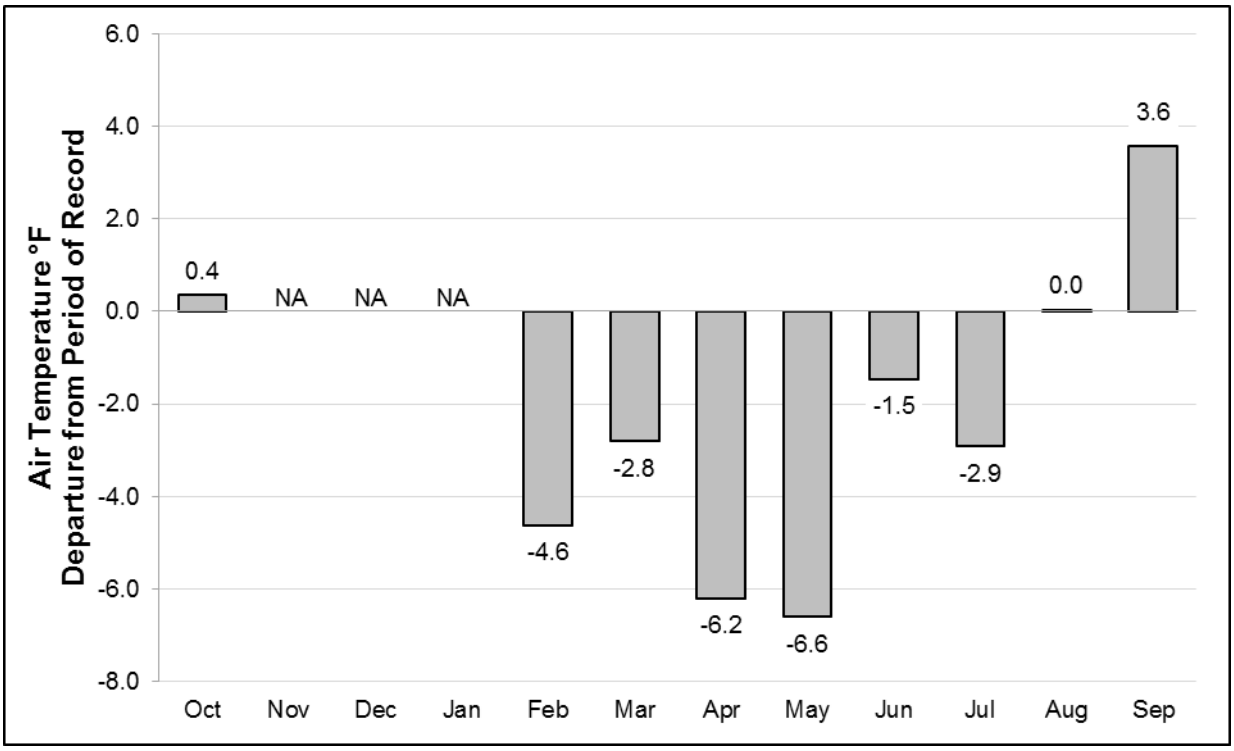

Figure E-1. Comparison of average monthly temperature (°F) for the Ohanapecosh RAWS Station in Water Year 2011 against monthly averages for the period of record (1926-2001).

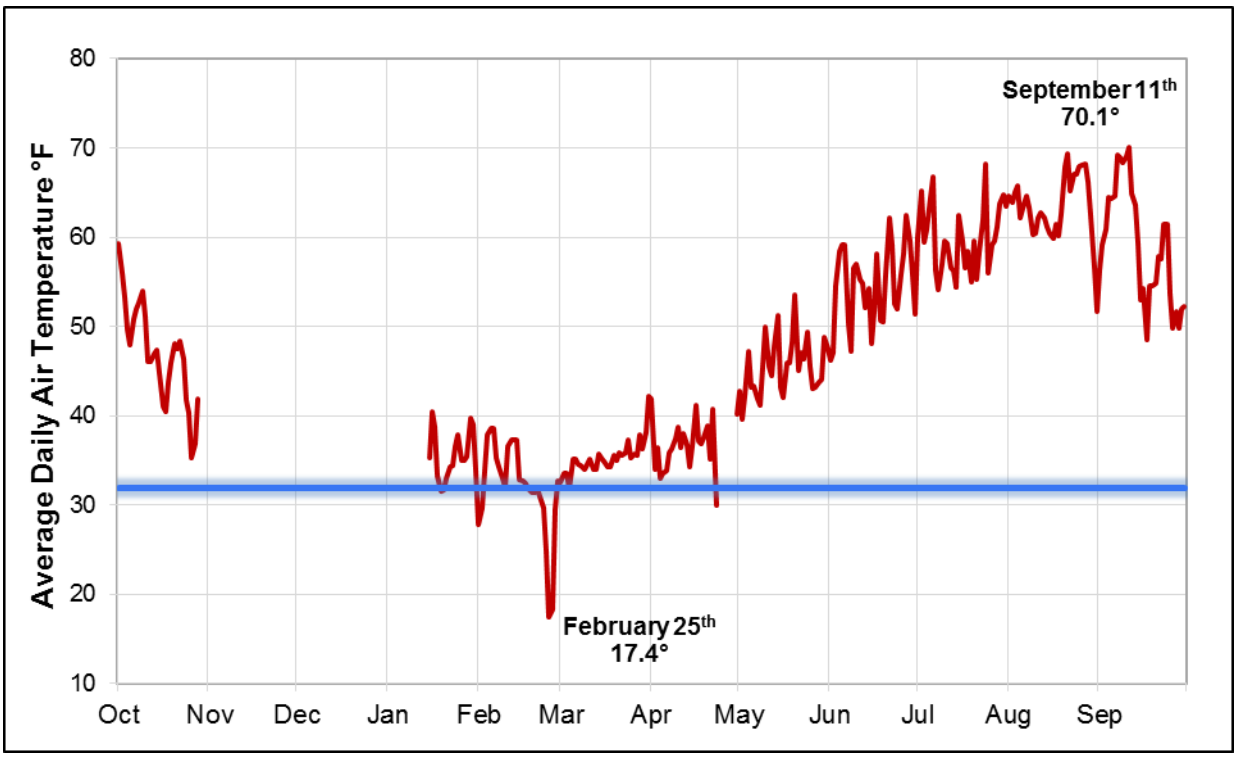

Figure E-2. Daily average air temperature (°F) at the Ohanapecosh RAWS Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

Appendix F: Paradise NWS COOP and SNOTEL - Water Year 2011.

