National Park Service
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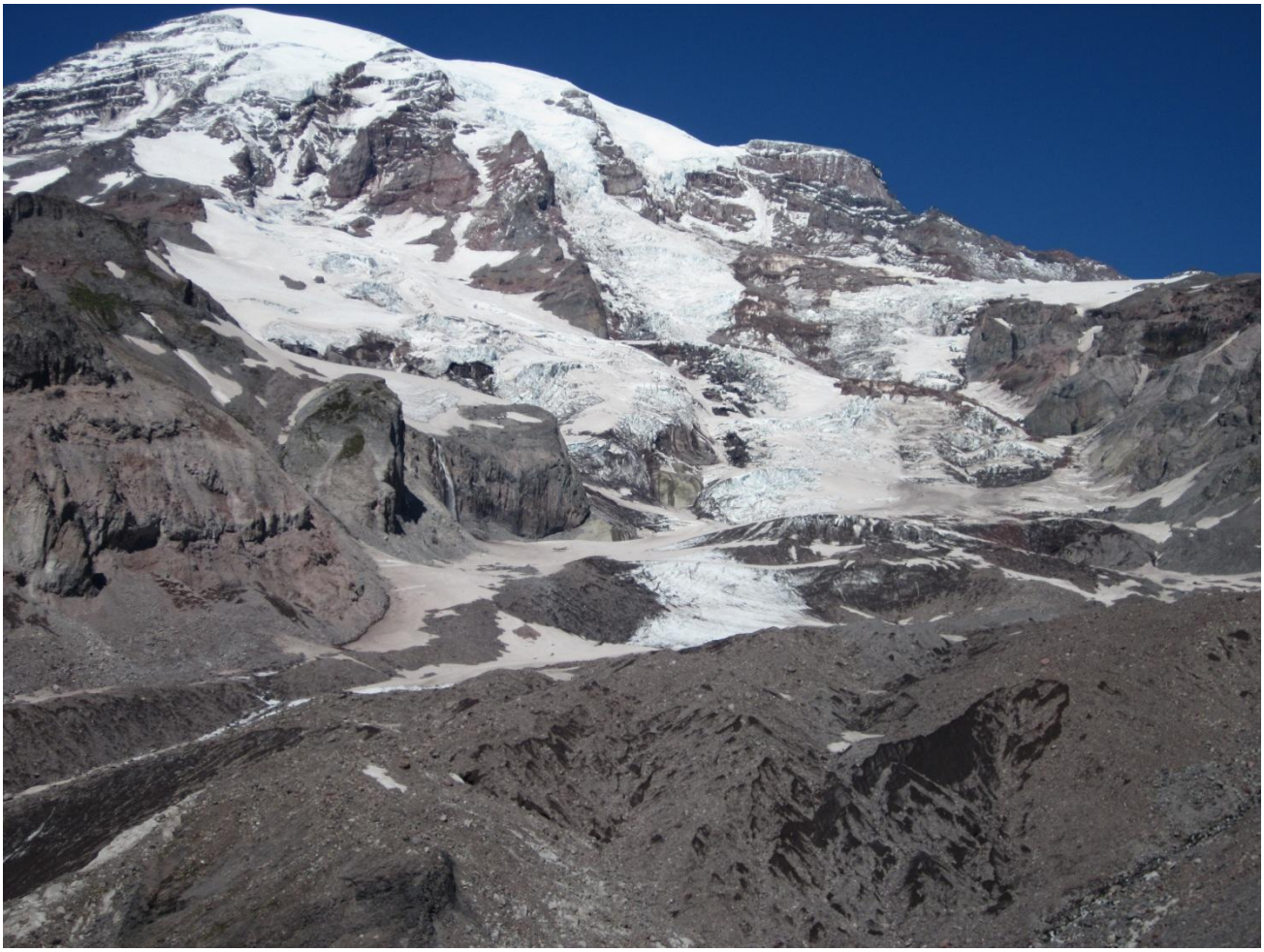
Natural Resource Stewardship and Science

North Coast and Cascades Network Climate Monitoring Report

Mount Rainier National Park; Water Year 2010

Natural Resource Data Series NPS/NCCN/NRDS—2012/318



ON THE COVER
View of the south side of Mount Rainier, September 30th, 2010.
Photograph by: Rebecca Lofgren

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 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/).

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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 2010 water year, and is part of a set of climate summary reports from seven national and historic parks in the North Coast and Cascades Network. Published in the National Park Service's Natural Resource Data Series, annual climate summary reports are intended to provide basic data sets and data summaries in a timely manner, with minimal interpretation and analyses. We intend that the primary audience for this document will be National Park staff, especially decision makers, planners, and interpreters; partners; and interested public.

Temperature and precipitation data are presented from eight weather stations located within Mount Rainier National Park: Camp Muir (10,100' elevation), Carbon River (1735'), Cayuse (5200'), Longmire (2760'), Ohanapecosh (1950'), two stations at Paradise (5550' and 5120'), and Sunrise (6420'). Data were recorded using automated and manual instruments operated by the National Park Service and other collaborators, including the National Weather Service, National Interagency Fire Center, Natural Resources Conservation Service, and Northwest 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 2010 indicated that average annual temperatures and precipitation were both near normal; however significant monthly departures from normal were recorded throughout the year. Overall, conditions in winter were both warmer and drier than normal, with a shift to cooler and wetter conditions in the spring through early summer. Snowpack remained below normal during the warmer, drier winter months only to build in the wetter, cooler late spring to above normal conditions that persisted into July.

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 Climate Stations

Data management is critical to provide for the availability and analysis of climate data. We depend on the NCCN Data Managers, specifically John Boetsch, Bret Christoe and Ruth Jenkins; the Western Regional Climate Center; and the National Climate Data Center for climate data management. We thank Catharine Copass and Barbara Samora for their review of this document. Finally, we 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 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 2010 is the 12-month period beginning 01 October 2009 and ending 30 September 2010. The period is chosen so as to encompass a full cycle of precipitation accumulation.

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

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

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

This report summarizes climate data collected from eight weather stations located in Mount Rainier National Park during the 2010 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 eleven 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.

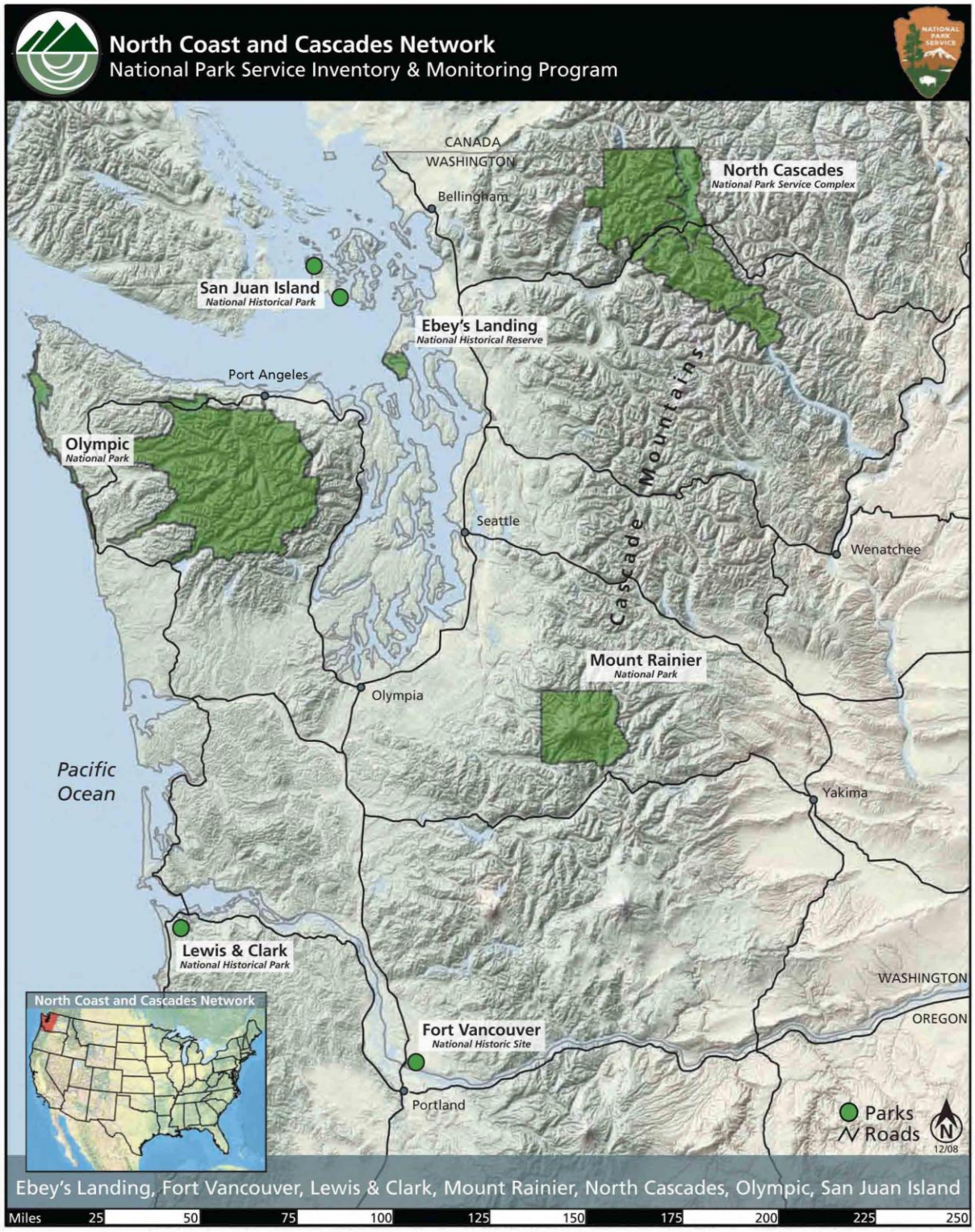

Figure 1. North Coast and Cascades Network Parks (NCCN).

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	5550	Subalpine	1916 to Present
Paradise	SNOTEL	Southwest	5120	Subalpine	1981 to Present
Sunrise High Elevation	NPS	Northeast	6420	Subalpine	2004 to Present

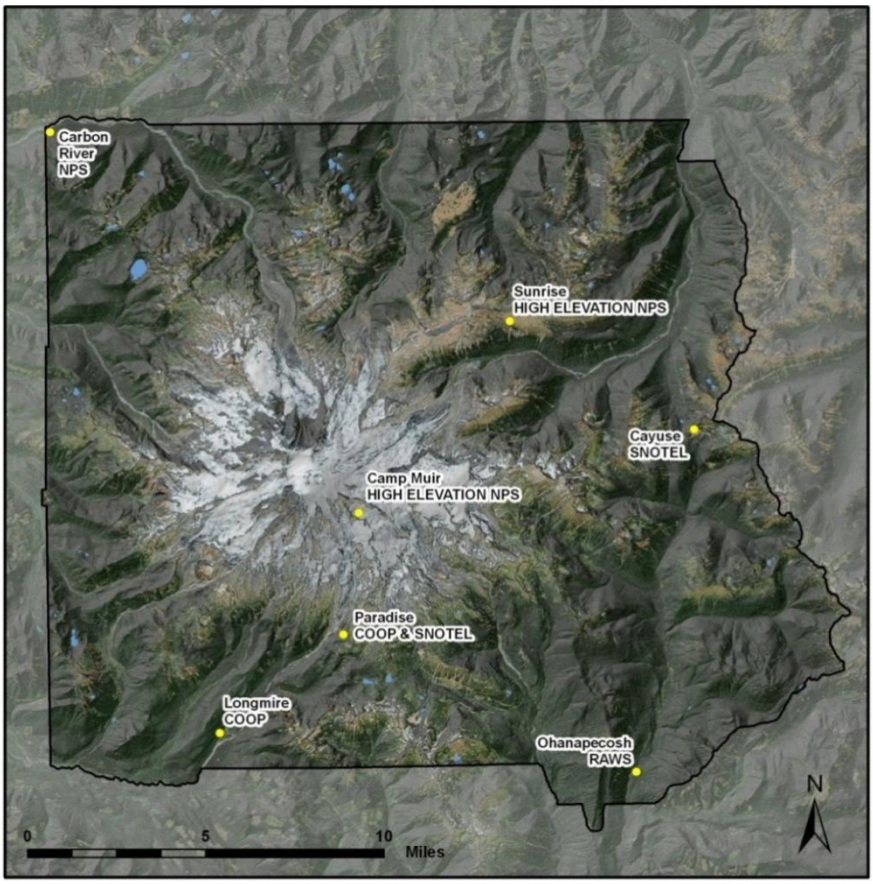

Figure 2. Location of weather stations referenced in this report. The Paradise SNOTEL and Paradise COOP stations are in two separate locations within the same general area.

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**				
Longmire	NWS COOP[3]	**X**		**X**	**X**	**X**					
Ohanapecosh	NIFC-RAWS[4]	**X**		**X**	**X**			X			
Paradise	NWS COOP[3]	**X**		**X**	**X**	X					
Paradise	NRCS-SNOTEL[2]	**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.

[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 failure and access to these remote sites, data gaps exist at several stations.

Precipitation data are missing from the Sunrise High Elevation weather station during all months except for October. Gaps exist in the Ohanapecosh RAWS precipitation data during December. These months were omitted from analysis.

More than six days of temperature data is missing from the Paradise COOP weather station in the months of May and April. The monthly averages for these months are within 1°F of the adjacent Paradise SNOTEL station, and are therefore included in analysis.

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. This data was removed for analysis purposes. Finally, high (out of range) temperature spikes occurred at Camp Muir for more than six days in July. Data from this month were therefore removed for analysis purposes.

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 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 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 2010 weather data for each climate station is reported in a separate appendix. The appendices include daily precipitation, temperature and snowfall or snow water equivalent when available. Maximum and minimum temperatures for each month are also reported. Maximum and average wind speed are provided for the Camp Muir High Elevation station. While the main report compares Water Year 2010 with the 30-year climate normal, the appendices compare 2010 with the period of record. Detailed discussion of maintenance issues or data concerns associated with each specific station is also presented.

Results

Temperature

Temperatures were below average at all sites for October, with Longmire recording a monthly departure from normal of -4.3°F. Below normal temperatures persisted in November and December at most stations (Table 3; Figures 3 and 4). The exception was Paradise where temperatures were slightly above normal. All stations recorded warmer than average temperatures during January, February, and March (Appendices A to G). January provided the most extreme example with temperatures 5.5°F above normal at Paradise and 4.9ºF at Longmire. Climate conditions changed drastically however, in the spring and early summer. Temperatures for April, May, and June were all well below normal (Figures 3 and 4). By July and August, temperatures returned to at or above normal temperatures, followed by a return of colder than normal conditions in September.

Table 3. Average monthly air temperatures (°F) from weather stations within Mount Rainier National Park in Water Year 2010.

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 2009	25.5	44.8	36.5	41.6	44.2	36.6	34.4
	November 2009	18.8	39.6	31.6	34.4	36.8	31.1	28.8
Winter	December 2009	16.8	30.2	26.5	28.1	28.3	26.9	23.8
	January 2010	19.2	40.7	32.0	35.9	36.6	32.1	30.1
	February 2010	18.2	38.0	31.7	37.4	37.3	32.2	29.8
Spring	March 2010	17.4	38.9	32.3	38.0	38.0	32.9	29.3
	April 2010	18.1	41.2	32.6	39.1	41.7	32.0[b]	29.5
	May 2010	21.9	45.4	36.3	44.4	48.2	36.5[b]	34.1
Summer	June 2010	31.7	51.9	43.1	50.5	54.5	42.6	41.3
	July 2010	----[a]	60.1	53.4	59.9	63.4	56.0	53.8
	August 2010	39.5	59.4	52.7	60.4	62.6	54.3	52.0
Fall	September 2010	34.4	53.6	46.9	52.5	55.4	47.6	45.4
Water Year		----[a]	45.3	37.5	43.5	45.6	38.4	36.3

[a] Values for the months of April and May are missing 6 days of temperature. Monthly average values are within 1°F of data from nearby Paradise SNOTEL site.

[b] Six days of temperature data are missing due to equipment error.

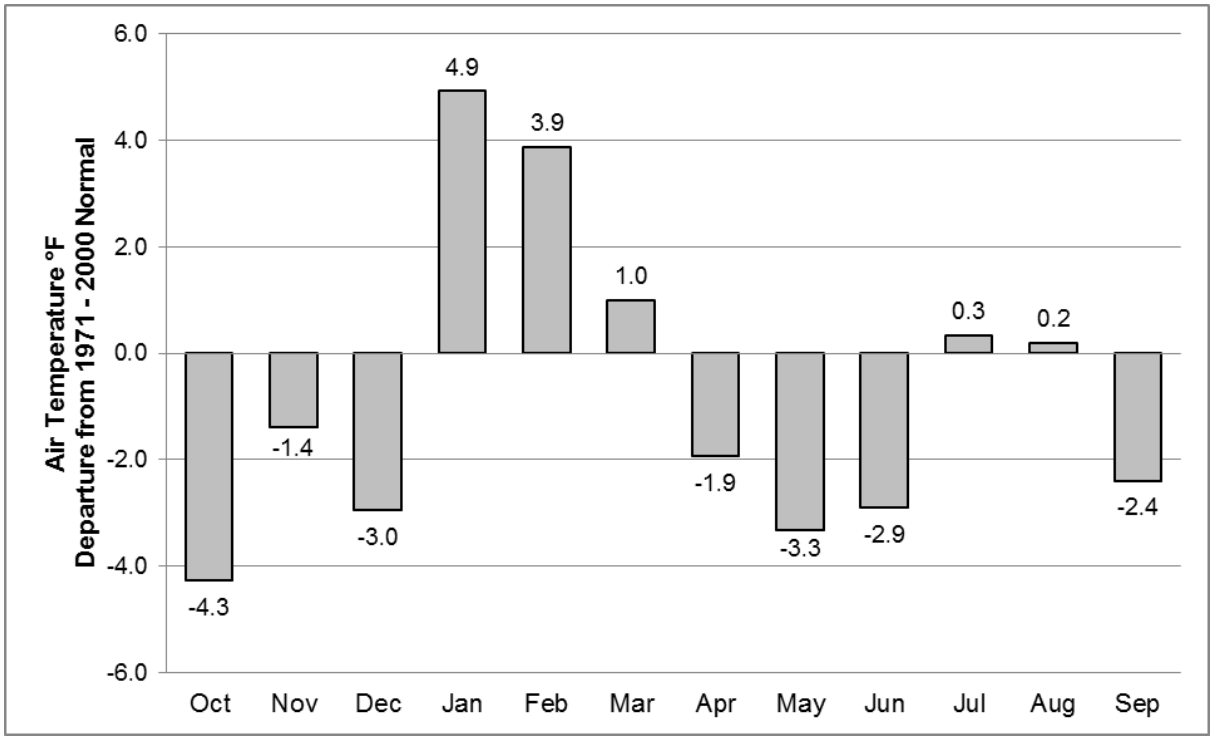

Figure 3. Comparison of average monthly temperature (°F) for Longmire (COOP) in Water Year 2010 against monthly averages for the climatological normal 1971-2000.

