National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

North Coast and Cascades Network Climate Monitoring Report

Olympic National Park; Water Year 2011

Natural Resource Data Series NPS/NCCN/NRDS—2013/568

ON THIS PAGE
The Seven Lakes Basin remains blanketed in snow in late July, 2011 (above). Lower photograph (inset) shows the basin during a more typical July (2008). A cool and wet spring and summer preserved the winter snowpack to one of the latest dates on record.
Photograph by: Bill Baccus

ON THE COVER
Park ranger Bryan Bell skis to the Wolf Creek Snow Course following one of many March snow events in 2011.
Photograph by: Bill Baccus

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

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

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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 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/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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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 Olympic National Park during Water Year 2011, 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 11 weather stations ranging in location from the coast to high elevation sites in the mountainous core of the Olympics. Data were recorded using automated instruments operated by the National Park Service and other collaborators, including the National Weather Service and the Natural Resources Conservation Service. For two stations with long term records, the Quillayute Airport representing wet, west side conditions and the Elwha Ranger Station representing the drier, northern portions of the park, monthly average temperatures and monthly total precipitation are reported and compared to the 30-year normal (1971 to 2000). Monthly snow depth and snow water equivalent (SWE) are reported for two Snow Telemetry (SNOTEL) stations and three snow courses within the park.

Daily and monthly air temperature, precipitation and snowpack for the nine park operated 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.

Water Year 2011 continued a two year trend of wetter and cooler than normal weather conditions. Of particular importance was a six month period from February to July with above normal precipitation and much below normal temperatures. For the second year in a row, these conditions delayed spring phenology of many species, contributed to high stream flows in late spring and early summer months, and left mountain elevations buried in record snow until the last few weeks of summer.

Acknowledgments

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

- National Weather Service – National Weather Service Cooperative Observer Program
- National Climate Data Center
- Natural Resources Conservation Service - National Water and Climate Center, SNOTEL and Snow Survey Program
- Northwest Weather and Avalanche Center – High Elevation Weather Stations
- US Climate Reference Network, National Oceanic and Atmospheric Administration – National Climate Data Center.
- Western Regional Climate Center

The NPS would also like to thank the Office of the Washington State Climatologist and Dr. Cliff Mass (Weather Blog) for their regional and statewide weather and climate discussions.

Acronyms

COOP	Cooperative Observer Station
I&M	Inventory and Monitoring
NCCN	North Coast and Cascades Network
NCDC	National Climatic Data Center
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWAC	Northwest Weather and Avalanche Center
NWS	National Weather Service
OLYM	Olympic National Park
PNW	Pacific Northwest
RAWS	Remote Automatic 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 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, storage type precipitation gauge 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 1 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, 2011 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) (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 growing or shrinking 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 means, 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 as well as park infrastructure such as roads and campgrounds.

Given the importance of climate, it has been identified as a primary vital sign by all 32 Inventory and Monitoring (I&M) networks within the National Park Service (NPS) (Gray 2008). The NCCN monitors climate in order to understand variations in other park resources being monitored, 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). The climate data developed by the NCCN climate monitoring program plays an important role in understanding and interpreting the other physical and ecological Vital Signs monitored within NCCN parks.

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 NPS. 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, and provides supplemental information on snowpack.

This report summarizes climate data collected from 11 weather stations located in and adjacent to Olympic 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 NCCN (Figure 1). Temperature, precipitation, and snow data from the 11 weather stations are summarized in the results section of this report. Detailed climate data recorded from each weather station are presented in Appendices A to I.

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 NRCS (SNOTEL), and the NWS (COOP) (Table 1 and Figure 2).

Table 1. Weather stations referenced in this report.