Temperatures observed at the Paradise COOP station ranged from -4.0 to 78.0°F (Table F-2). Overall, monthly average temperature were cooler than average (1916-2010) with only October (+3.3°F), January (+3.1°F), and September (+4.8°F) recording above normal average temperatures. Temperatures from February through July reflected similar conditions as the rest of the park, with cooler than average conditions (Figure F-1). April provided the most extreme example with temperatures -6.9°F below normal at Paradise, which ranks April as the second coldest on record at Paradise. The coldest day of the year was November 24, which broke the record for both the coldest daily maximum (3°F) and minimum (-4°F) for the period of record (Figure F-2). September recorded the warmest average daily temperature of the year, 70°F on September 11th.

Total annual precipitation was 134.2 inches, 120% compared to the period of record (Figure F-3). The Paradise COOP recorded 17.3 inches of precipitation in April, making it the wettest April on record (Figure F-4). The wettest dates of the year occurred between March 30 and April 4, 2010 when Paradise received 12.4 inches (Figure F-5) of precipitation. The highest daily precipitation was recorded on January 16 at Paradise, with 5.1 inches falling as rain. Cold temperatures and above average precipitation in spring and early summer resulted in an above average snowpack and snow water equivalent that persisted through nearly the entire summer (Figures F-6 and F-7). At Paradise, the record for the maximum snow depth was broken for eight consecutive days beginning on August 7 and ending on August 24. Snow finally melted at the Paradise COOP location on August 25, missing the record for latest snow on the ground by two days, which was set in 1974. July first-of-month snow water equivalent measurements at Paradise were over 260% of normal.

Table F-1. Monthly summary table, Paradise COOP Station, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Precipitation (inches)
Fall	October 2010	43.5	49.3	37.7	14.3
	November 2010	29.6	34.6	24.6	14.9
Winter	December 2010	26.0	30.1	21.9	15.1
	January 2011	29.5	33.8	24.8	23.8
	February 2011	24.4	29.3	18.1	9.5
Spring	March 2011	25.8	30.3	21.2	22.2
	April 2011	26.4	31.4	21.3	19.0
	May 2011	34.1[a]	40.3	25.4	5.9
Summer	June 2011	40.8	49.2	32.4	4.5[a]
	July 2011	47.6	56.3	38.9	1.7
	August 2011	52.2	61.5	42.9	0.2
Fall	September 2011	53.3	62.7	44.3	3.1
	Water Year	**36.2**	**42.4**	**29.5**	**134.2**

[a] Nine days of precipitation data, totaling 0.5 inches, were estimated from the Paradise SNOTEL due to missing data.

Table F-2. Air temperature extremes, Paradise COOP Station, Water Year 2011.

Date	Max Air Temp °F[1]	Date	Min Air Temp °F[a]
September 8, 2011	78.0	November 24, 2010	-4.0
September 9, 2011	78.0	November 23, 2010	-1.0
September 11, 2011	78.0	February 25, 2011	0.0
September 12, 2011	78.0	November 25, 2010	1.0
September 5, 2011	77.0	February 26, 2011	3.0