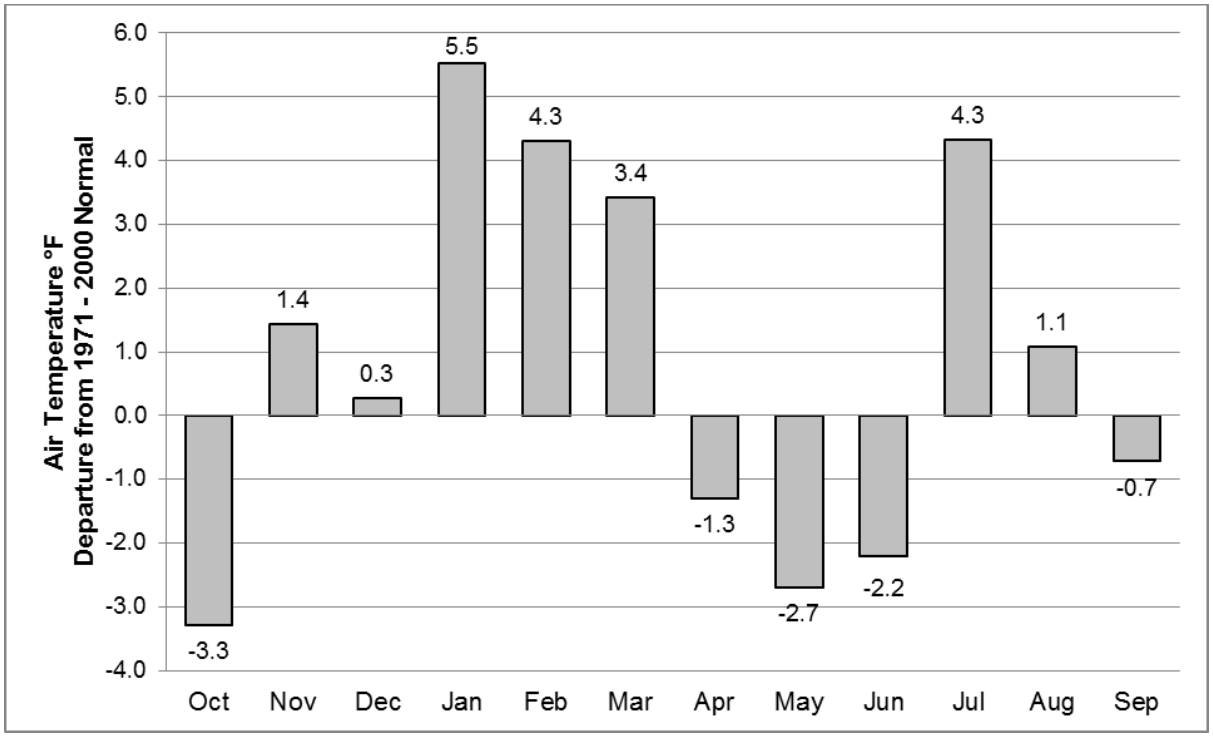

Figure 4. Comparison of average monthly temperature (°F) for Paradise (COOP) in Water Year 2010 against monthly averages for the climatological normal 1971-2000.

Precipitation

Precipitation was above normal in October followed by November returning to near normal precipitation (Table 4; Figures 4 and 5). October precipitation was 167% above normal at the Paradise COOP station and 151% above normal at the Longmire COOP station. An extended period of below normal precipitation began in December and continued through February. Precipitation for this three-month period averaged approximately 60% below normal at the Longmire and Paradise COOP stations (Figures 4 and 5). Conditions in April returned to near normal followed by an extremely wet May and June. May recorded the largest departure from normal with precipitation 220% and 206% above normal at the Paradise and Longmire COOP sites respectively (Figures 4 and 5). The Paradise COOP recorded 12.1 inches of precipitation in May, making it the wettest May on record. July and August brought notably dry conditions to the park; no station recorded more than 0.7 inches of precipitation in the month of July. September brought the return of wetter than normal conditions to all stations.

Table 4. Total Monthly precipitation (inches) from weather stations within Mount Rainier National Park in Water Year 2010.

Season	Month & Year	Carbon River NPS	Cayuse Pass SNOTEL	Longmire NWS COOP	Ohanapecosh RAWS	Paradise NWS COOP	Sunrise High Elevation NPS
Fall	October 2009	8.9	6.0	10.6	9.6	14.2	7.7
	November 2009	10.6	12.2	14.4	12.7	18.7	----[b]
Winter	December 2009	4.4	5.1	5.7	----[a]	9.2	----[b]
	January 2010	8.6	9.1	9.6	9.4	12.9	----[b]
	February 2010	4.4	7.6	4.4	4.5	7.4	----[b]
Spring	March 2010	5.7	10.0	7.0	7.9	9.6	----[b]
	April 2010	6.5	12.2	5.9	5.6	9.0	----[b]
	May 2010	10.5	6.3	9.3	5.7	12.1	----[b]
Summer	June 2010	6.9	5.5	6.4	4.6	6.2	----[b]
	July 2010	0.7	0.7	0.5	0.1	0.6	----[b]
	August 2010	1.7	0.8	0.3	0.2	0.9	----[b]
Fall	September 2010	6.1	5.4	6.5	6.1	8.2	----[b]
Water Year		75.0	80.9	80.6	----[a]	109	----[b]

[a] Nine days of precipitation data are missing due to power loss of the heated precipitation gauge.

[b] Precipitation at Sunrise High Elevation station is missing due to equipment malfunction.

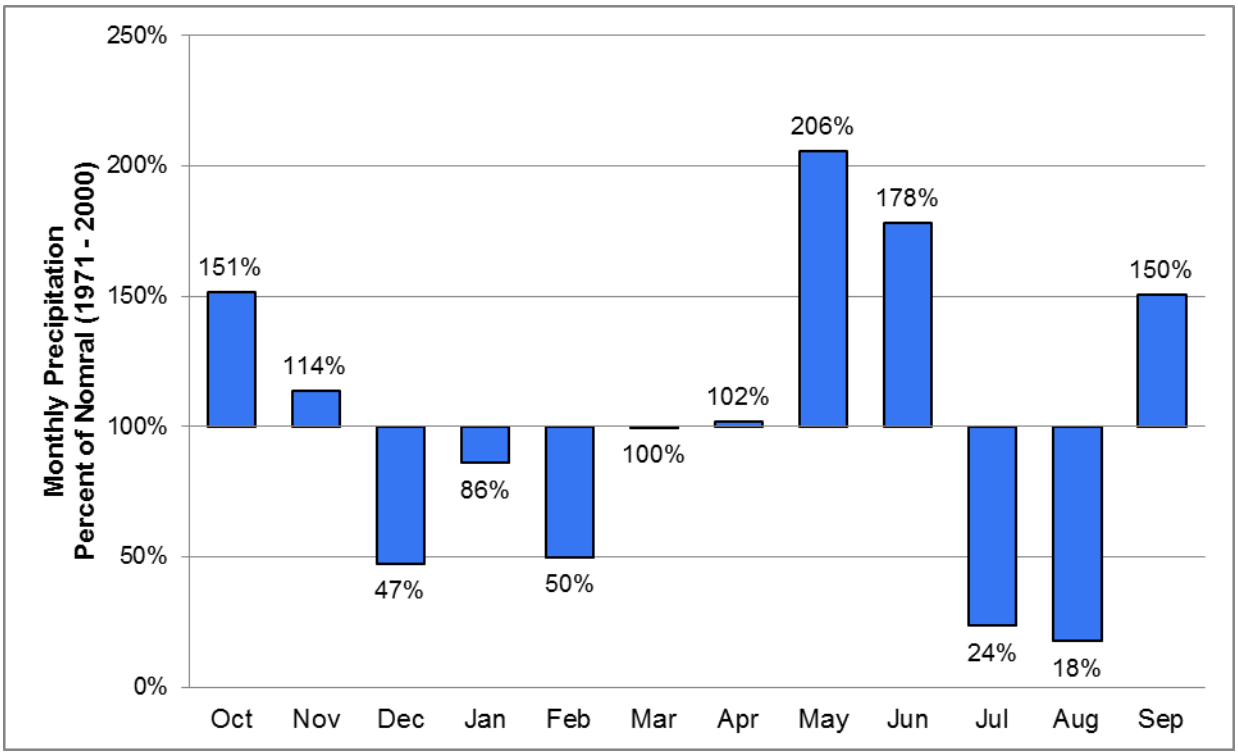

Figure 4. Comparison of total monthly precipitation (inches) at Longmire (COOP) in Water Year 2010 against the climatological normal 1971-2000.

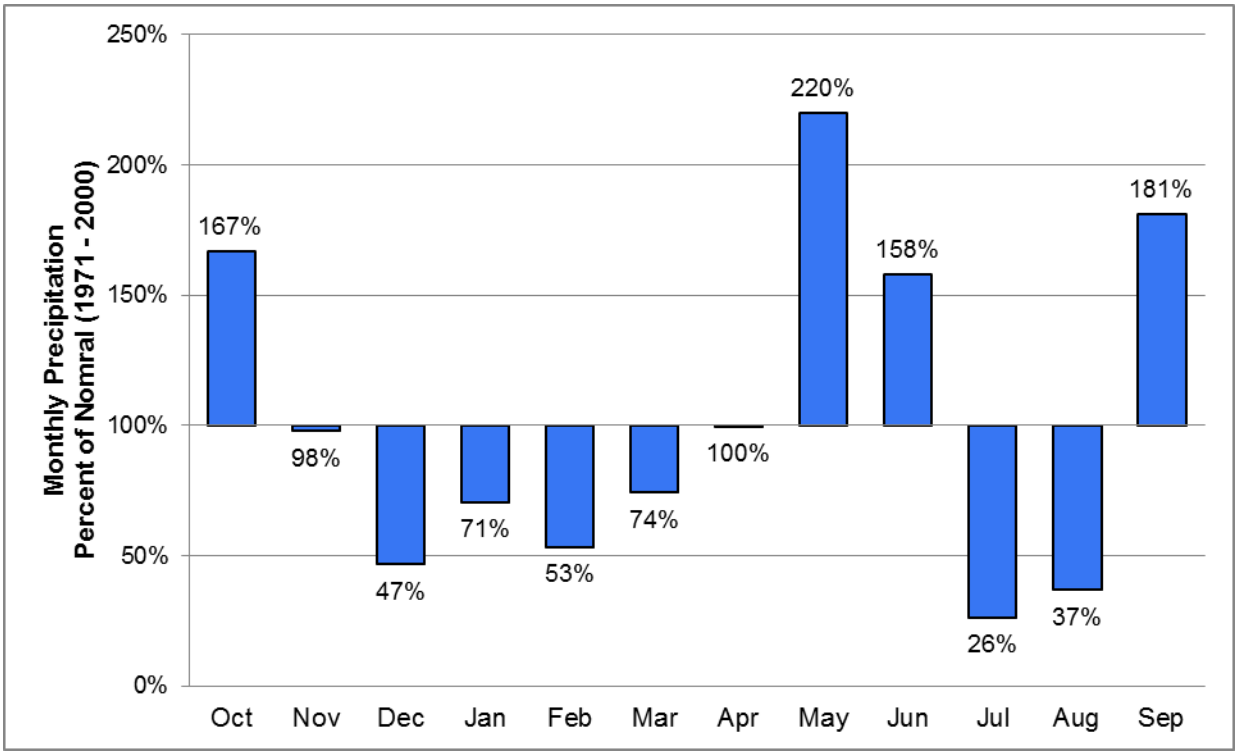

Figure 5. Comparison of monthly precipitation (inches) at the Paradise (COOP) in Water Year 2010 against the climatological normal 1971-2000.

Snow

The snowpack was above normal during November (Appendix F: Figure F-6) and early December. Below normal precipitation in December, combined with drier and warmer conditions for the remaining winter months resulted in little snow accumulation, particularly at lower elevations such as Longmire (Table 5). Snow water equivalent at Paradise remained below normal for all of the winter and spring (Figure 6). Significant new snow resulting from the cold wet spring supplemented and maintained the seasonal snowpack; the summer month of June was the first time when the first-of-month snow water equivalent measurements were above normal at Paradise.

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 2010.

Month & Year	Cayuse Pass SNOTEL	Longmire NWS COOP	Paradise NWS COOP	Sunrise High Elevation
October 1st 2009	0.0	0.0	0.0	0.0
November 1st 2009	0.0	0.0	2.0	4.0
December 1st 2009	46.0	0.0	59.0	39.0
January 1st 2010	71.0	0.0	81.0	60.0
February 1st 2010	90.0	0.0	105.0	77.0
March 1st 2010	111.0	0.0	118.0	106.0
April 1st 2010	139.0	3.0	154.0	121.0
May 1st 2010	132.0	0.0	175.0	116.0
June 1st 2010	109.0	0.0	142.0	97.0
July 1st 2010	37.0	0.0	74.0	37.0
August 1st 2010	0.0	0.0	0.0	0.0

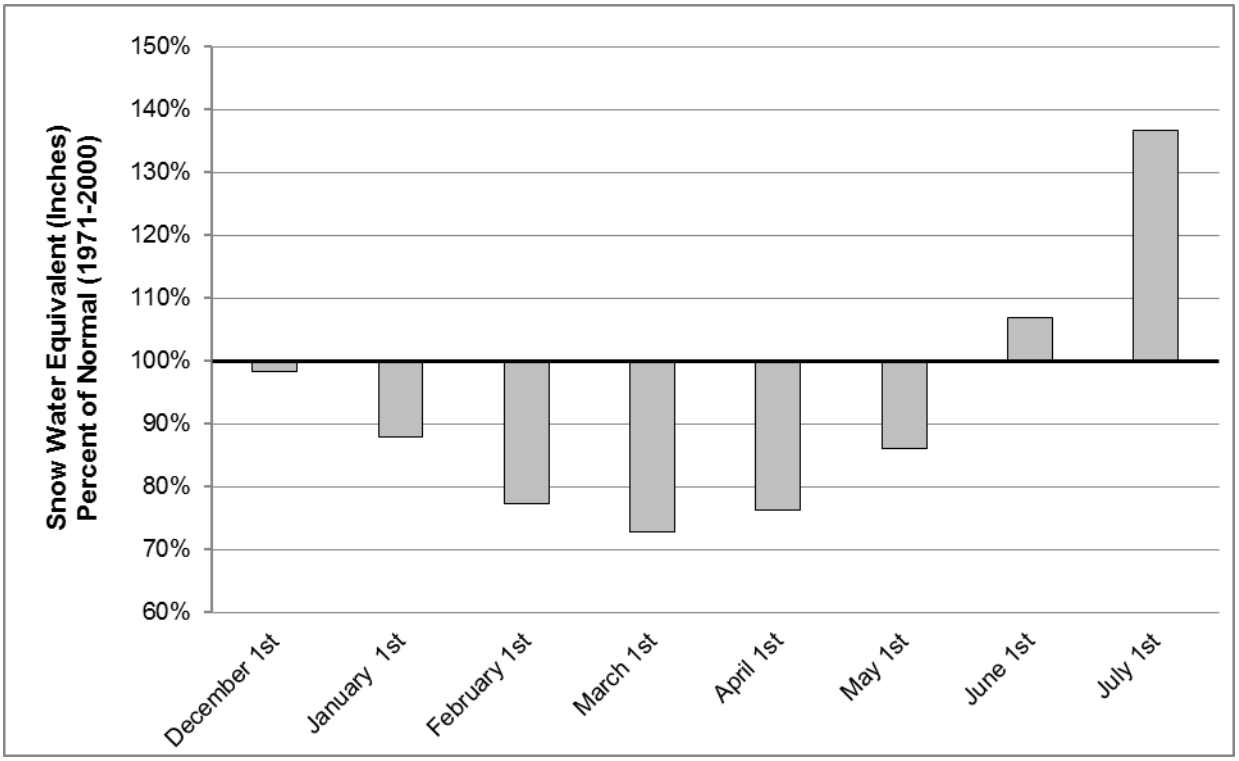

Figure 6. Comparison of snow water equivalent (inches) on the first day of each month at the Paradise Snow Course in Water Year 2010 against the climatological normal 1971-2000.

Summary

Average annual temperatures and precipitation were both near normal for Water Year 2010; however significant monthly departures from normal were recorded throughout the year. Overall conditions in winter were warm and dry, with a shift to cooler and wetter conditions in the spring through early summer. Snowpack remained below normal during the warmer, drier winter months then shifted to above normal conditions in the wetter, cooler late spring. The above normal snowpack persisted well into July.