Station Name	Station Type	Location	Elevation (ft)	Forest Zone	Period of Record
Buckinghorse Ridge	SNOTEL	Interior	4870	Subalpine	2008 to Present
Deer Park Ranger Station	NPS	Northeast	5250	Subalpine	2007 to Present
Deer Park Road	NPS	Northeast	3115	Montane	1999 to Present
Elwha Ranger Station	COOP	North	390	Lowland	1942 to Present
Hayes River Guard Station	NPS	Interior	1700	Lowland	2007 to Present
Hoh Rainforest	NPS	West	406	Lowland	2000 to Present
Kalaloch Ranger Station	NPS	West	42	Coastal	1966[a] to Present
Ozette Ranger Station	NPS	Northwest	31	Coastal	1982[b] to Present
Quillayute Airport	COOP	West	180	Coastal	1966 to Present
Quinault Rainforest	NPS	Southwest	372	Lowland	1999 to Present
Waterhole	SNOTEL	North	4961	Subalpine	2000 to Present

[a] Annual precipitation values only. Hourly data available from 2009 to present.

[b] Daily precipitation values only. Hourly data available from 2003 to present.

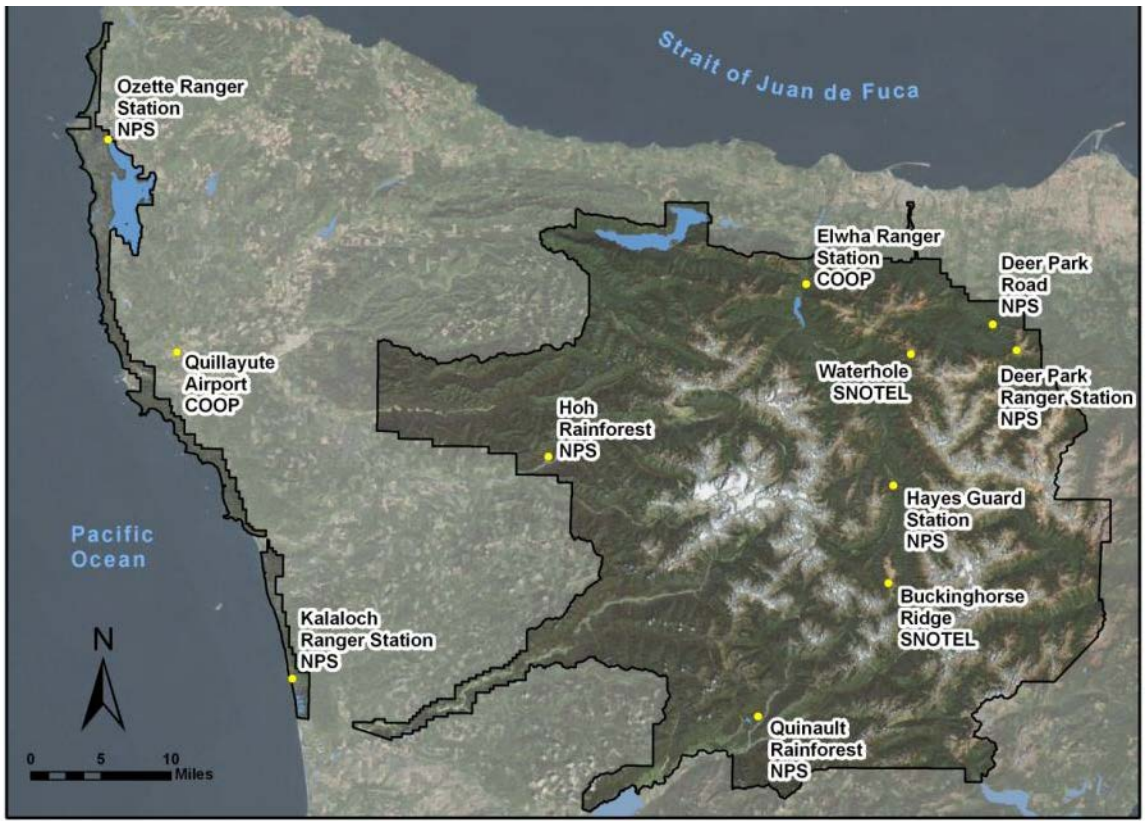

Figure 2. Location of weather stations referenced in this report.