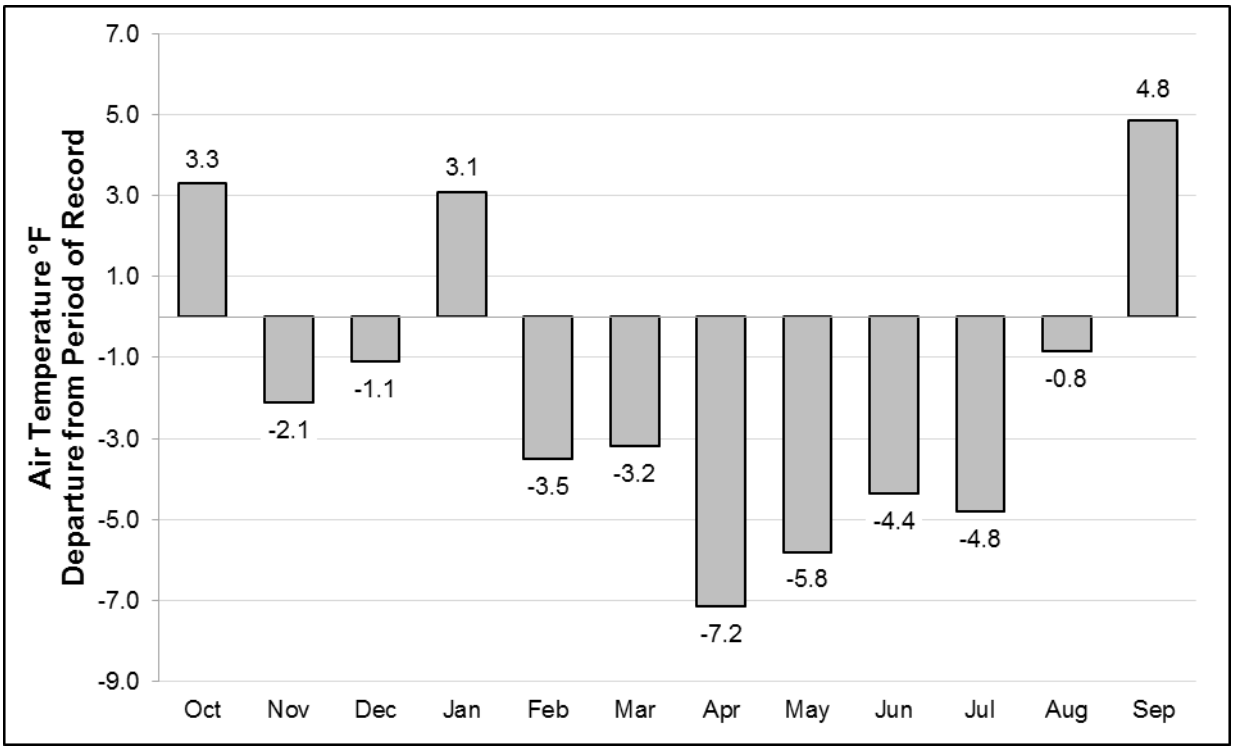

Figure F-1. Comparison of average monthly temperature (°F) for the Paradise COOP Station in Water Year 2011 against monthly averages for the period of record (1916-2010).

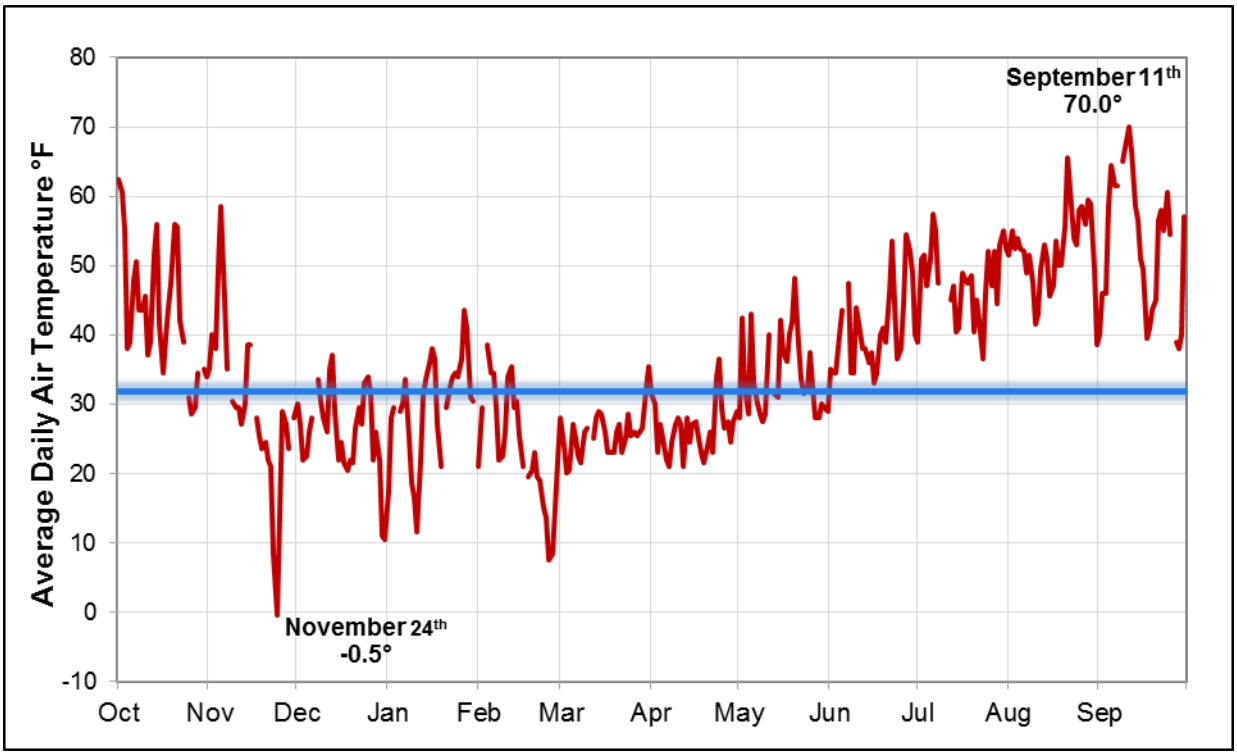

Figure F-2. Daily average air temperature (°F) at the Paradise COOP Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