Literature Cited

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

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

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

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

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

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

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

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

Appendix A: Carbon River NPS - Water Year 2010.

Daily temperatures observed at the Carbon River NPS station ranged from 11.5 to 88.4 °F (Table A-1). The highest mean daily average temperature was 71ºF on July 9. The coldest recorded mean daily temperature was 14.5ºF on December 8 (Fig. A-1). Annual precipitation totaled 75 inches (Table A-1, Figure A-2). November and May had the highest monthly precipitation totals (Figure A-2). The highest daily precipitation fell on October 27 (Fig A-3). The site was installed in February of 2008. Due to the recent installation of this site, no period of record comparisons are reported.

Table A-1. Monthly summary data, Carbon River Station, Water Year 2010.

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Precipitation (inches)
Fall	October 2009	44.8	68.4	33.3	8.9
	November 2009	39.6	56.7	28.4	10.6
Winter	December 2009	30.2	46.9	11.5	4.4
	January 2010	40.7	60.5	31.5	8.6
	February 2010	38.0	52.1	28.6	4.4
Spring	March 2010	38.9	64.2	24.0	5.7
	April 2010	41.2	64.8	29.2	6.5
	May 2010	45.4	69.0	33.1	10.5
Summer	June 2010	51.9	74.3	39.0	6.9
	July 2010	60.1	88.4	43.1	0.7
	August 2010	59.4	87.6	40.1	1.7
Fall	September 2010	53.6	71.9	43.4	6.1
Water Year Total		**45.3**	**88.4**	**11.5**	**75.0**

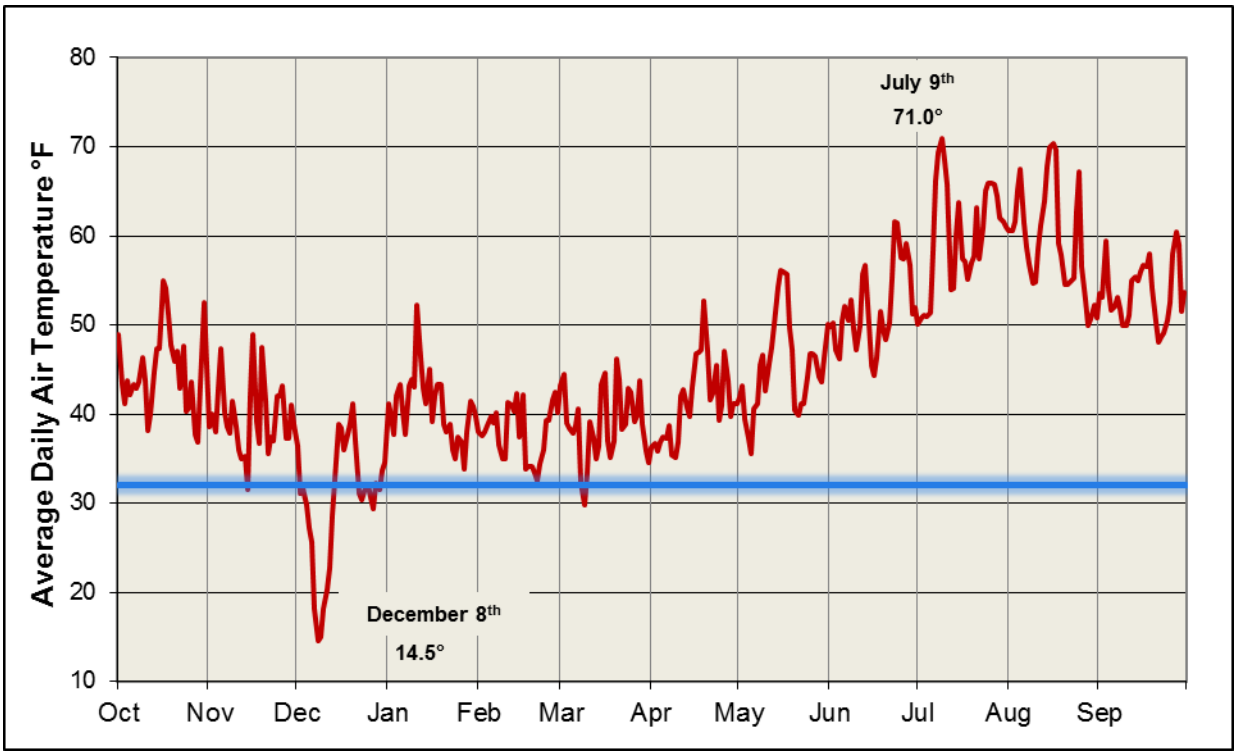

Figure A-1. Daily average air temperature (°F) at the Carbon River Station, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

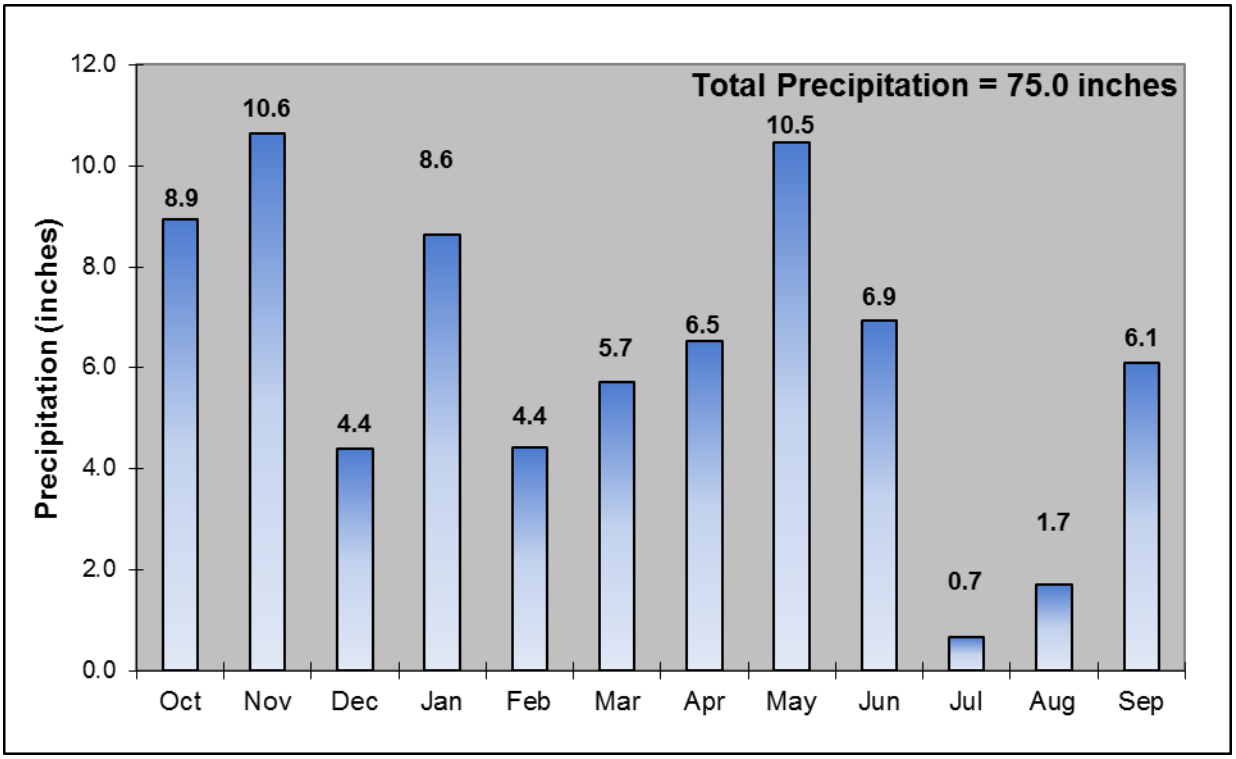

Figure A-2. Monthly precipitation (inches) at the Carbon River Station, Water Year 2010.

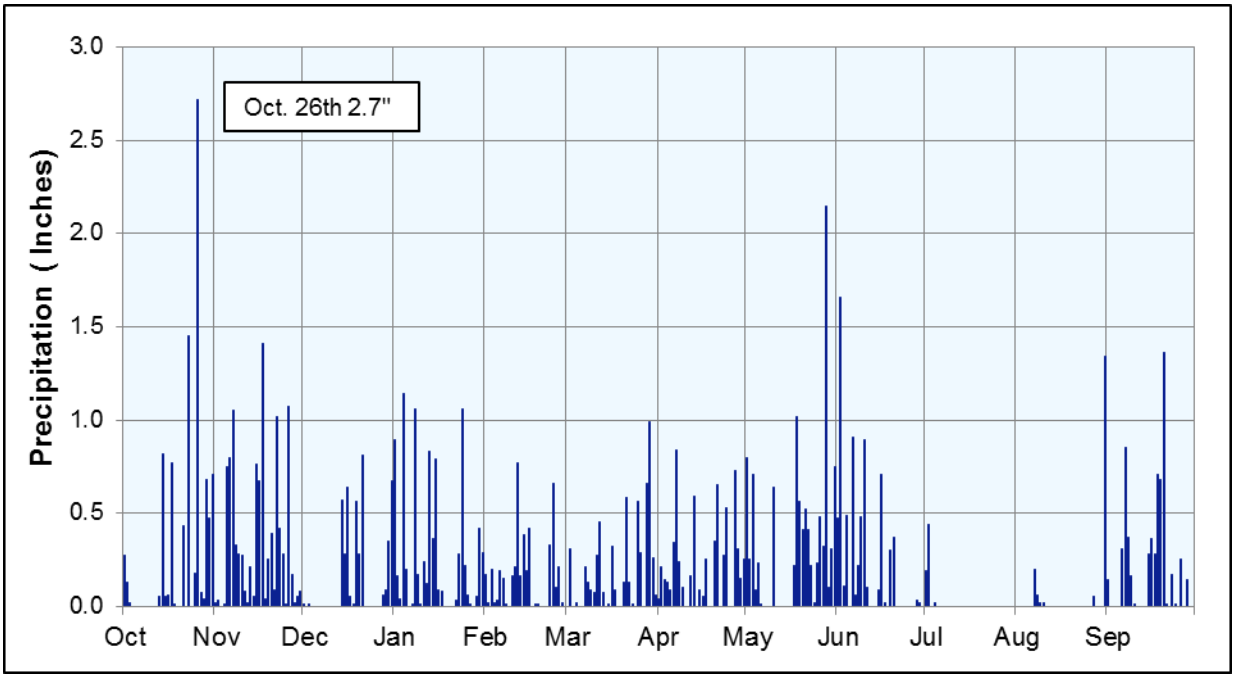

Figure A-3. Daily total precipitation (inches) at the Carbon River Station, Water Year 2010

Appendix B: Camp Muir High Elevation - Water Year 2010.

Temperatures observed at the Camp Muir High Elevation station ranged from -13.3 to 67.5 °F (Table B-1). The year was generally cooler than average at this site, with only four months (December-March) having average temperatures higher than the 2006-2010 period of record (Figure B-1). The coldest day was on December 7, 2009 and the warmest day was July 24, 2010 (Figure B-2). May was significantly cooler (5.1°F) than average. The maximum recorded hourly wind speed was also recorded in May, measuring 112 mph (Figure B-3).

The wind speed sensor is not heated and can rime[1] 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[2]. Data gaps represent periods when zero wind speed was recorded for more than 3 hours. These data were removed from this analysis. Unexplained high temperatures were observed between July 19 and July 26, 2010, causing this month to be removed from this analysis. The temperature sensor was replaced on August 1, 2010.

Table B-1. Monthly summary data, Camp Muir High Elevation Station, Water Year 2010

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Maximum Daily Wind Speed (mph)
Fall	October 2009	25.5	47.2	4.7	106
	November 2009	18.8	38.8	-1.4	97.9
Winter	December 2009	16.8	39.5	-13.3	94.2
	January 2010	19.2	34.7	6.4	64.62
	February 2010	18.2	38.5	7.7	75.7
Spring	March 2010	17.4	35.2	-4.8	105.5
	April 2010	18.1	42.0	-0.6	97
	May 2010	21.9	44.4	1.8	112.8
Summer	June 2010	31.7	51.1	13.3	78.2
	July 2010	---[1]	67.5	21.9	58.03
	August 2010	39.5	58.6	18.7	69.44
Fall	September 2010	34.4	53.8	16.8	92.7
Water Year Total		**----**	**67.5**	**-13.3**	**112.8**

[1] Six days of temperature data are missing due to equipment error
[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.

[1] 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.

[2] 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.

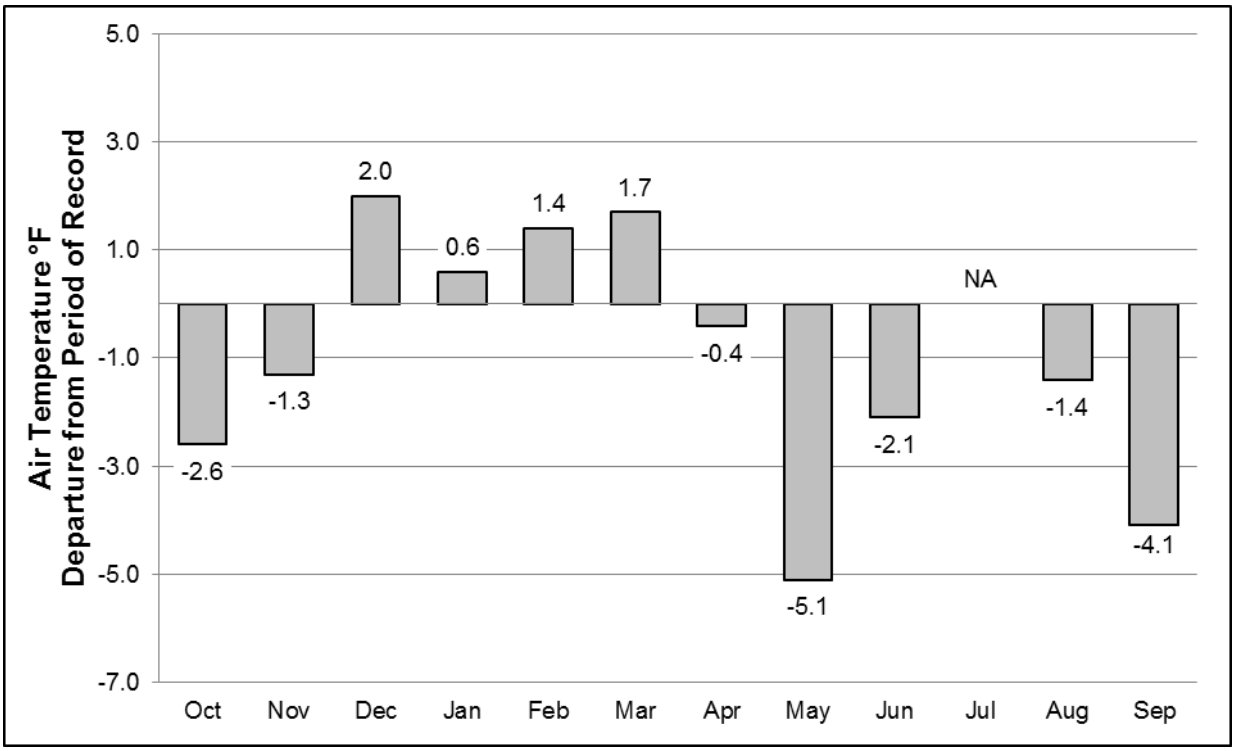

Figure B-1. Comparison of average monthly temperature (°F) for the Camp Muir High Elevation Station in Water Year 2010 against monthly averages for the period of record (2006-2010).