Weather Station Measurements

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

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

Station Name	Managing Agency – Station Type	Air Temp	Relative Humidity	Precipitation	Snow Depth	Snowfall	Snow Water Equivalent	Solar Radiation	Photosynthetic Active Radiation	Wind Speed & Direction	Soil Temperature	Soil Moisture
Buckinghorse Ridge	SNOTEL[1]	**X**	X	**X**	X		**X**				X	X
Deer Park Ranger Station	NPS[2]	**X**	X	**X**	**X**							
Deer Park Road	NPS[2]	**X**	X	**X**					X	X	X	X
Elwha Ranger Station	NWS COOP[3]	**X**		**X**		X						
Hayes River Guard Station	NPS[2]	**X**	X	**X**	X						X	X
Hoh Rainforest	NPS[2]	**X**	X	**X**					X	X	X	X
Kalaloch Ranger Station	NPS[2]	**X**	X	**X**								
Ozette Ranger Station	NPS[2]	**X**	X	**X**				X		X		
Quillayute Airport	NWS COOP[3]	**X**		**X**		X						
Quinault Rainforest	NPS[2]	**X**	X	**X**					X	X	X	X
Waterhole	SNOTEL[1]	**X**	X	**X**	X		**X**				X	X

[1] 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. These stations are managed and operated by the United States Department of Agriculture Natural Resource Conservation Service (USDA-NRCS)

[2] National Park Service (NPS) stations utilize a standard array of automated weather instruments which are measured at 5 minute intervals and output as hourly averages.

[3] National Weather Service Cooperative Stations (NWS COOP) stations rely on a standard array of manually operated weather instruments. Parameters are measured and recorded daily.

Data Quality Assurance and Control

NWS COOP station and NRCS SNOTEL station data presented in this report are acquired directly from the managing agencies (Western Regional Climate Center 2012 and National Water and Climate Center 2012, respectively). 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 in this report from the NPS operated stations are derived from hourly data which have been evaluated through manual display and graphing of single and multiple parameters to identify unusual values or trends. Data not meeting standards are removed or flagged as suspect and omitted from daily summaries (Lofgren et al. 2011). 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 a nearby weather station for the purposes of reporting monthly and annual totals. This only occurs when nearby data are available and a known correlation exists between the sites. When estimates are generated from nearby stations, data are footnoted and a description of the quantity and source of data replacement is given.

Water Year 2011 Data Quality

An unusually deep snowpack buried and damaged the snow depth sensor at the Buckinghorse SNOTEL station. The sensor was over-topped on March 10, 2011, eliminating snow depth measurements for the remainder of the spring and early summer. Snow water equivalent and precipitation measurements were not affected. The depth sensor was replaced and mounted ten feet higher on an extension pole attached to the existing tower. This will allow measurement of snow depth in future winters with unusually deep snowpacks.

Power limitations restrict the use of heated tipping buckets at two weather stations that receive appreciable winter snowfall. Despite extended snow tubes on the gages, precipitation at the Deer Park Ranger Station and the Hayes River Guard Station are assumed to underestimate total amounts during months with snowfall (Deer Park: Oct. to May, Hayes River: Nov. to March).

Fall and early winter air temperature data from the Kalaloch Ranger Station were omitted due to values appearing 5° to 10°F lower than at adjacent stations. This intermittent failure relates to site-specific conditions adversely affecting the operation of the Vaisala HMP 45C temperature and relative humidity probe. Similar issues have been noted with these probes when operated at park rainforest research sites beneath the forest canopy that are exposed to prolonged periods of high humidity. This probe was replaced with a Campbell Scientific 109 temperature probe on December 21, 2010. The CS 109 is a simple thermistor that is stable in all moisture conditions.