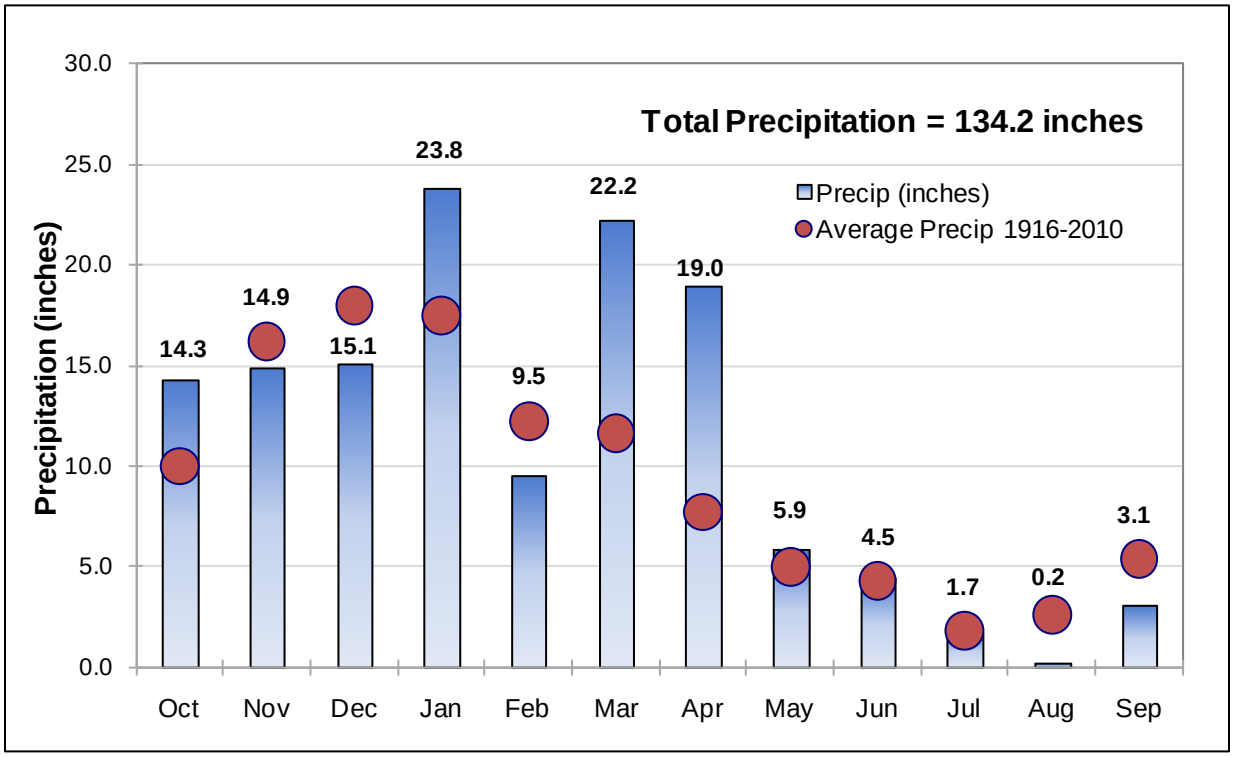

Figure F-3. Monthly precipitation (inches) at the Paradise COOP Station, Water Year 2011, compared to the monthly averages for the period of record (1916-2010).

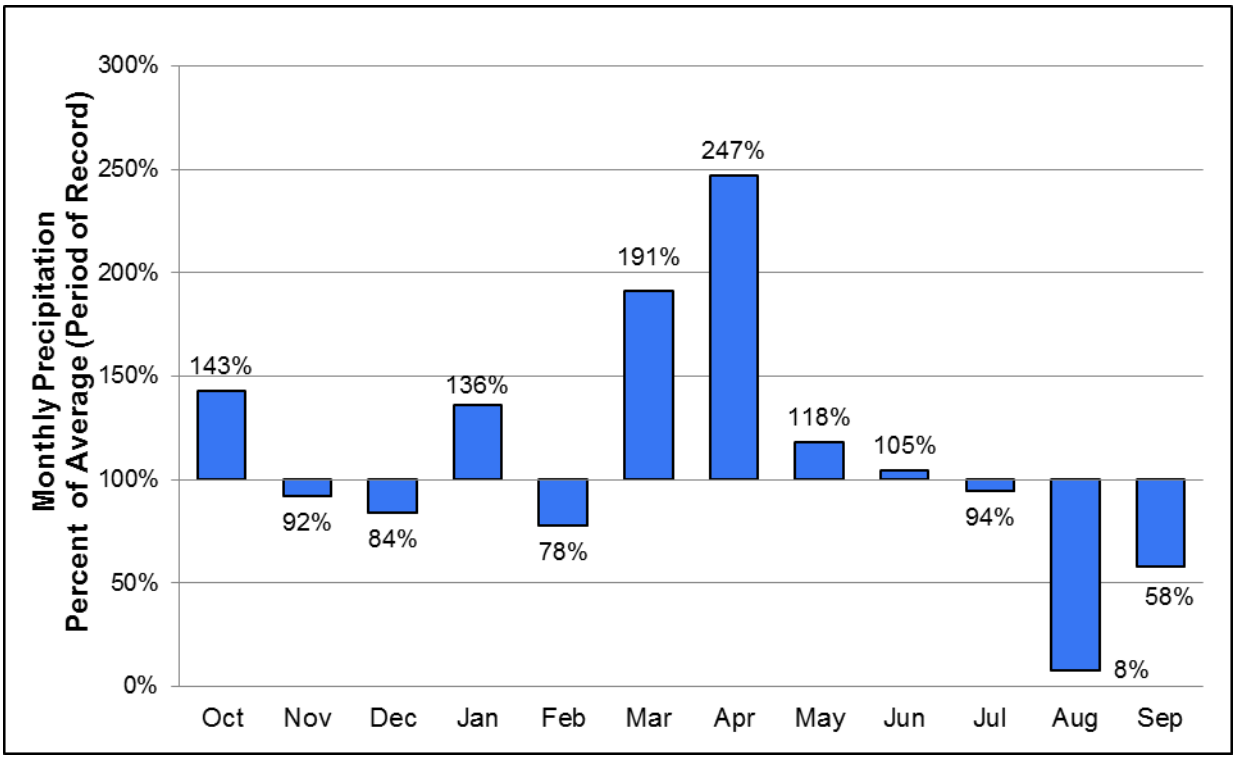

Figure F-4. Percent of average precipitation for the period of record (1916-2010) at the Paradise COOP Station in Water Year 2010.