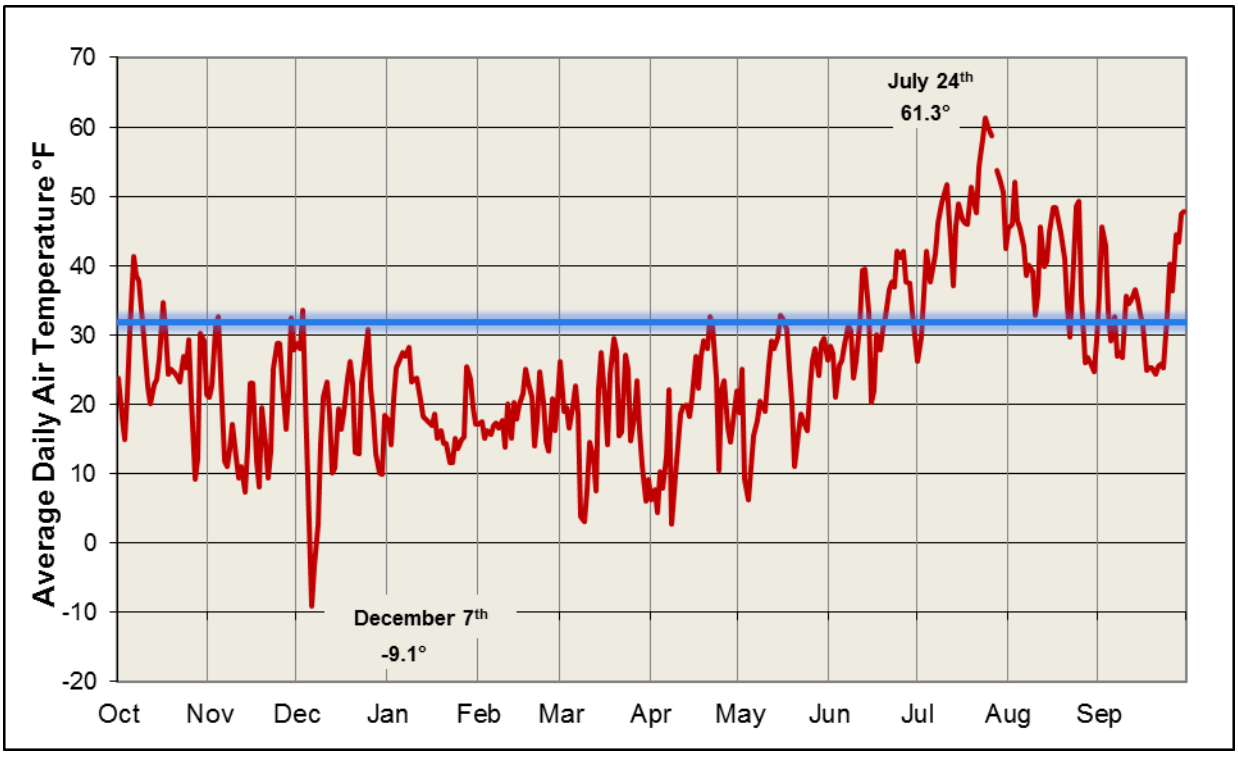

Figure B-2. Daily average air temperature (°F) at the Camp Muir High Elevation Station, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

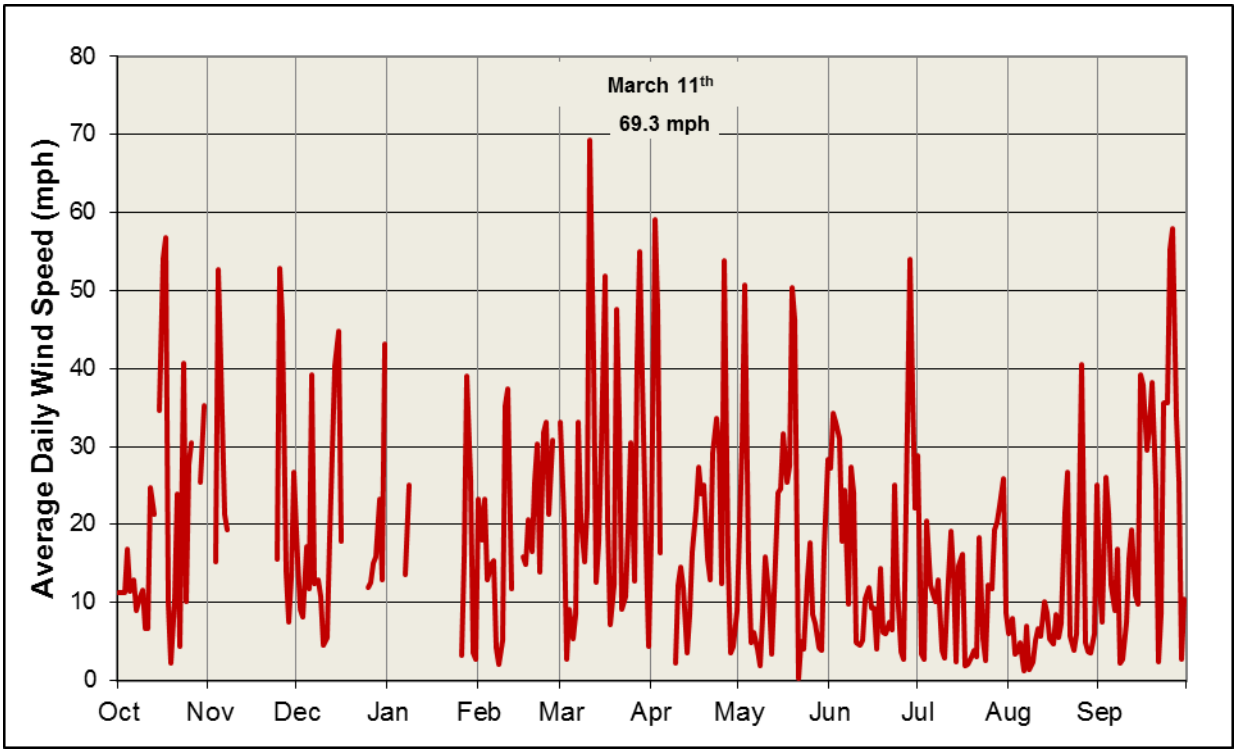

Figure B-3. Daily average wind speed (mph) at the Camp Muir High Elevation Station, Water Year 2010. Wind speed sensor is not heated and can rime during cold, wet conditions. Data represents recorded daily average wind speed, but may not capture actual average wind speed due to riming events. Data gaps 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 2010.

Temperatures observed at the Cayuse Pass SNOTEL station ranged from -3.0 to 78.0°F (Table C-1). The coldest average daily temperature recorded was -2° F on December 8, 2009. The warmest average daily temperature was 67 °F on August 26, 2010 (Figure C-1).

Total annual precipitation was 80.9 inches (Table C-1). It is noteworthy that November, which is normally the wettest month of the year, was tied with the month of April for the highest monthly precipitation (Fig. C-2). Highest daily precipitation values were recorded on March 29 and April 2, 2010 (Fig. C-3). Both events contributed 2.2 inches of precipitation. Snow water equivalent reached its peak on April 16th, with 56 inches on the ground (Fig C-4). Snowpack began accumulating on November 6, 2009 and melted July 11, 2010, persisting for 248 days.

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

Table C-1. Monthly summary data, Cayuse Pass SNOTEL, Water Year 2010.

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Precipitation (inches)
Fall	October 2009	36.5	52.0	24.0	6.0
	November 2009	31.6	53.0	21.0	12.2
Winter	December 2009	26.5	51.0	-3.0	5.1
	January 2010	32.0	46.0	21.0	9.1
	February 2010	31.7	46.0	24.0	7.6
Spring	March 2010	32.3	50.0	14.0	10.0
	April 2010	32.6	56.0	21.0	12.2
	May 2010	36.3	60.0	22.0	6.3
Summer	June 2010	43.1	65.0	30.0	5.5
	July 2010	53.4	76.0	32.0	0.7
	August 2010	52.7	78.0	34.0	0.8
Fall	September 2010	46.9	70.0	35.0	5.4
Water Year Total		**37.5**	**78.0**	**-3.0**	**80.9**

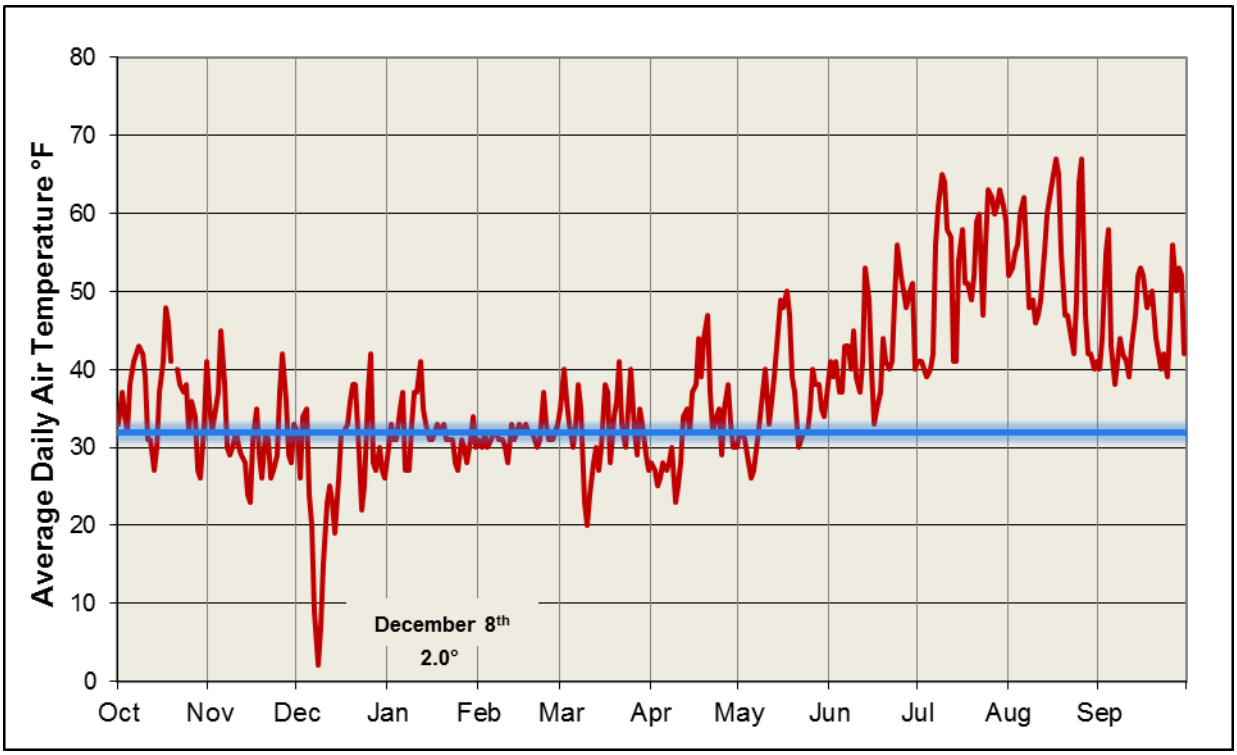

Figure C-1. Daily average air temperature (°F) at the Cayuse Pass SNOTEL, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

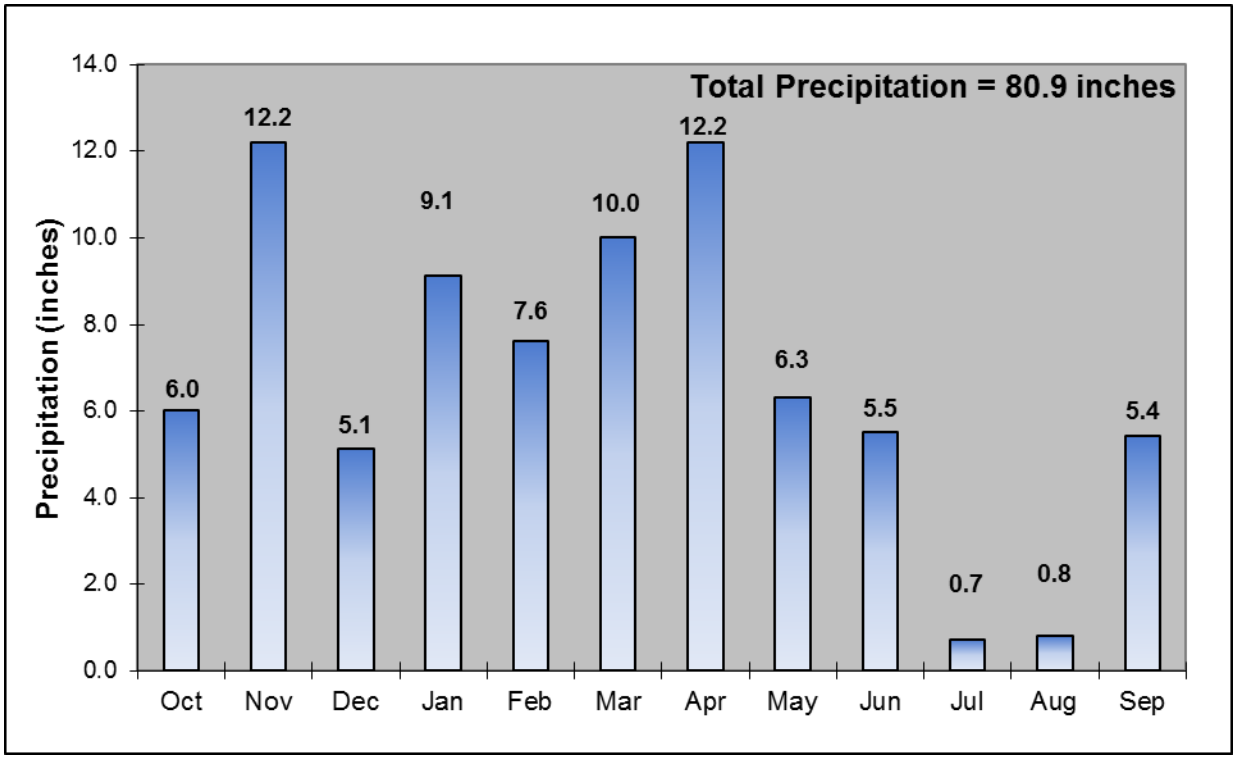

Figure C-2. Monthly total precipitation (inches) at the Cayuse Pass SNOTEL, Water Year 2010.

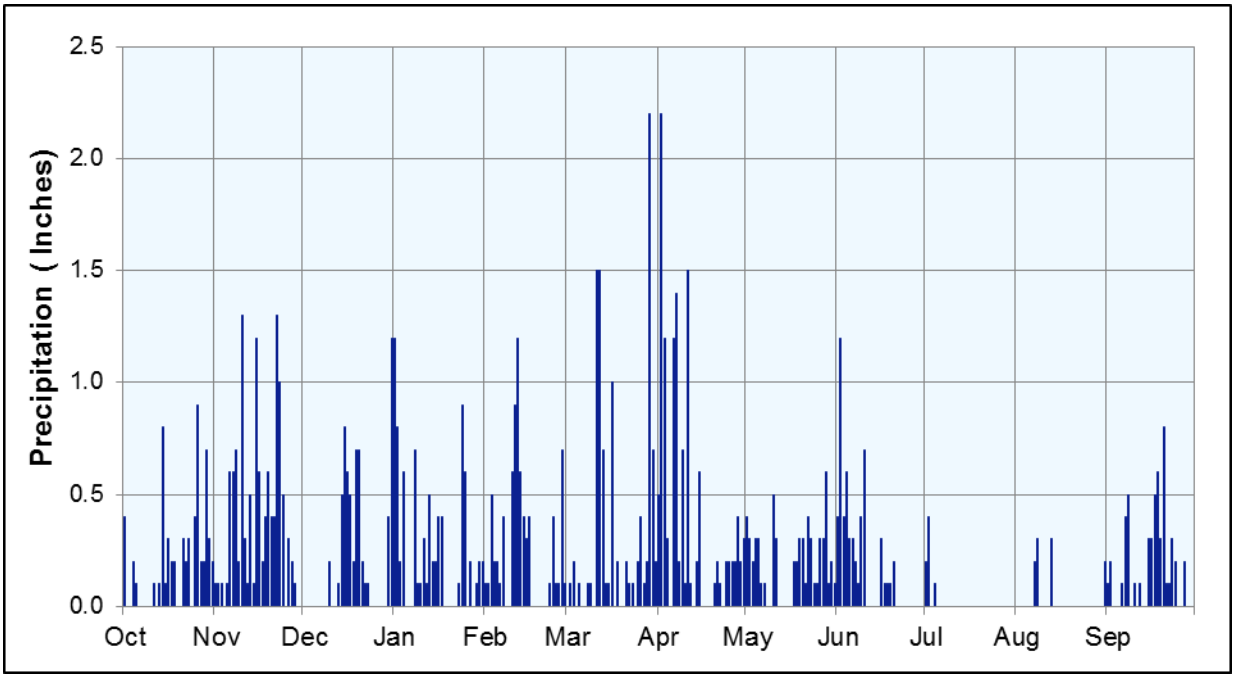

Figure C-3. Daily total precipitation (inches) at the Cayuse Pass SNOTEL, Water Year 2010.

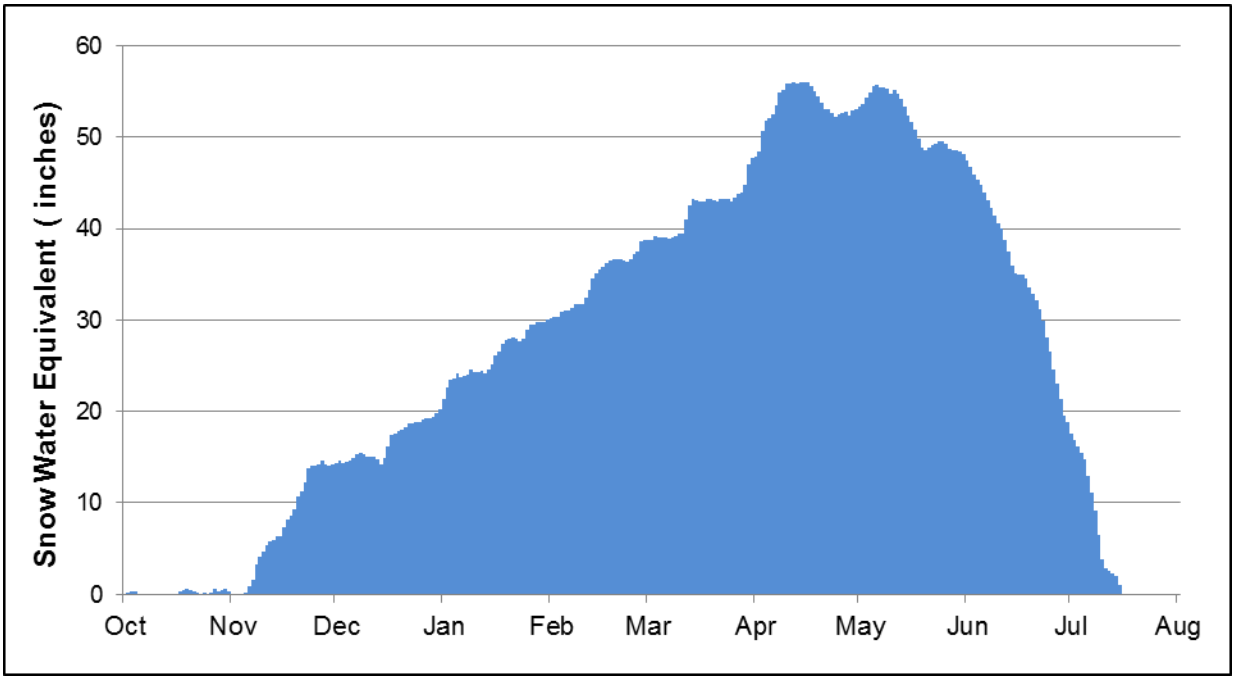

Figure C-4. Daily snow water equivalent (inches) at the Cayuse Pass SNOTEL, Water Year 2010.

Appendix D: Longmire COOP - Water Year 2010.