Ten days of data are missing from the Ozette Ranger Station in November due to hardware-memory malfunctions. Missing air temperature and precipitation data were replaced with values from the nearby Quillayute Airport. A data logger with upgraded memory was installed at this site in April 2011.

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 that generally begins in late October and ends 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, the magnitude and timing of stream flow, emergence and flowering of plants and the migratory timing of bird species.

Seasons in this report follow National Weather Service standards for the Northern Hemisphere, which define 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 Table 2. While routinely collected in metric units, the data are presented in Fahrenheit and inches to more easily facilitate use and interpretation by park staff and the public. Two stations with long term records: the Quillayute Airport representing wet, west side conditions and the Elwha Ranger Station representing the drier, northern portions of the park are compared to the 30-year climate normal. Snow water equivalent is reported and compared to the 30-year climate normal for one SNOTEL and three snow courses within the park.

Data from each individual weather station are presented in a separate appendix. The appendices report 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. While the main report compares Water Year 2011 with the 30-year climate normal (1971 to 2000), the appendices compare 2011 with the period of record for that station. This is due to the fact that most of these stations were established within the last decade and therefore do not have a 30 year data record for establishing a climatic normal. Detailed discussion of maintenance issues or data concerns associated with each specific station is also presented.

Results

Temperature

Above normal temperatures prevailed in the fall and early winter months of Water Year 2011. The one exception was a slightly cooler than normal November, when monthly averages were influenced by an arctic air mass which generated low elevation snow and the coldest temperatures of the year. The warmer than normal conditions in early winter came to an abrupt end in February with all sites recording below normal temperatures. Quillayute Airport, had an average temperature of 37.9 in February (Table 3). This was 4.3°F below normal, ranking this as the second coldest February on record for this site (Figure 3).

Spring months averaged 2.6° and 2.3°F below normal at Quillayute Airport and Elwha Ranger Station respectively (Figures 3 and 4). The coldest May in the 45 year record of the Quillayute Airport (-3.2 departure from normal) was recorded in the 2011 Water Year (Figure 3).

Early summer months continued to be cool, with June and July averaging 0.9° and 1.6°F below normal at Quillayute Airport and Elwha Ranger Station respectively (Figures 3 and 4). Summer temperatures in mountainous areas of the park exhibited an even greater departure from normal, especially during the month of July. The Waterhole SNOTEL and Deer Park Road weather stations recorded air temperatures 6.1° and 4.6°F below the 10 year average (Appendices C and I, Figures C-1 and I-1, respectively). While these sites have a limited period of record, the measured departure at these high elevation sites corresponded well to long term records at Paradise in Mt. Rainier National Park, where July temperatures were 4.8°F below the 100+ year average (Lofgren et al. 2013). Temperatures finally climbed above normal in mid-August creating near normal averages for this month. September temperatures were well above normal with Quillayute and Elwha, +2.0 and +3.0 respectively (Figures 3 and 4). Unusually cool summer months for the Park are exhibited in the record of daily maximum temperatures for all weather stations (see Table 2 in Appendices A through I). With few exceptions, the warmest four days of Water Year 2011 occurred during the fall month of September.

Table 3. Average monthly air temperatures (°F) from weather stations within or adjacent to Olympic National Park in Water Year 2011.