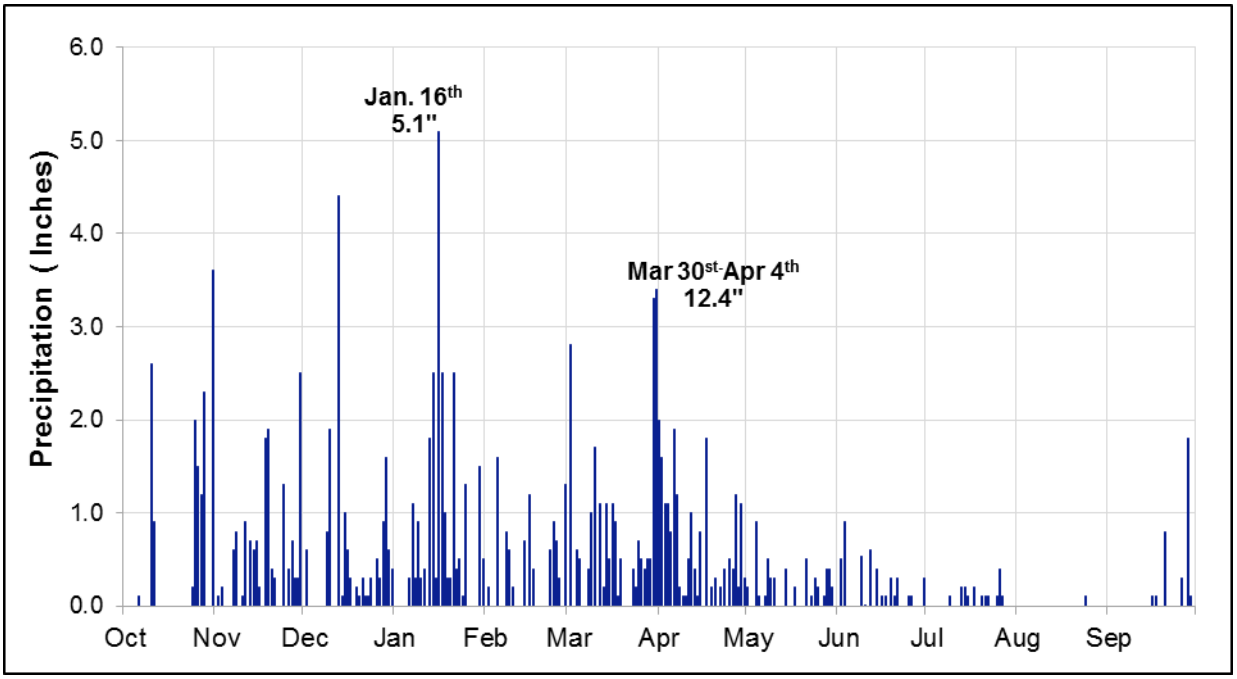

Figure F-5. Daily precipitation (inches) at the Paradise COOP Station, Water Year 2011.

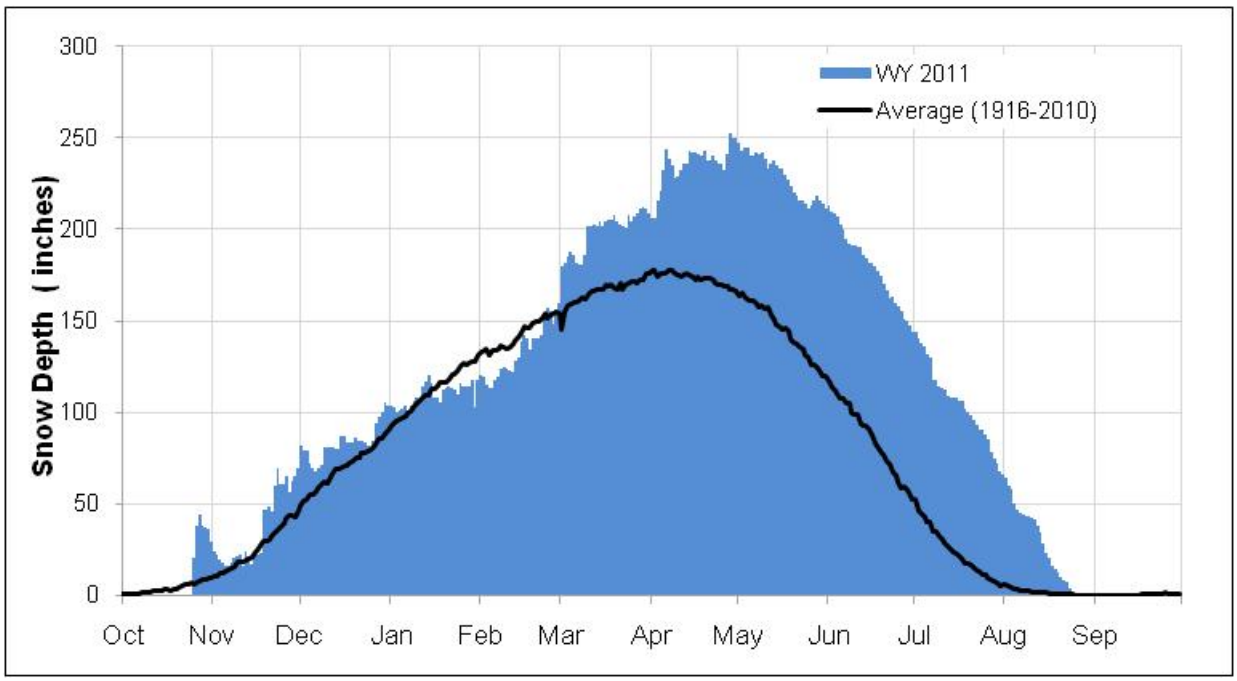

Figure F-6. Daily snow depth (inches) at the Paradise COOP Station, Water Year 2010, compared to the period of record daily average (1916-2010). Fifteen days of missing snow depth data were linearly interpolated from adjacent daily values.