Temperatures observed at the Longmire COOP station ranged from 3.0 to 93.0°F (Table D-1). January was significantly warmer, with a 5.2°F departure from the period of record average (1909-2010) (Figure D-1). October was significantly cooler than average with a -5.0 °F departure from the period of record. The coldest day was December 8, 2009 and the hottest day was July 9, 2010 (Figure D-2). Annual precipitation totaled 80.6 inches (Figure D-3). May was significantly wetter than average with 9.3 inches of rain and snow, more than twice the average for the period of record (Figure D-4). February was significantly drier than average with only 4.4 inches of precipitation, only 50 percent of the average precipitation (Figure D-3). The wettest period was November 16 to 26, 2009 when 9.7 inches of precipitation fell. Snowpack for the 2010 water year was well below average due to low precipitation and warmer than average temperatures during the winter months (Figure D-6).

Table D-1. Monthly summary data, Longmire COOP Station, Water Year 2010.

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Precipitation (inches)
Fall	October 2009	41.6	60.0	24.0	10.6
	November 2009	34.4	52.0	25.0	14.4
Winter	December 2009	28.1	44.0	3.0	5.7
	January 2010	35.9	49.0	25.0	9.6
	February 2010	37.4	52.0	24.0	4.4
Spring	March 2010	38.0	61.0	16.0	7.0
	April 2010	39.1	69.0	23.0	5.9
	May 2010	44.4	71.0	29.0	9.3
Summer	June 2010	50.5	77.0	33.0	6.4
	July 2010	59.9	93.0	40.0	0.5
	August 2010	60.4	93.0	35.0	0.3
Fall	September 2010	52.5	83.0	35.0	6.5
Water Year Total		**43.5**	**93.0**	**3.0**	**80.6**

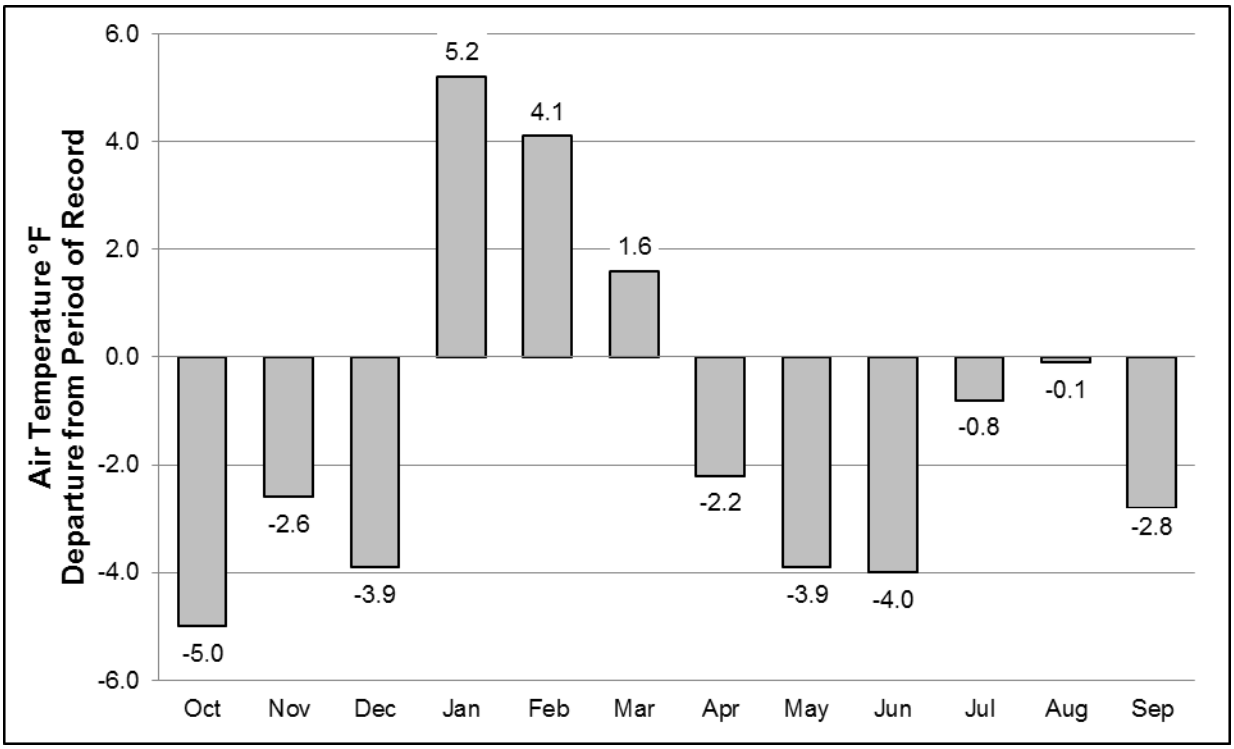

Figure D-1. Comparison of average monthly temperature (°F) for the Longmire COOP Station in Water Year 2010 against monthly averages for the period of record (1909-2010).

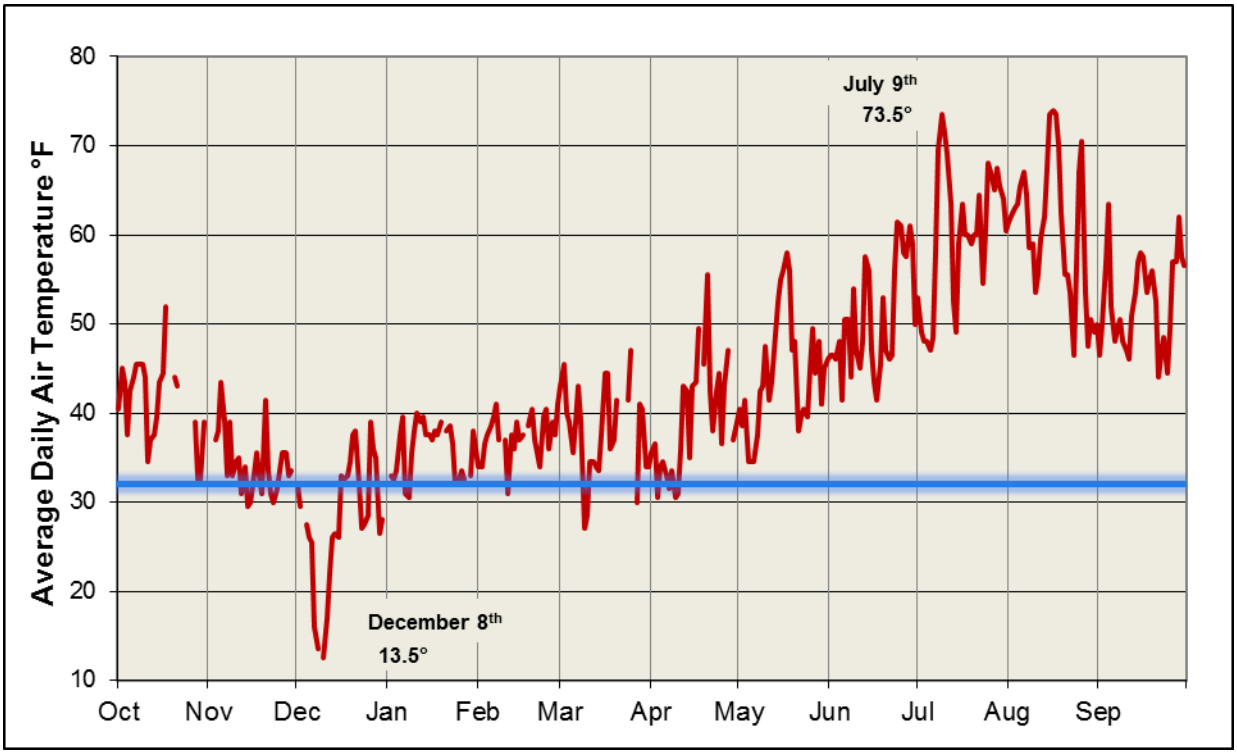

Figure D-2. Daily average air temperature (°F) values at the Longmire COOP Station, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

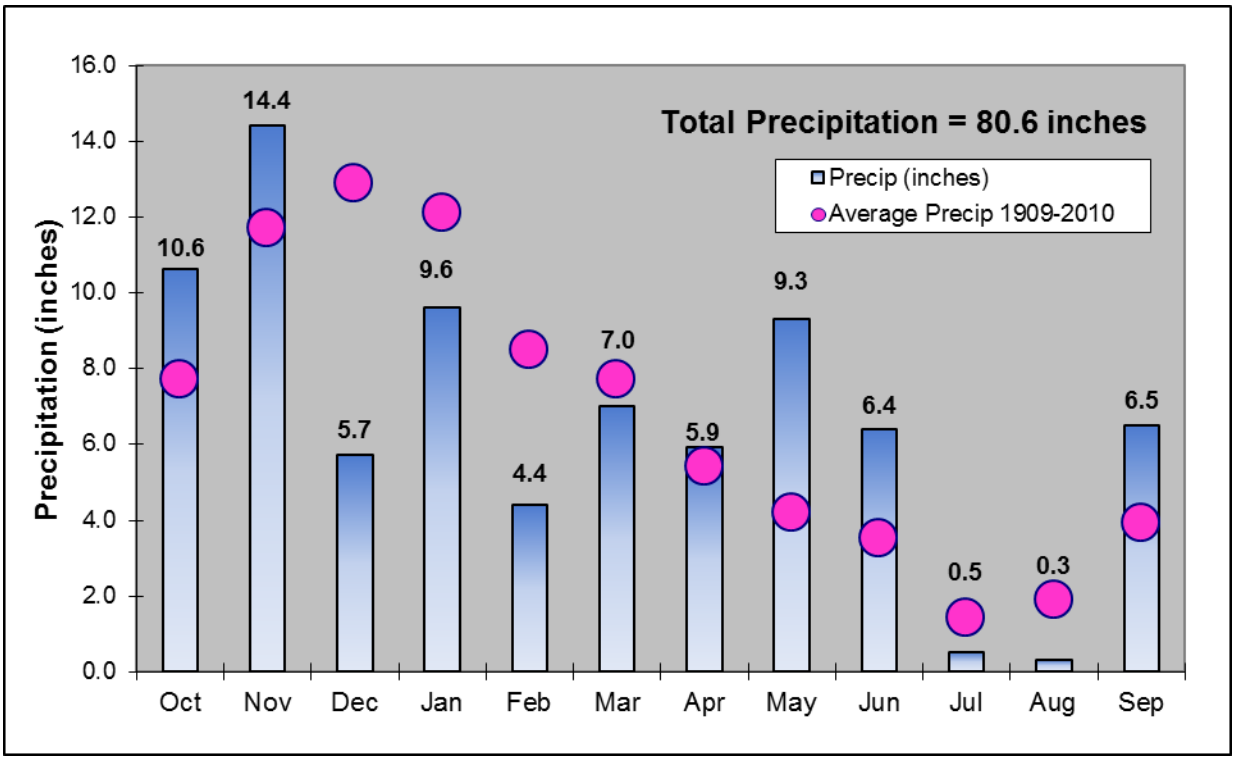

Figure D-3. Monthly precipitation (inches) at the Longmire COOP Station, Water Year 2010, compared to the monthly averages for the period of record (1909-2010).

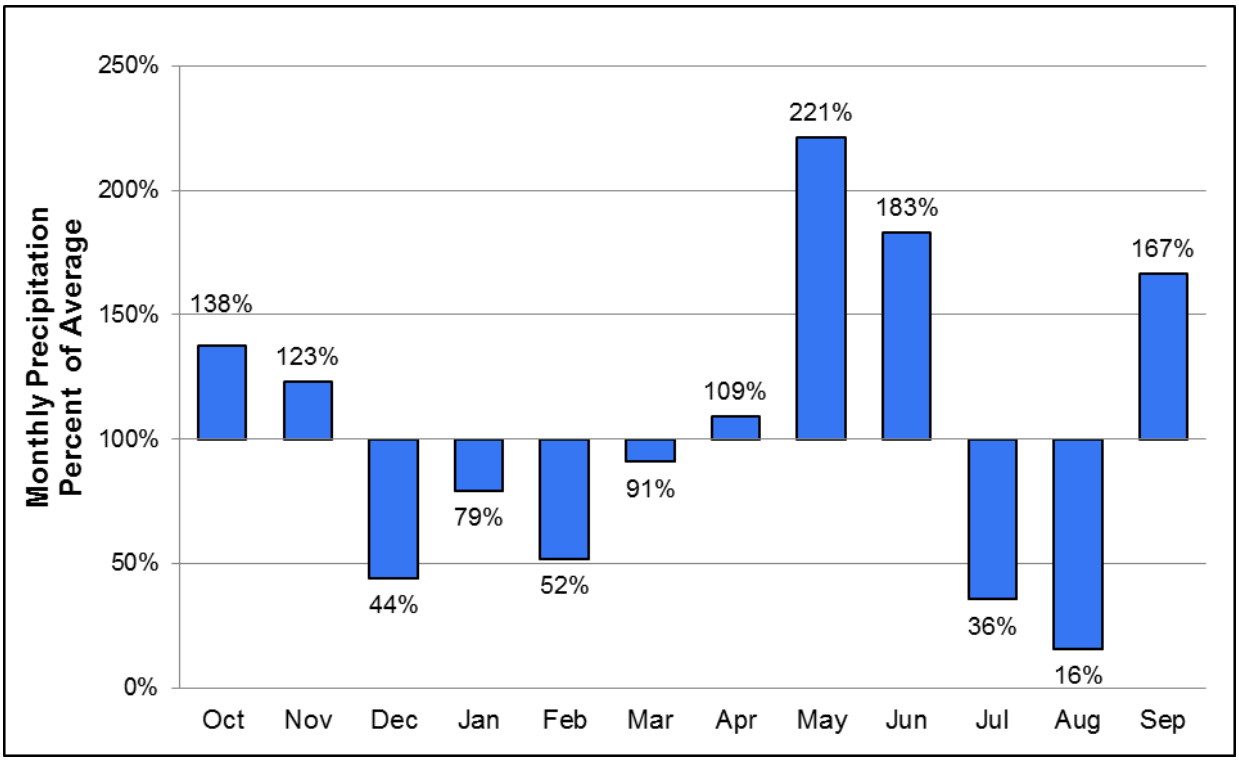

Figure D-4. Percent of average for period of record (1909-2010) for precipitation at the Longmire COOP Station in Water Year 2010.

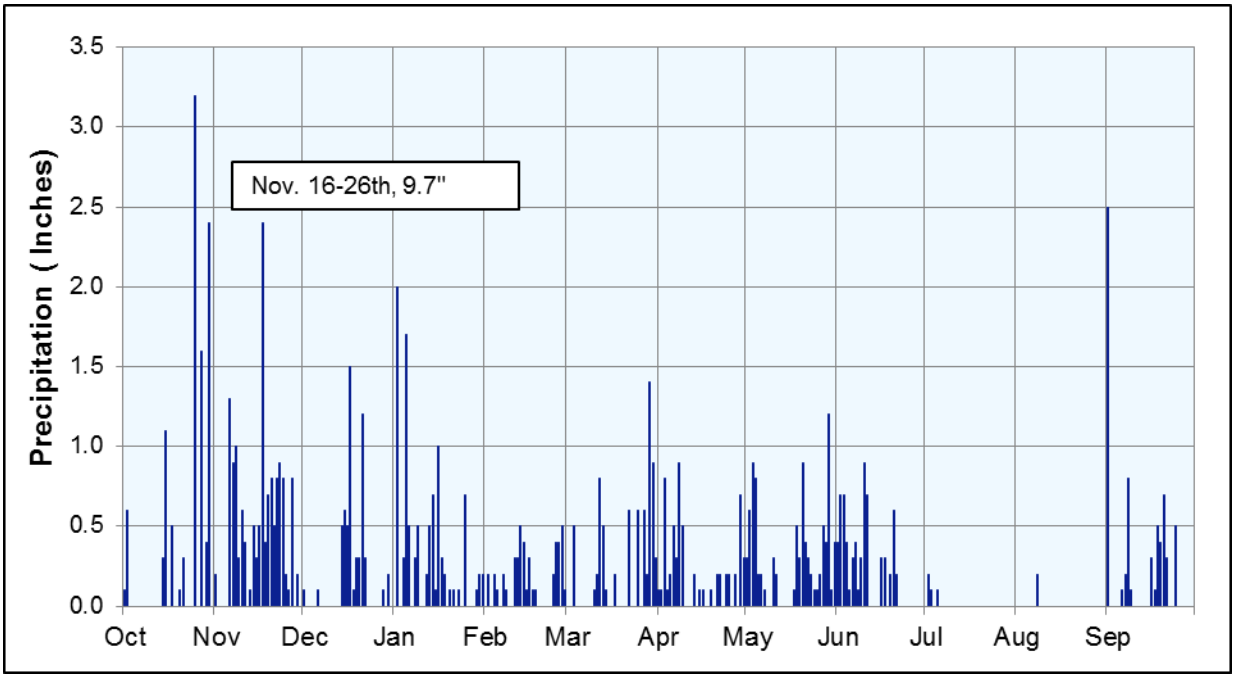

Figure D-5. Daily total precipitation (inches) at the Longmire COOP Station, Water Year 2010.