Season	Month & Year	Buckinghorse Ridge SNOTEL	Deer Park Ranger Station	Deer Park Road	Elwha Ranger Station COOP	Hayes River Guard Station	Hoh Rainforest	Kalaloch Ranger Station	Ozette Ranger Station	Quillayute Airport COOP	Quinault Rainforest	Waterhole SNOTEL
Fall	October 2010	43.1	39.0	47.6	49.2	43.1	47.6	----[a]	50.5	51.4	49.9	40.4
	November 2010	31.4	26.9	27.3	39.9	34.7	39.0	----[a]	42.5 [b]	42.7	40.4	29.3
Winter	December 2010	29.4	23.5	34.7	37.3	32.5	38.1	----[a]	38.6	42.2	38.6	27.8
	January 2011	32.9	28.1	36.6	37.2	32.3	37.9	42.1	37.5	41.4	38.4	30.6
	February 2011	27.6	22.2	31.7	37.2	31.5	36.3	39.5	34.2	37.9	36.7	25.2
Spring	March 2011	29.3	25.3	35.2	40.6	34.1	40.1	43.7	37.8	43.1	40.5	28.0
	April 2011	30.7	25.3	34.9	42.9	35.9	40.0	43.9	38.8	42.7	41.2	28.3
	May 2011	37.4	33.9	42.3	49.9	44.5	46.9	49.1	48.6	48.0	49.6	35.5
Summer	June 2011	44.5	40.6	49.1	54.8	52.8	53.4	55.2	54.8	54.5	56.4	41.9
	July 2011	48.9	46.3	53.8	59.2	56.6	57.1	57.0	56.7	57.3	60.3	46.4
	August 2011	53.6	50.7	58.4	62.9	58.2	59.2	57.2	58.1	59.2	61.4	50.9
Fall	September 2011	53.1	51.1	59.2	60.0	54.0	58.2	55.9	56.9	58.5	59.4	50.1
Water Year		38.5	34.4	42.5	47.6	42.5	46.2	----[a]	46.2	48.2	47.7	36.2

[a] Air temperature data are missing due to the failure of the air temperature sensor. A new air temperature sensor was installed on 12/21/2012.

[b] Ten days of missing data in November were replaced with values from Quillayute Field COOP.