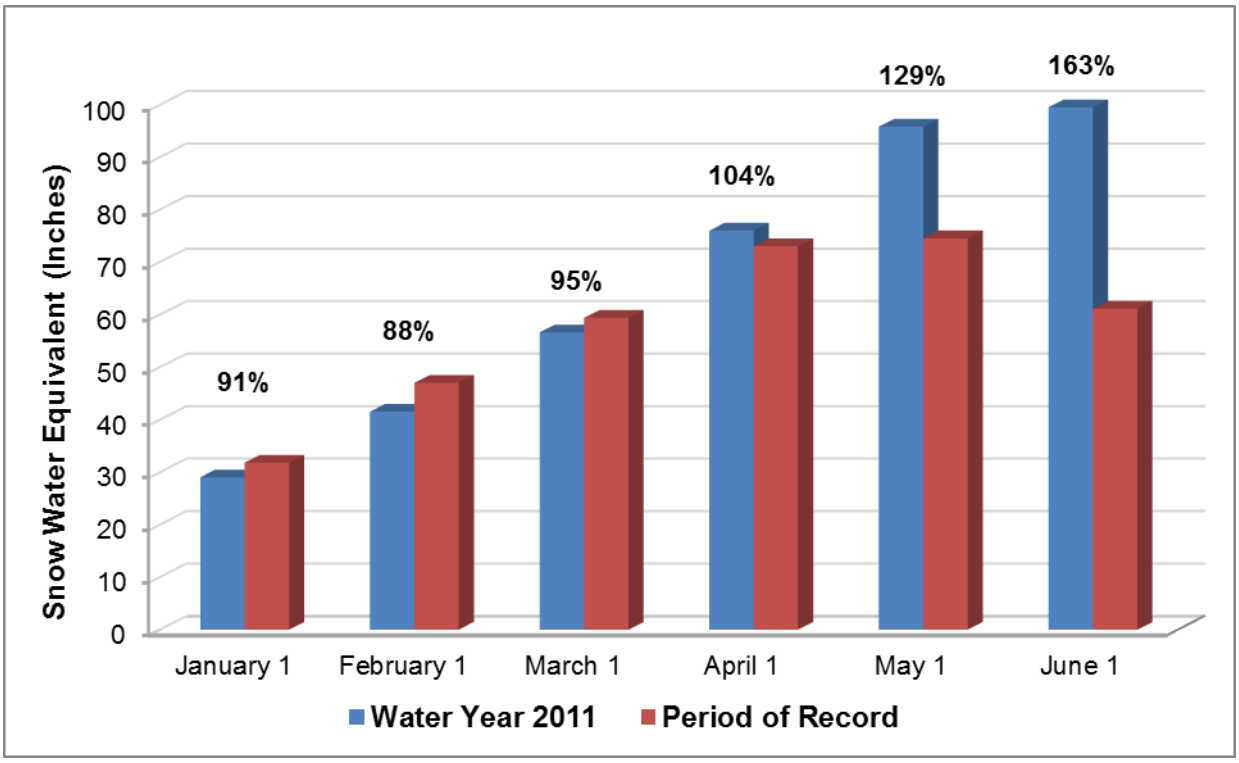

Figure F-7. First of the month snow water equivalent (inches) at the Paradise snow course in Water Year 2011, compared with the period of record (1940-2010).

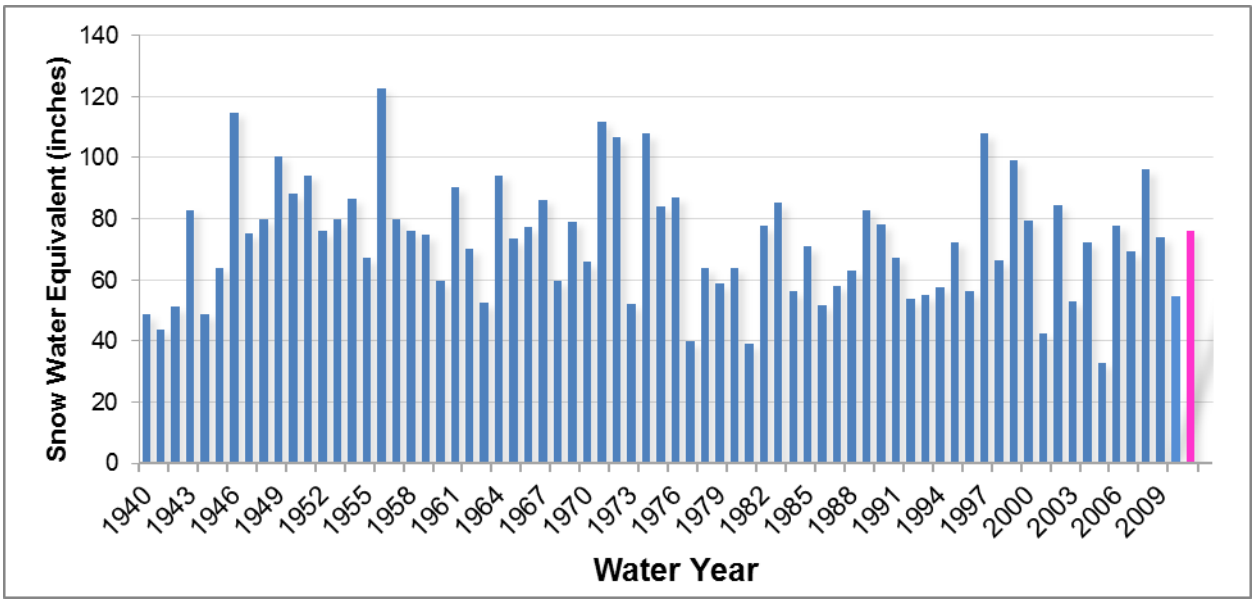

Figure F-8. April 1 snow water equivalent (inches) at the Paradise snow course for the period of record (1940-2011). Highlighted column indicates Water Year 2011.

Appendix G: Sunrise High Elevation - Water Year 2011.