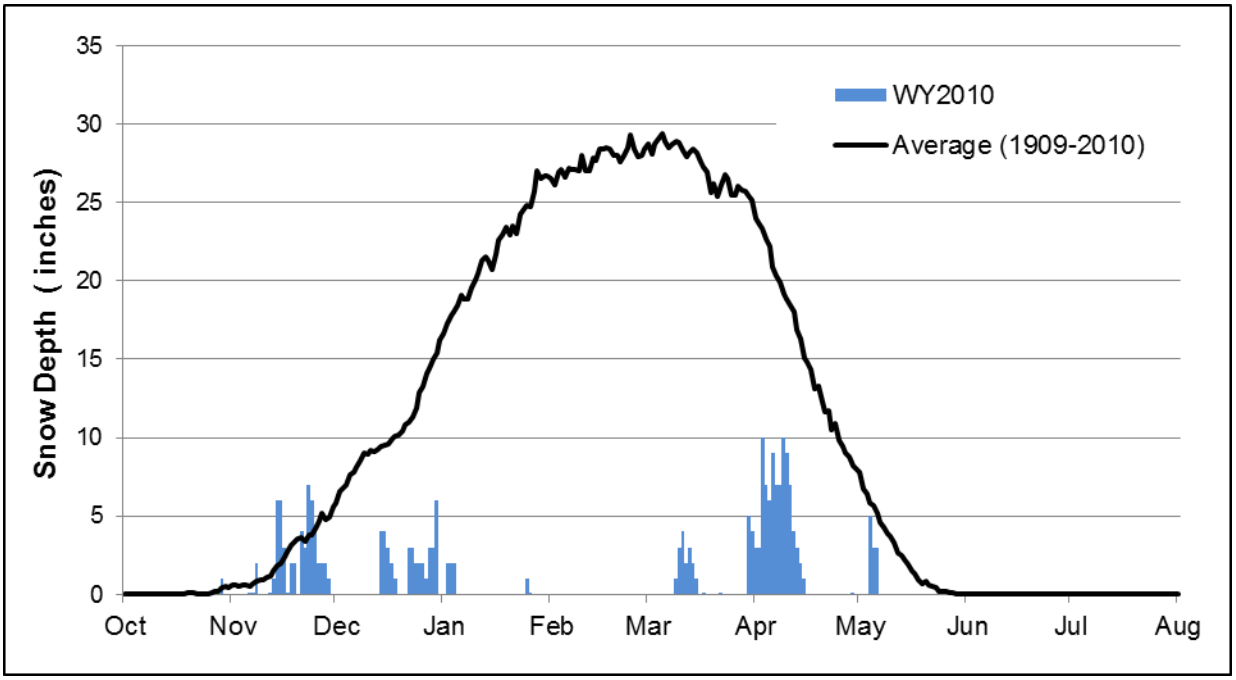

Figure D-6. Daily snow depth (inches) at the Longmire COOP Station, Water Year 2010, compared to the period of record daily average (1909-2010).

Appendix E: Ohanapecosh RAWS - Water Year 2010.

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. Temperature records are not available. The 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.

Temperatures observed at the Ohanapecosh RAWS station ranged from 9.0 to 98.0°F (Table E-1). The highest daily air temperature for the park was recorded at Ohanapecosh on July 9 and August 25, with a maximum value of 98°F. July 9, 2010 had the maximum average temperature of 73.3ºF (Figure E-1). September was significantly wetter than average with 6.1 inches of rain, more than twice the period of record average (Figures E-2 and E-3). February was significantly drier than average with 4.5 inches of precipitation, only 50 percent of the period of record average precipitation (Figure E-3). A 36 day period with no precipitation occurred between July 2 and August 7, 2010 (Figure E-4).

Due to power outages at Ohanapecosh in December, the heated precipitation gauge was not operational for nine days and data for this month is not included in the analysis.

Table E-1. Monthly summary data, Ohanapecosh RAWS, Water Year 2010.

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Precipitation (inches)
Fall	October 2009	44.2	63.0	29.0	9.6
	November 2009	36.8	51.0	32.0	12.7
Winter	December 2009	28.3	38.0	9.0a	----2
	January 2010	36.6	44.0	28.0	9.4
	February 2010	37.3	51.0	26.0	4.5
Spring	March 2010	38.0	63.0	26.0	7.9
	April 2010	41.7	76.0	29.0	5.6
	May 2010	48.2	80.0	32.0	5.6
Summer	June 2010	54.5	84.0	39.0	4.6
	July 2010	63.4	98.0	41.0	0.1
	August 2010	62.6	98.0	38.0	0.2
Fall	September 2010	55.4	83.0	39.0	6.1
Water Year Total		**45.6**	**98.0**	**9.0**	**----**[b]

[a] Three hours of data are missing on December 8th. Minimum daily temperature may actually be lower than indicated.

[b] Nine days of precipitation data are missing due to power loss of the heated precipitation gauge

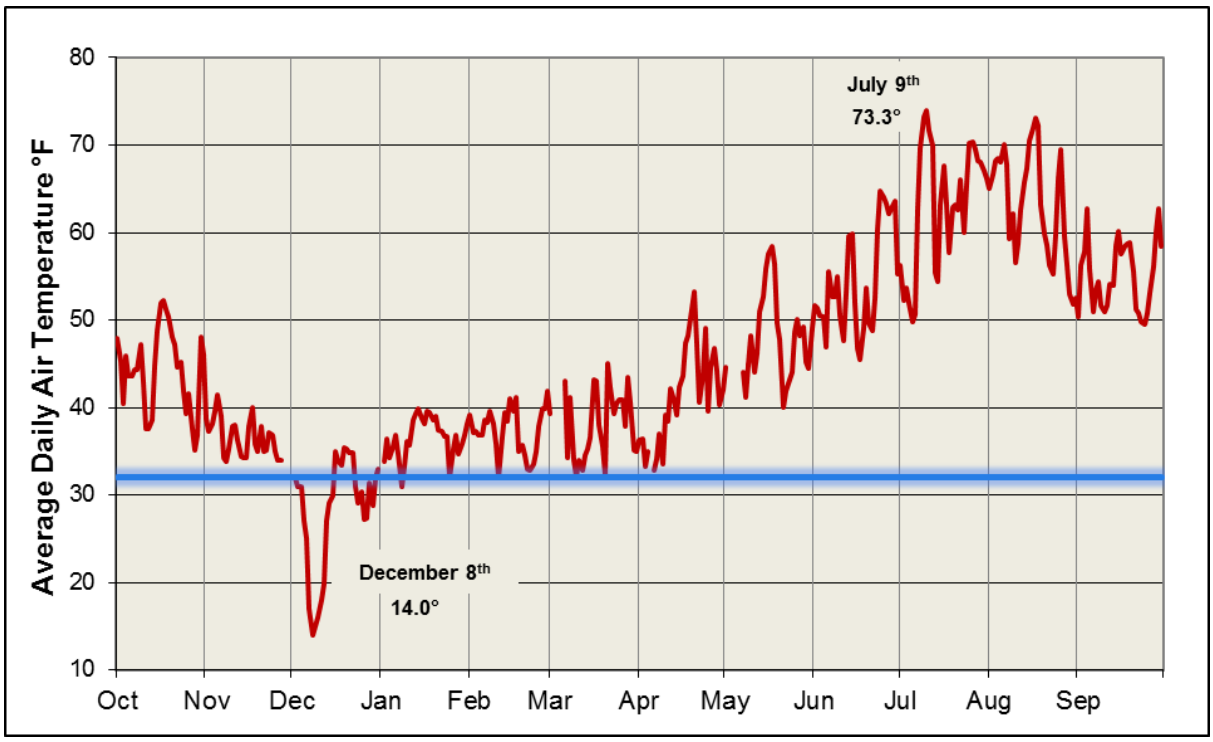

Figure E-1. Daily average air temperature (°F) at the Ohanapecosh RAWS Station, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

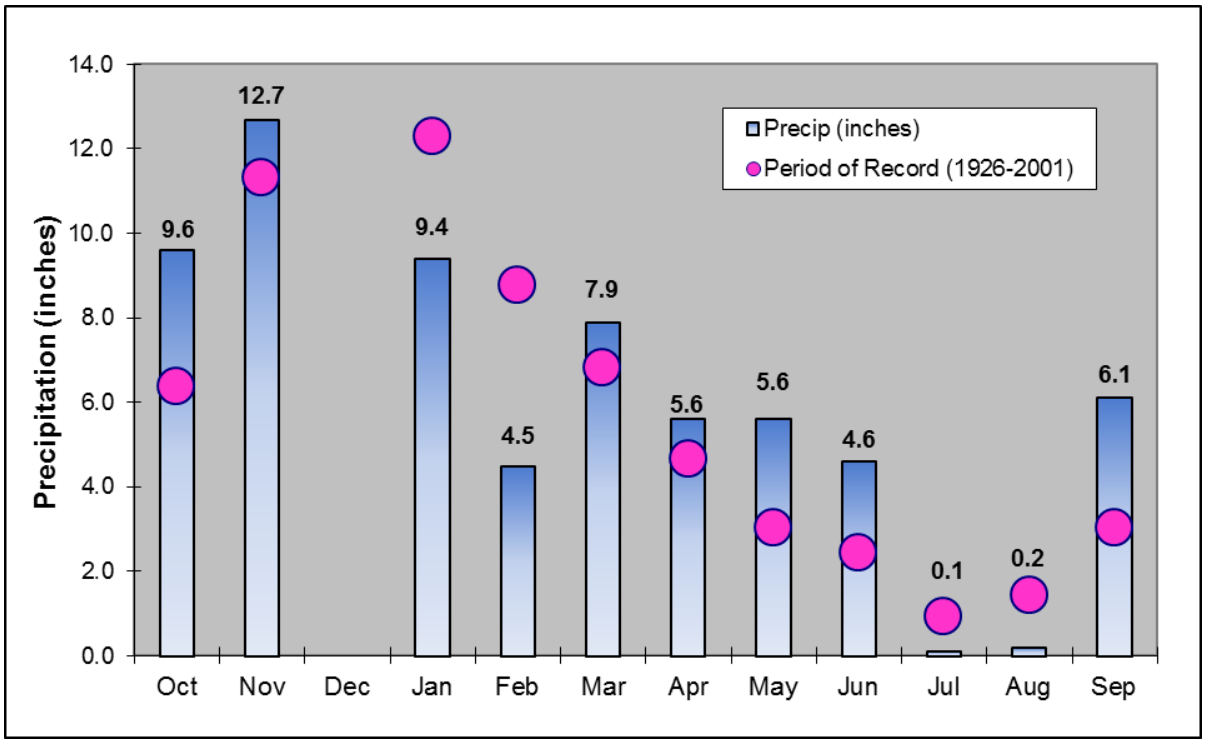

Figure E-2. Monthly precipitation values at the Ohanapecosh RAWS Station, Water Year 2010. Total precipitation values cannot be determined, as nine days of precipitation data are missing in December due to power loss of the heated precipitation gauge.

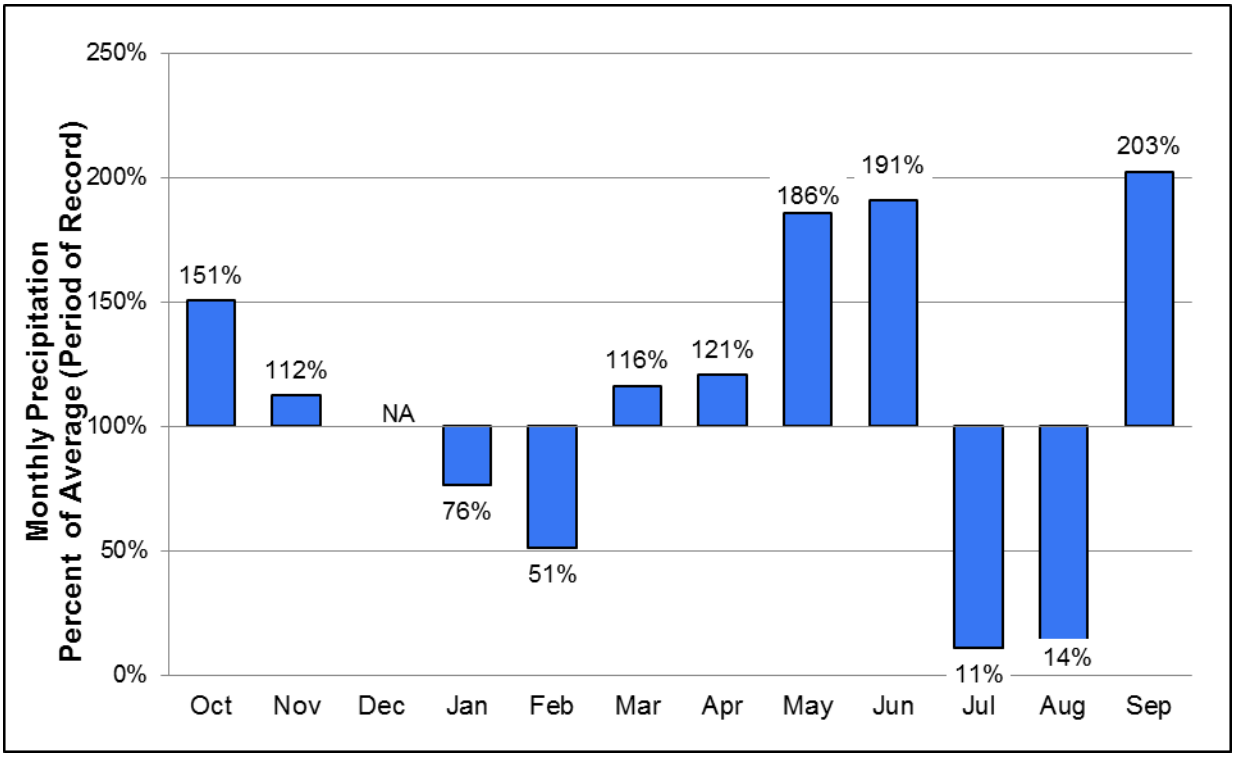

Figure E-3. Percent of average for the period of record (1926-2001) for precipitation at the Ohanapecosh RAWS Station in Water Year 2010.

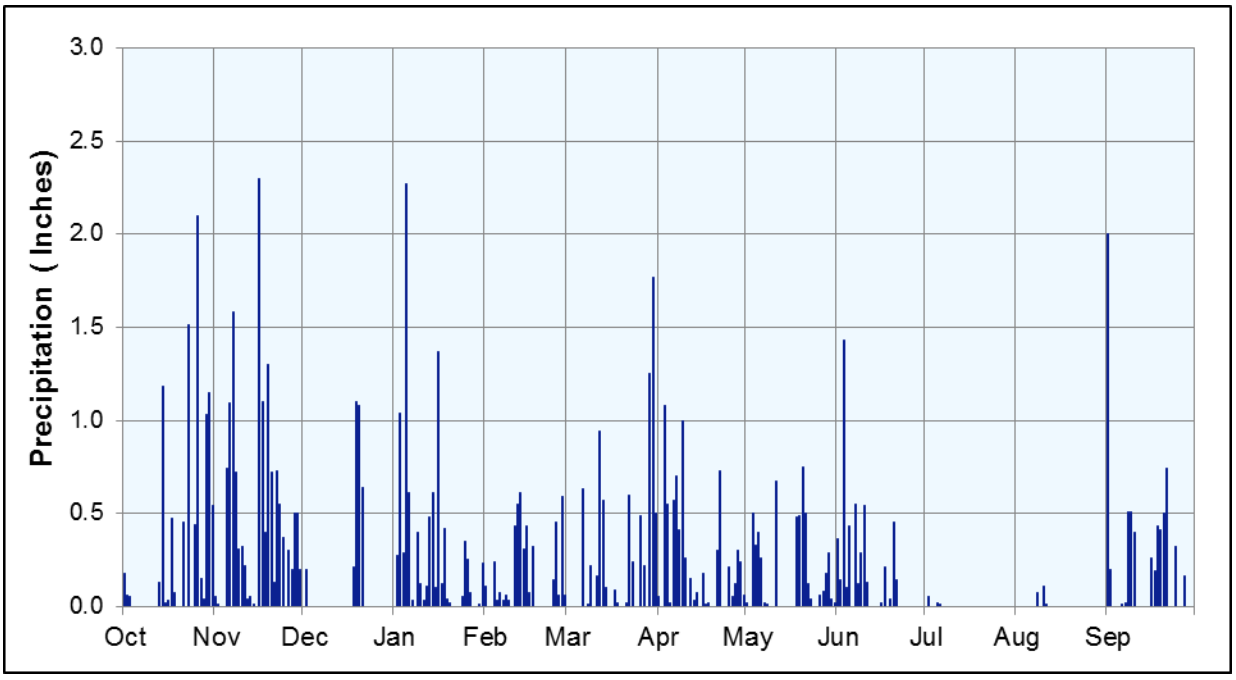

Figure E-1. Daily precipitation (inches) at the Ohanapecosh RAWS Station, Water Year 2010.

Appendix F: Paradise NWS COOP and SNOTEL - Water Year 2010.

Temperatures observed at the Paradise COOP station ranged from -1.0 to 84.0°F (Table F-1). January was significantly warmer than average, with a 5.7°F departure from the period of record (1916-2010) (Figure F-1). October and May were significantly cooler than average with a -3.5 and -3.6°F departure, from the period of record. The coldest day of the year was December 8, 2009 and the warmest day of the year was August 16, 2010 (Figure F-2). Total annual precipitation was 109 inches (Figure F-3). May was significantly wetter than average with 12.1 inches of precipitation, nearly 2.5 times the average for the period of record for this month (Figure F-4). December was 50% drier than average with only 9.2 inches of precipitation (Figure F-3). The wettest day of the year was October 29, 2009 when 5.7 inches of precipitation fell (Figure F-5). Snowpack and snow water equivalent (SWE) were below average for most of the Water Year. Cold temperatures and above average precipitation in May and June resulted in an above average snowpack and snow water equivalent that persisted from the mid- May through early July (Figures F-6 and F-7). Snow remained on the ground until July 25, 2010.

Six days of temperature values for the months of April and May are missing for the Paradise COOP station. Monthly average values are within 1°F of data from the nearby Paradise SNOTEL site and thus were included in this analysis.

Table F-1. Monthly summary table, Paradise COOP Station, Water Year 2010.