Temperatures observed at the Sunrise High Elevation station ranged from -5.6 to 79.7°F (Table G-2). Temperatures from February through July averaged 5.1°F below the period of record (Figure G-1). The coldest day of the year was November 23, 2010 and the warmest day was September 11, 2011 (Figure G-2). The snowpack at Sunrise remained close to the period of record average from November through March. However, the snowpack persisted at above average levels for the remainder of the season due to the cooler, wet spring (Figure G-3). Snowpack began accumulating on October 24, 2010 and melted August 3, 2011, persisting for 283 days.

Precipitation data are missing from the Sunrise High Elevation weather station during all months due to malfunction of the precipitation gauge. Power limitations restrict the use of a heated tipping bucket at Sunrise, and heavy winter precipitation and low temperatures have tested the limits of the existing precipitation system. We are evaluating alternative methods to capture year round precipitation at Sunrise.

Table G-1. Monthly Summary data, Sunrise High Elevation Station, Water Year 2011.

Season	Month & Year	Mean Air Temp °F	Mean Daily Max Air Temp °F	Mean Daily Min Air Temp °F	Precipitation (inches)
Fall	October 2010	39.6	47.0	33.6	----[a]
	November 2010	27.2	32.3	22.1	----[a]
Winter	December 2010	26.3	29.5	23.0	----[a]
	January 2011	29.4	33.1	25.1	----[a]
	February 2011	22.9	28.6	18.8	----[a]
Spring	March 2011	24.9	30.1	21.0	----[a]
	April 2011	25.0	33.3	20.0	----[a]
	May 2011	34.2	42.4	26.7	----[a]
Summer	June 2011	41.3	49.4	34.3	----[a]
	July 2011	47.2	56.8	39.0	----[a]
	August 2011	53.1	61.5	46.0	----[a]
Fall	September 2011	52.7	63.1	42.1	----[a]
	Water Year	**35.3**	**42.3**	**29.2**	**----**[a]

[a] Precipitation at the Sunrise High Elevation Station is missing due to equipment malfunction.

Table G-2. Air temperature extremes, Sunrise High Elevation Station, Water Year 2011.

Date	Max Air Temp °F[1]	Date	Min Air Temp °F[a]
September 11, 2011	79.7	November 23, 2010	-5.6
August 28, 2011	77.8	February 25, 2011	-1.0
September 9, 2011	76.7	November 24, 2010	1.0
September 10, 2011	76.6	February 26, 2011	2.0
September 7, 2011	76.0	November 22, 2010	3.0

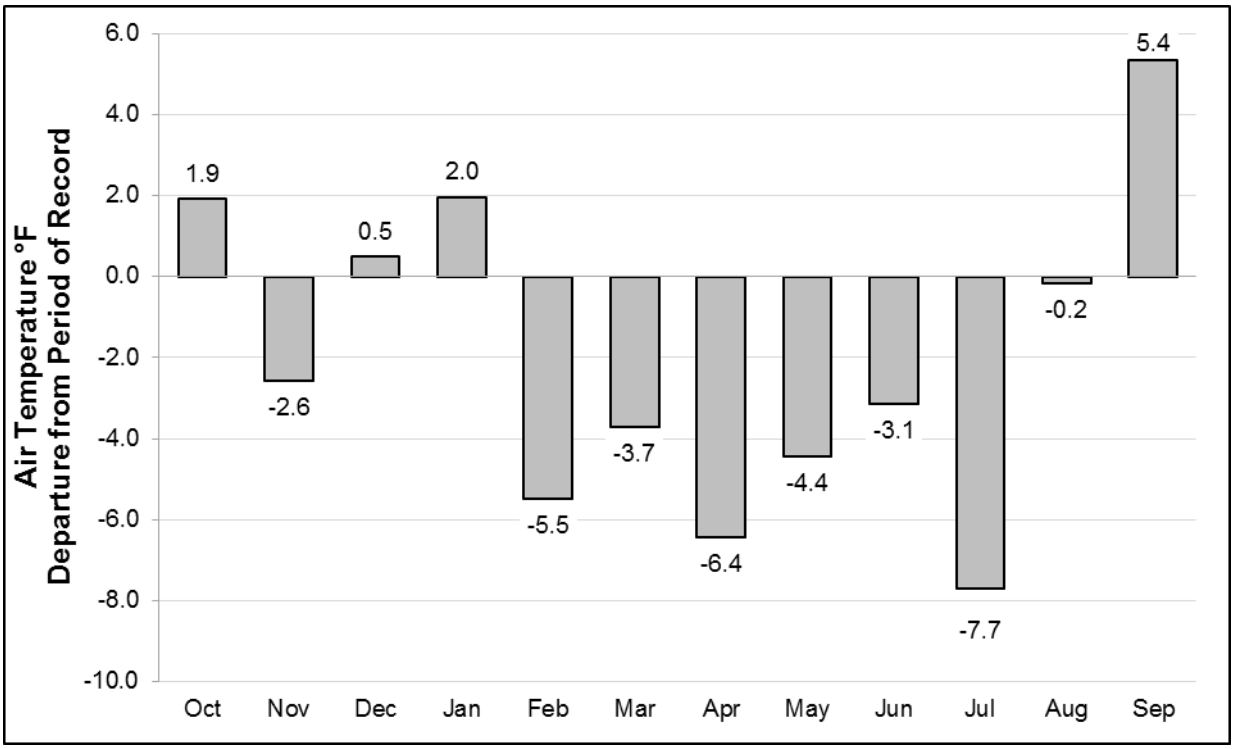

Figure G-1. Comparison of average monthly temperature (°F) for the Sunrise High Elevation Station in Water Year 2011 against monthly averages for the period of record (2004-2010).