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Precipitation (inches)
Fall	October 2009	36.6	53.0	21.0	14.2
	November 2009	31.1	67.0	19.0	18.7
Winter	December 2009	26.9	54.0	-1.0	9.2
	January 2010	32.1	46.0	21.0	12.9
	February 2010	32.2	48.0	22.0	7.4
Spring	March 2010	32.9	54.0	9.0	9.6
	April 2010	32.01	59.0	18.0	9.0
	May 2010	36.51	62.0	21.0	12.1
Summer	June 2010	42.6	66.0	26.0	6.2
	July 2010	56.0	81.0	29.0	0.6
	August 2010	54.3	84.0	31.0	0.9
Fall	September 2010	47.6	70.0	30.0	8.2
Water Year Total		**38.4**	**84.0**	**-1.0**	**109.0**

[1] Values for the months of April and May are missing 6 days of temperature. Monthly average values are within 1°F of data from nearby Paradise SNOTEL site.

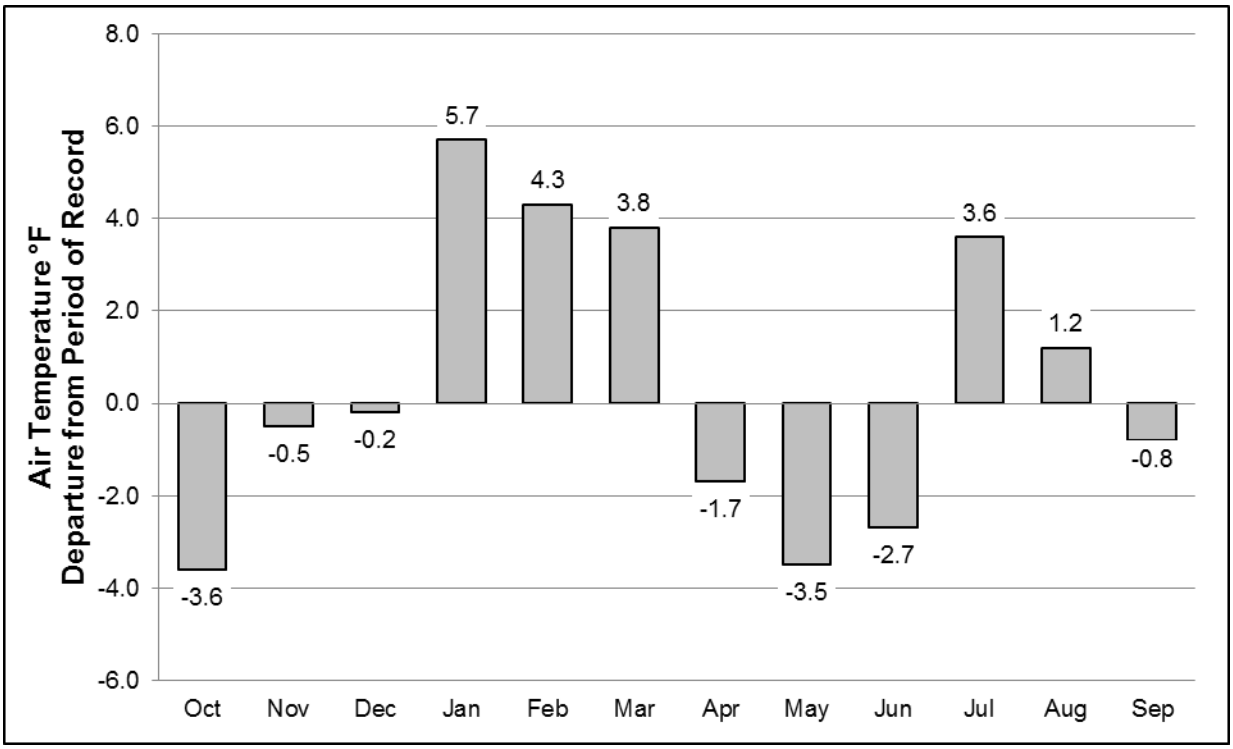

Figure F-1. Comparison of average monthly temperature (°F) for the Paradise COOP Station in Water Year 2010 against monthly averages for the period of record (1916-2010).

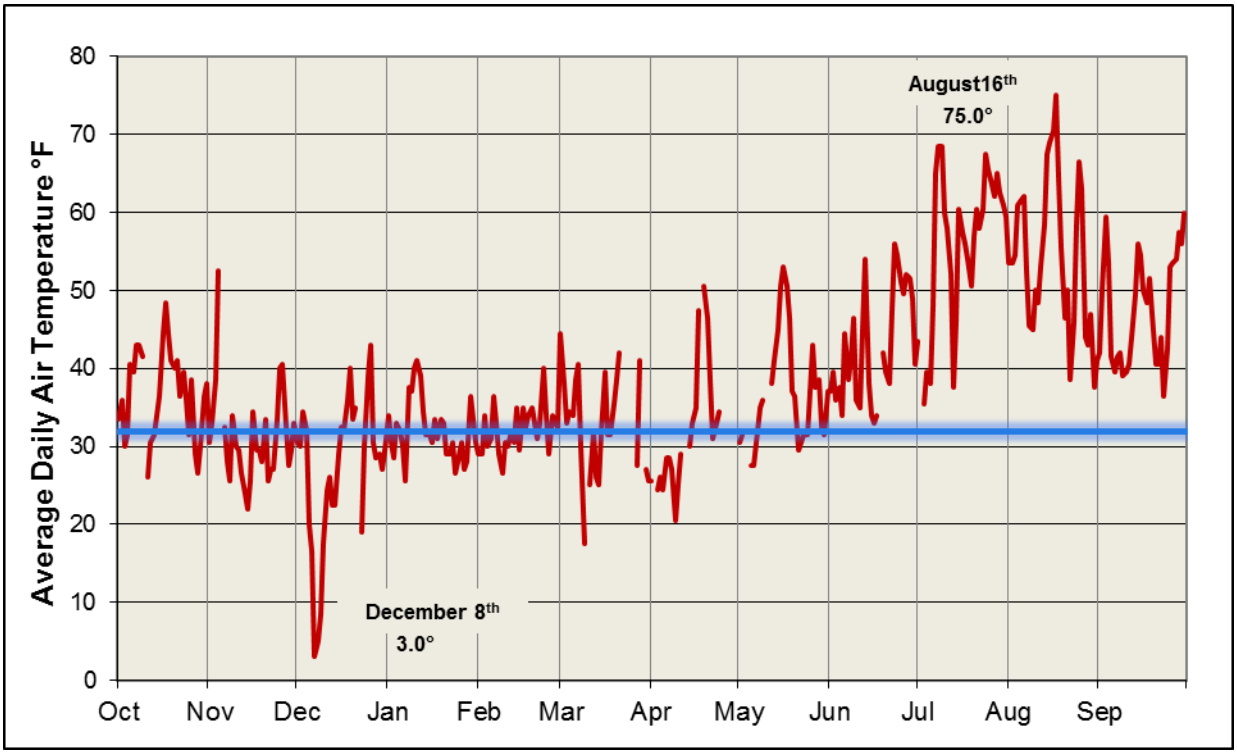

Figure F-2. Daily average air temperature (°F) at the Paradise COOP Station, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

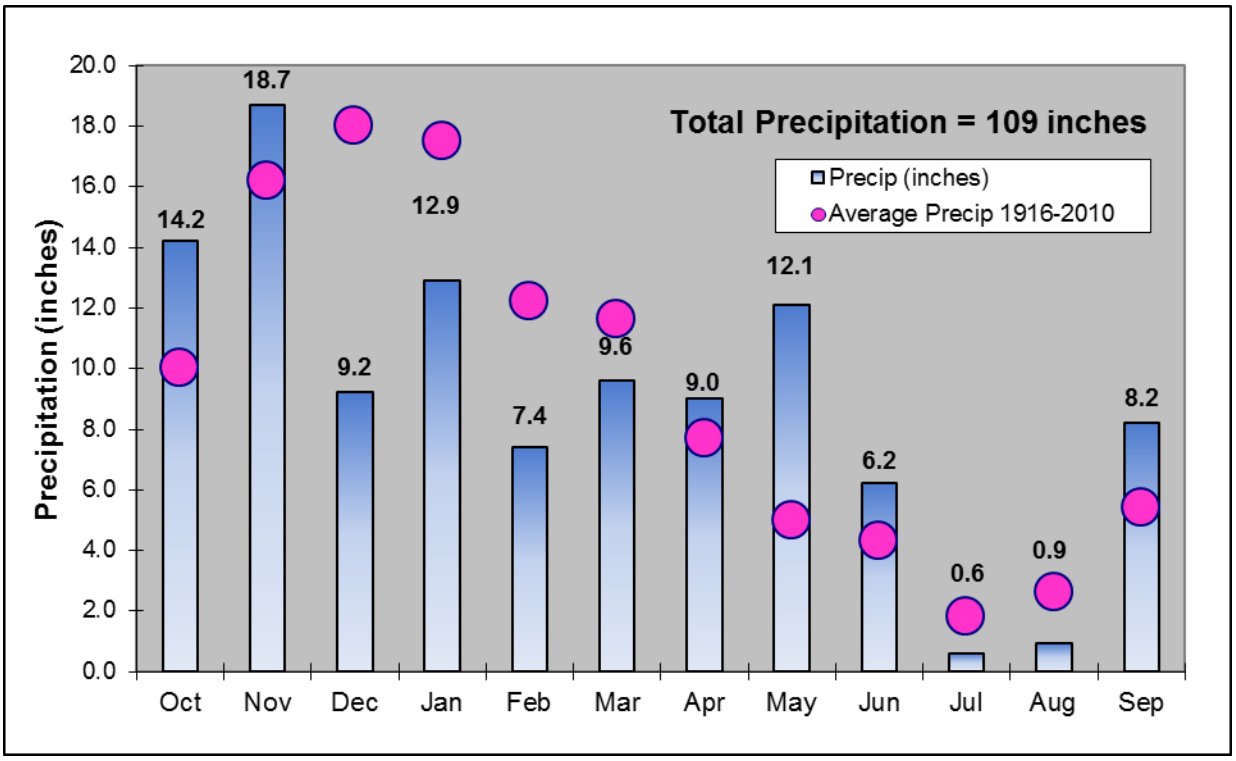

Figure F-3. Monthly precipitation (inches) at the Paradise COOP Station, Water Year 2010, compared to the monthly averages for the period of record (1916-2010).

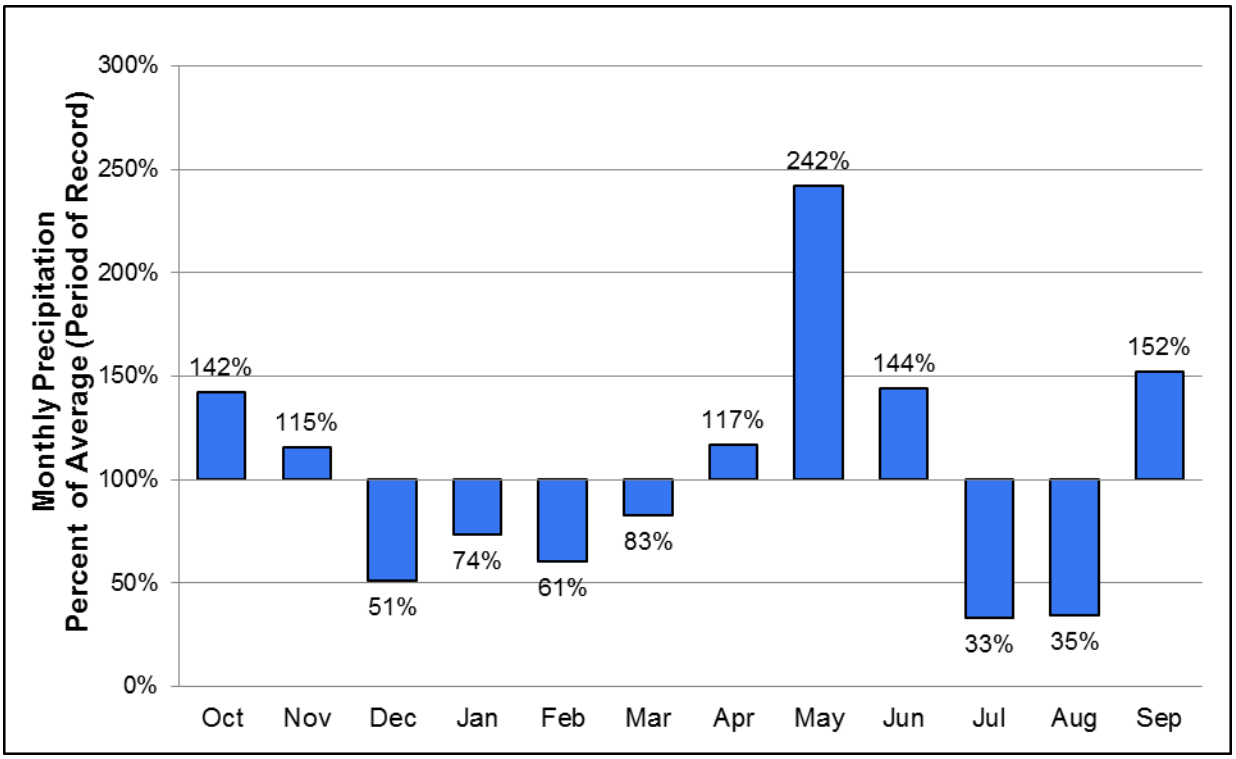

Figure F-4. Percent of average precipitation for the period of record (1916-2010) at the Paradise COOP Station in Water Year 2010.

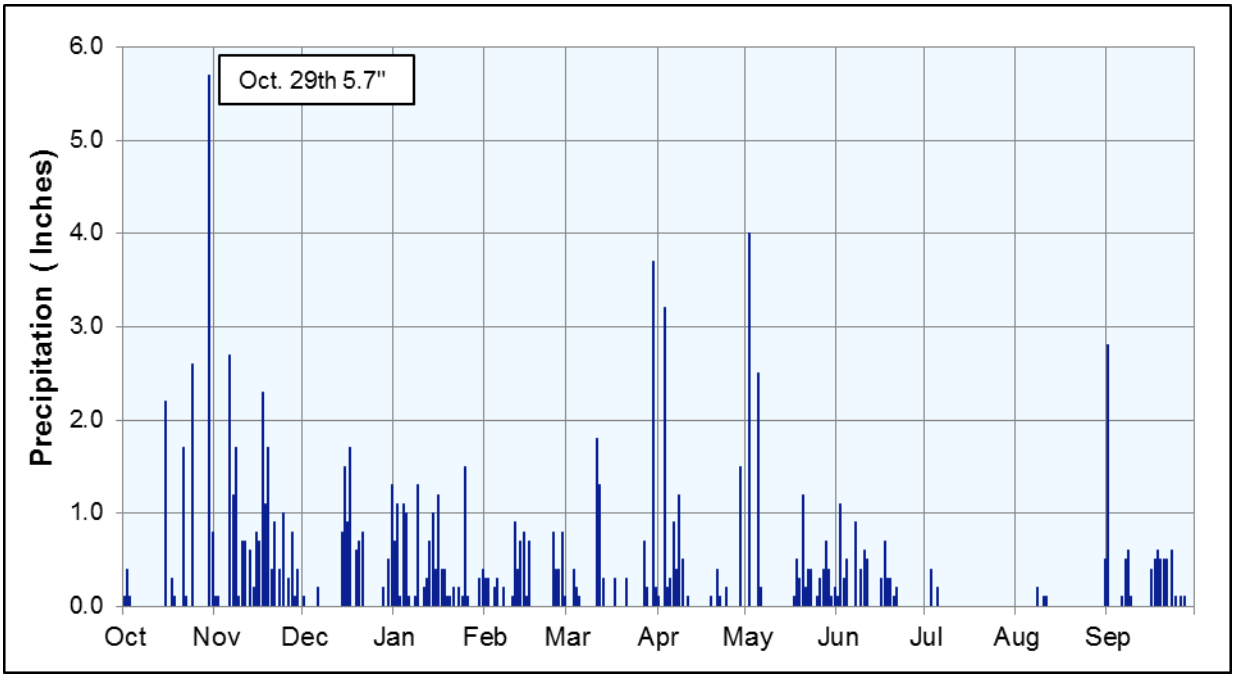

Figure F-5. Daily precipitation (inches) at the Paradise COOP Station, Water Year 2010.

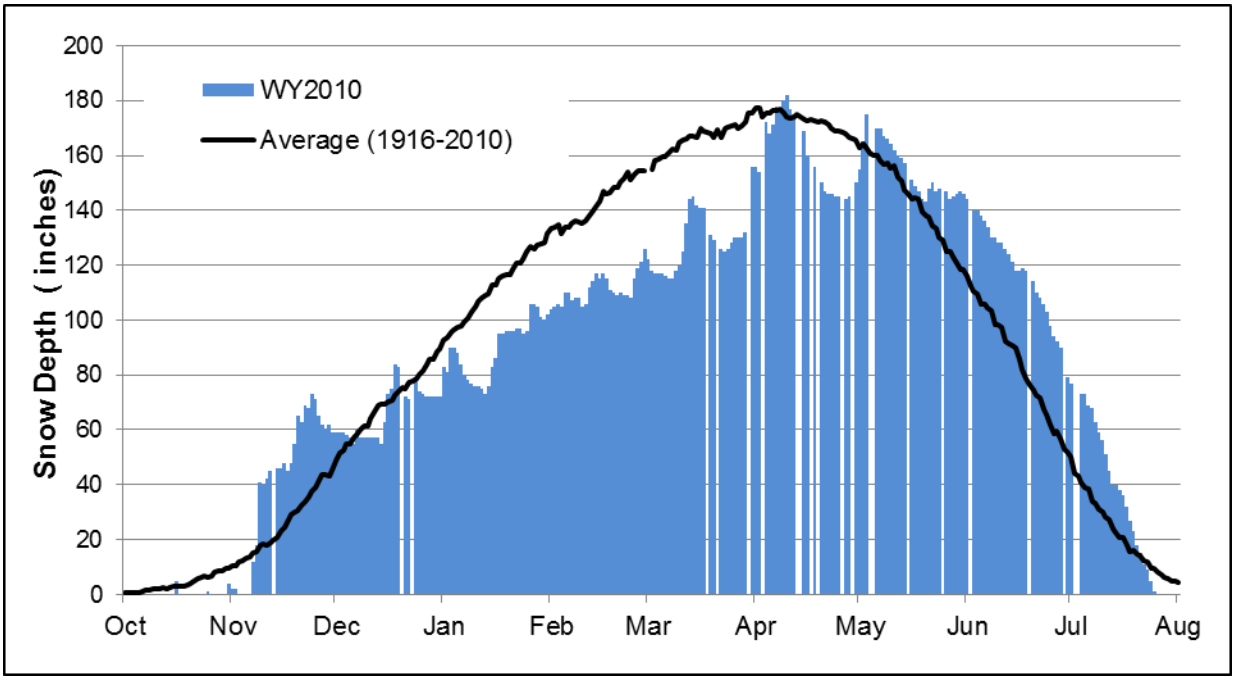

Figure F-6. Daily snow depth (inches) at the Paradise COOP Station, Water Year 2010, compared to the period of record daily average (1916-2010). White areas between bars indicate missing data for these time periods.

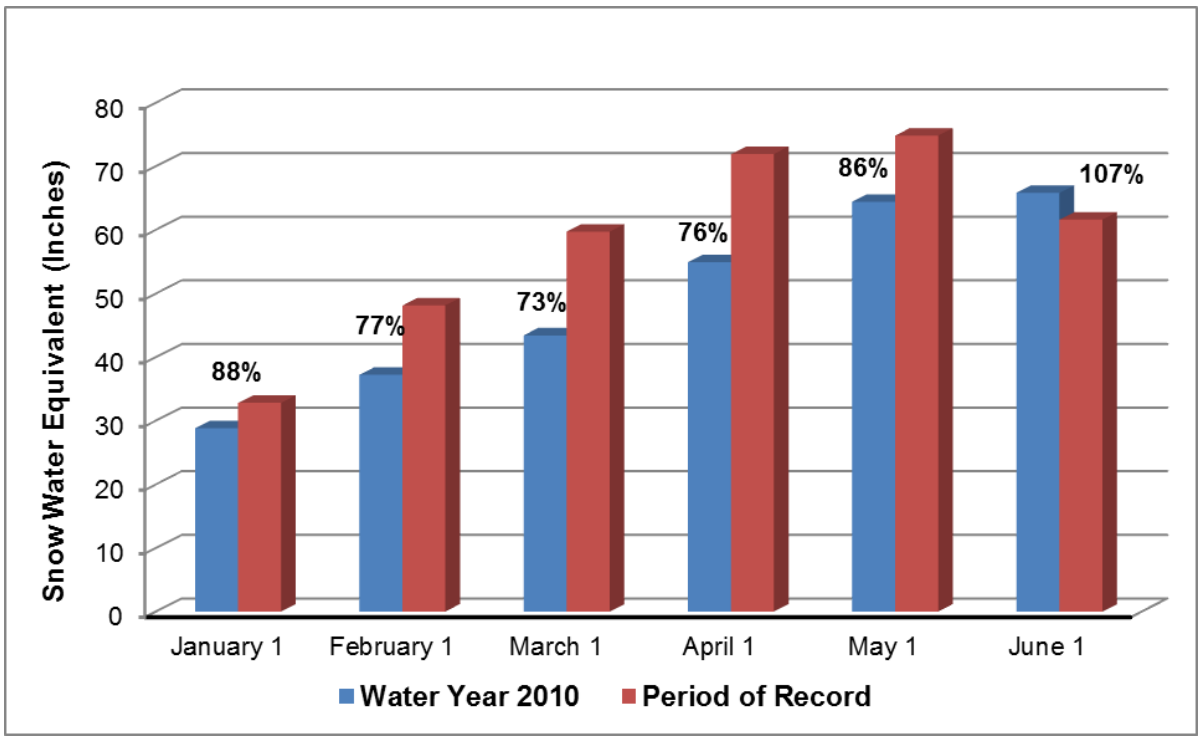

Figure F-7. First of the month snow water equivalent (inches) at the Paradise snow course in Water Year 2010, compared with the period of record (1940-2010).

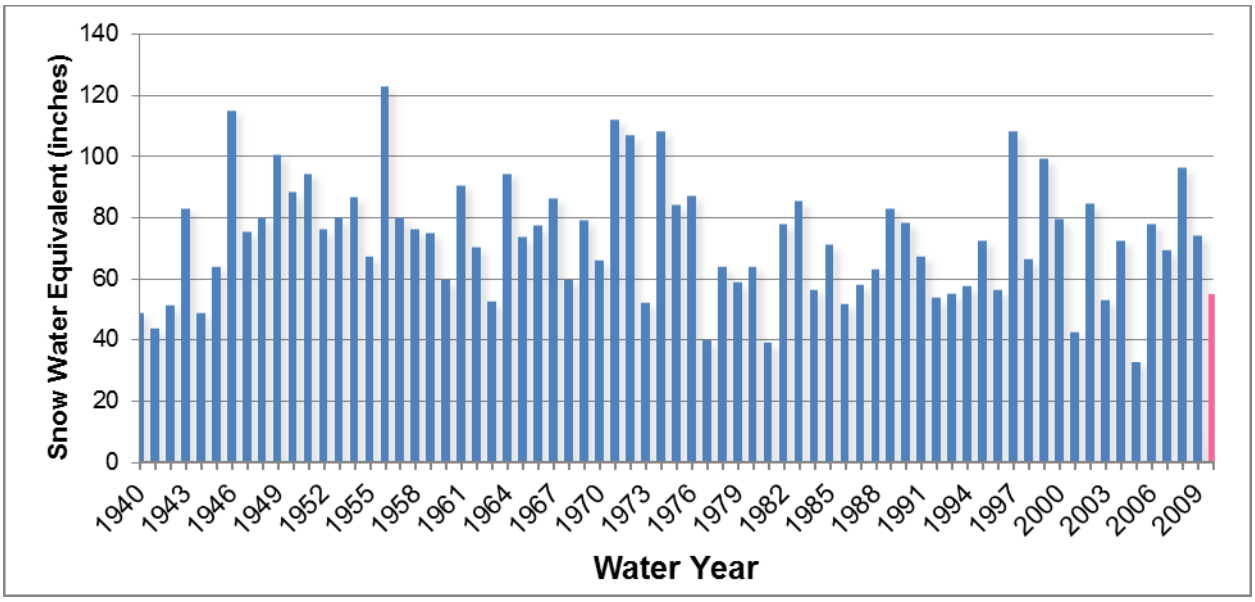

Figure F-8. April 1st snow water equivalent (inches) at the Paradise snow course for the period of record (1940-2010). Highlighted column indicates Water Year 2010.

Appendix G: Sunrise High Elevation - Water Year 2010.

Temperatures observed at the Sunrise High Elevation station ranged from -8.0 to 77.8°F (Table G-1). January was warmer than average, with a 2.7 °F departure from period of record (2004-2010) (Figure G-1). October and May were 3.0 and 4.5°F cooler than average respectively (Figure G-1). The coldest day of the year was December 7, 2009 and the warmest day was August 24, 2010 (Figure G-2). April through September was consistently cooler than average. 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).

The precipitation gauge at Sunrise relies on a propylene glycol mixture to operate since AC power is not available at the site. Due to the heavy precipitation, low temperatures, and overall harsh conditions at Sunrise, the gauge was not entirely reliable. The precipitation gauge was struck by lightning in November and did not operate reliably for the remainder of the water year.

Table G-1. Monthly Summary data, Sunrise High Elevation Station, Water Year 2010.

Season	Month & Year	Mean Air Temp °F	Max Daily Air Temp °F	Min Daily Air Temp °F	Precipitation (inches)
Fall	October 2009	34.4	51.8	18.0	7.7
	November 2009	28.8	51.6	11.1	----[a]
Winter	December 2009	23.8	51.8	-8.0	----[a]
	January 2010	30.1	44.3	21.7	----[a]
	February 2010	29.8	47.7	19.1	----[a]
Spring	March 2010	29.3	48.5	8.2	----[a]
	April 2010	29.5	55.8	14.0	----[a]
	May 2010	34.1	58.6	17.0	----[a]
Summer	June 2010	41.3	62.4	24.2	----[a]
	July 2010	53.8	74.6	31.7	----[a]
	August 2010	52.0	77.8	32.2	----[a]
Fall	September 2010	45.4	70.1	30.7	----[a]
Water Year Total		**36.0**	**77.8**	**-8.0**	**----**[a]

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

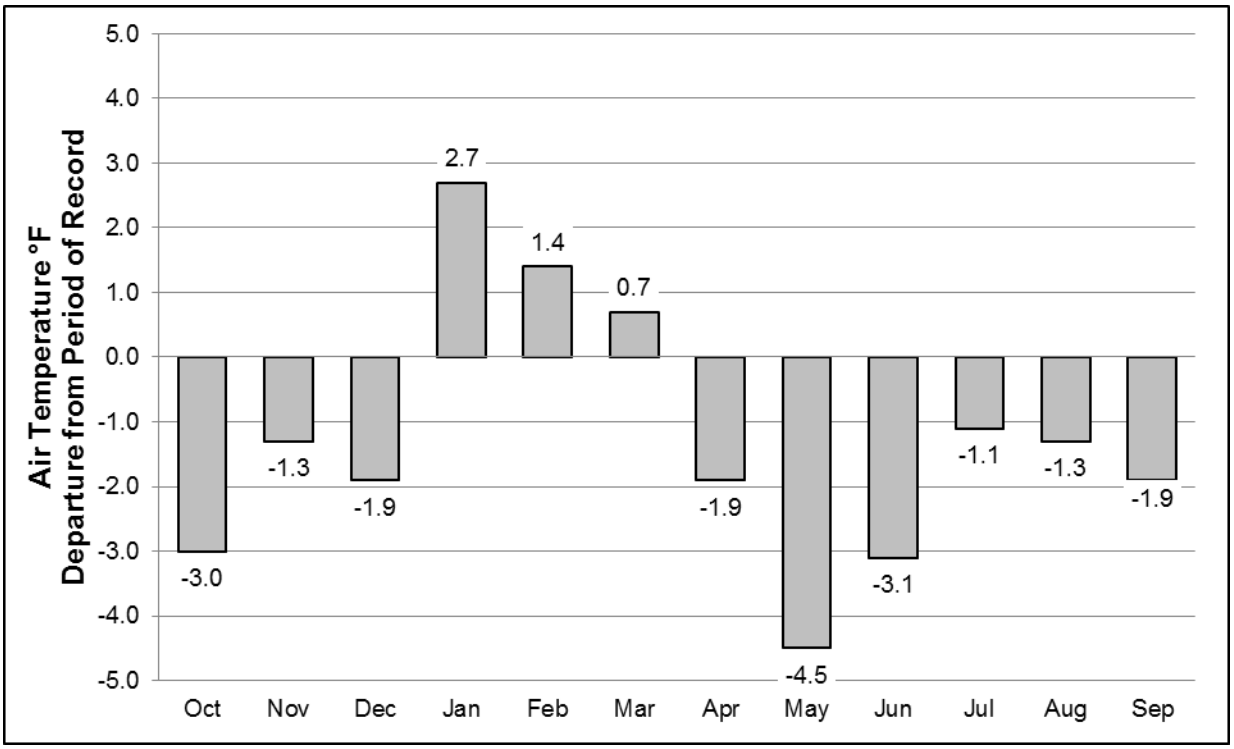

Figure G-1. Comparison of average monthly temperature (°F) for the Sunrise High Elevation Station in Water Year against monthly averages for the period of record (2004-2010).

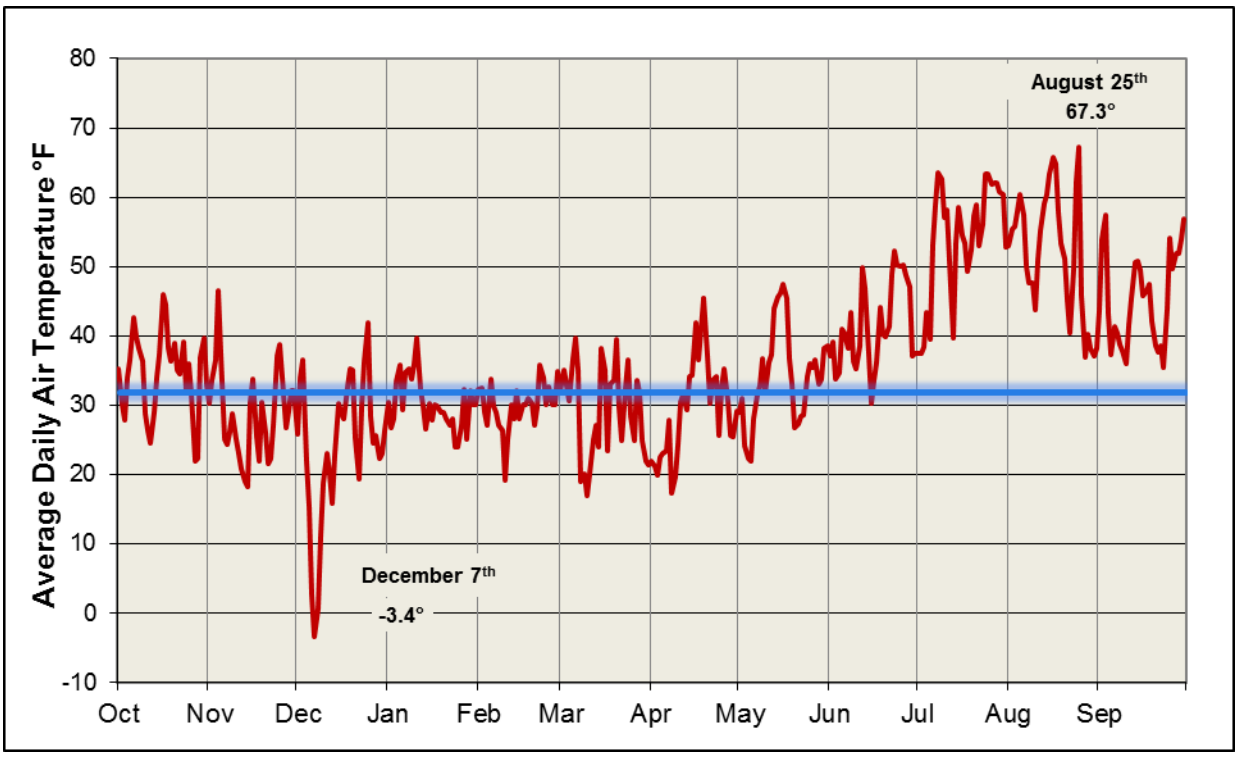

Figure G-2. Daily average air temperature (°F) at the Sunrise High Elevation Station, Water Year 2010. Blue line indicates 32ºF, the freezing point of water.

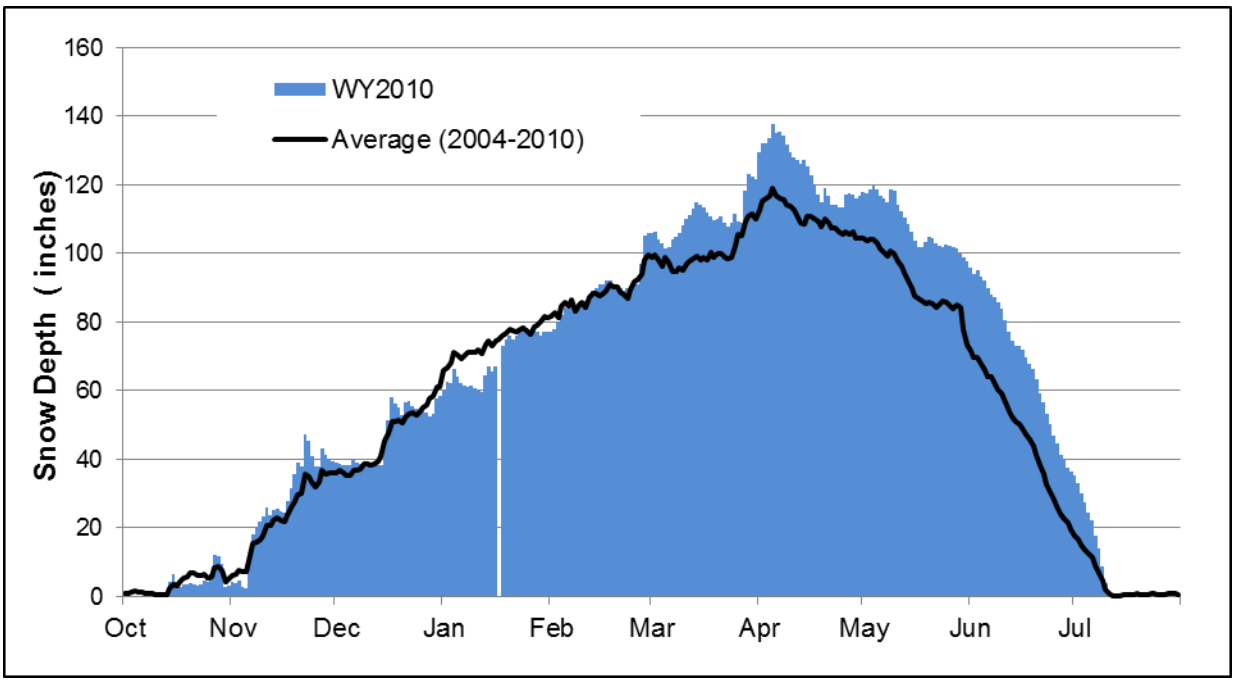

Figure G-3. Daily snow depth (inches) at the Sunrise High Elevation Station, Water Year 2010, compared with the period of record daily average (2004-2010).