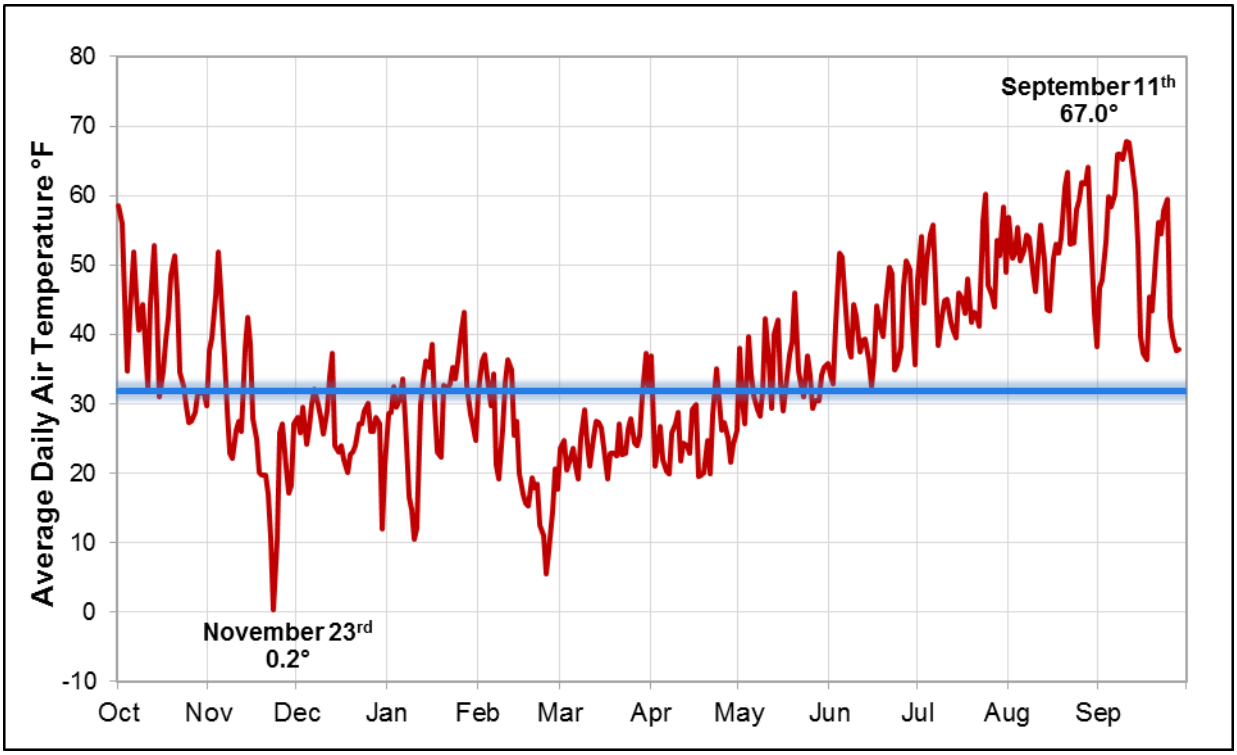

Figure G-2. Daily average air temperature (°F) at the Sunrise High Elevation Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

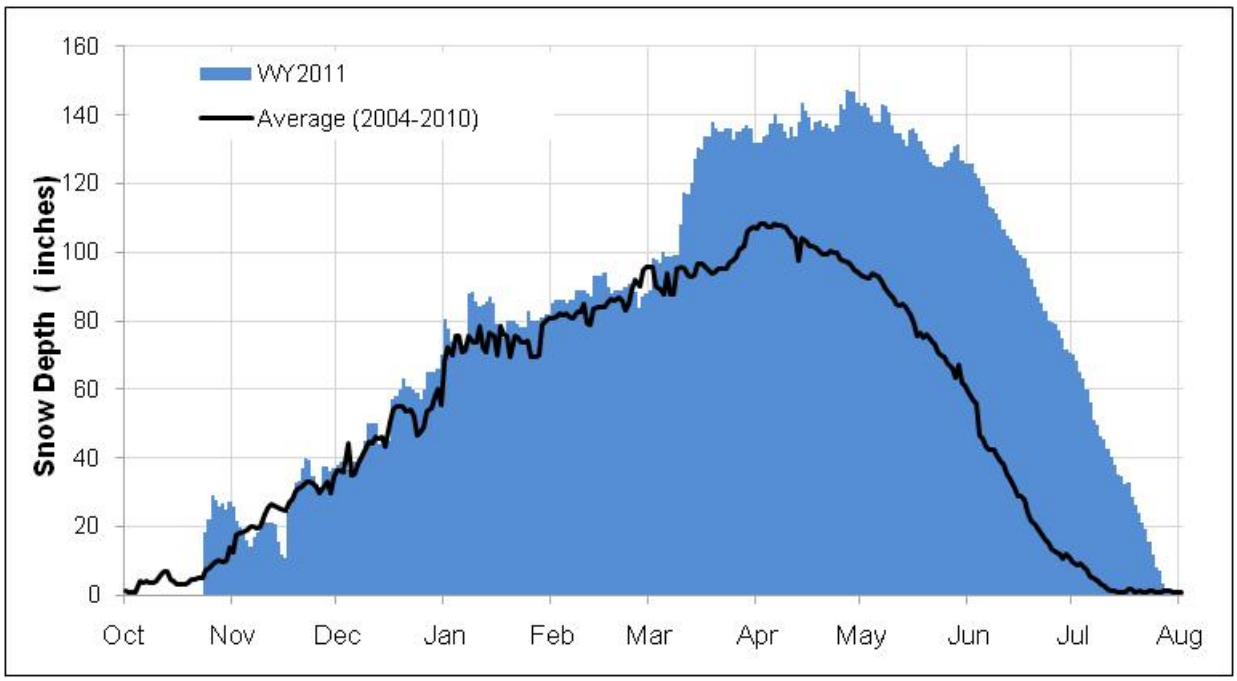

Figure G-3. Daily snow depth (inches) at the Sunrise High Elevation Station, Water Year 2011, compared with the period of record daily average (2004-2010).