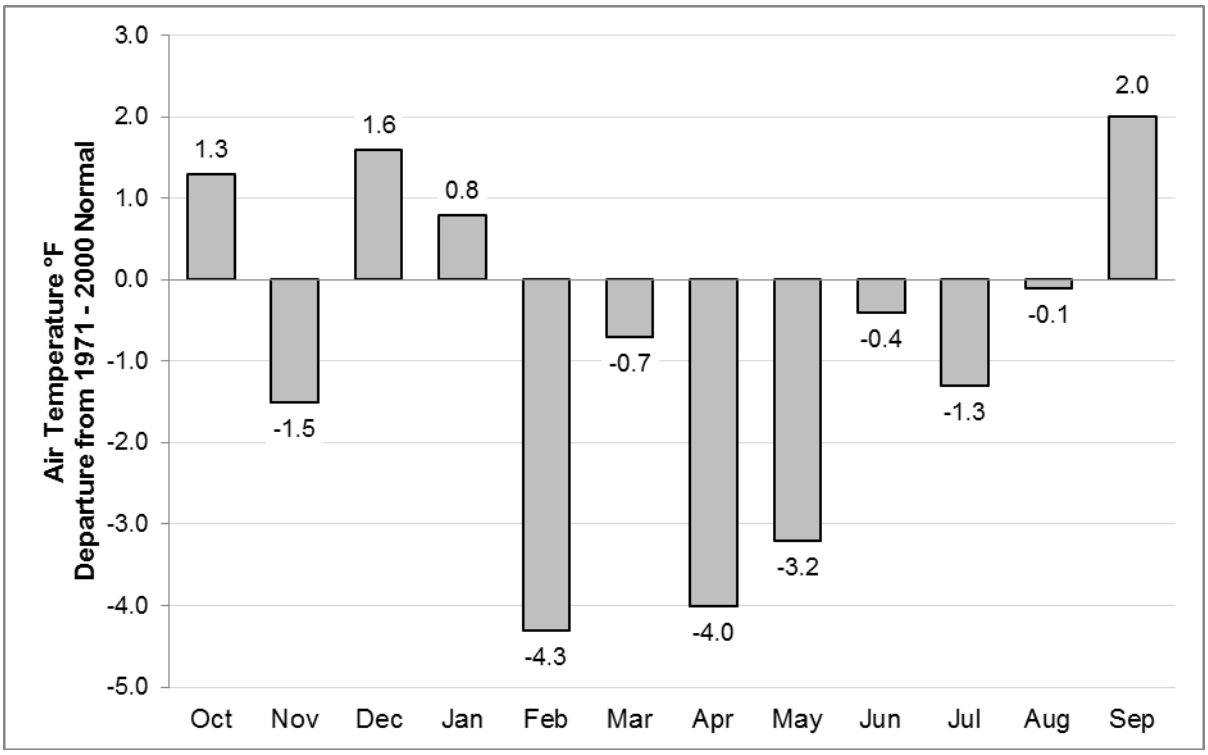

Figure 3. Comparison of average monthly temperature (°F) for Quillayute Airport in Water Year 2011 against monthly averages for the climatological normal 1971-2000.

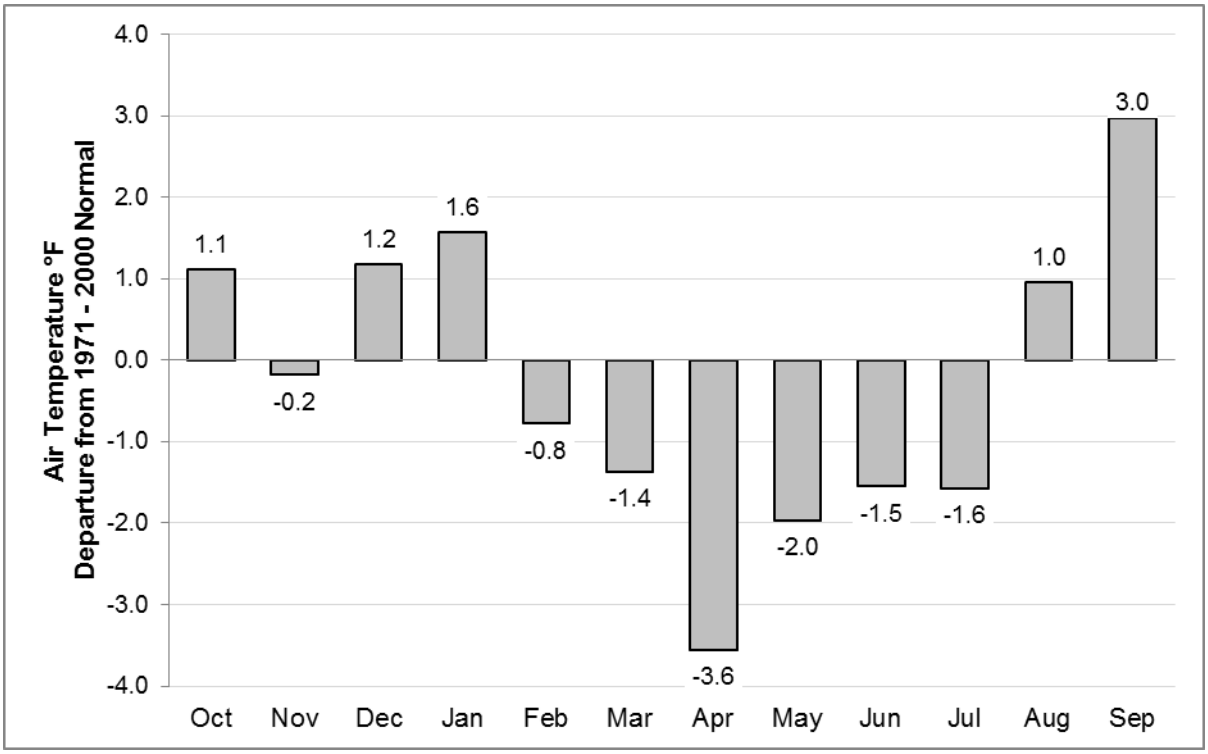

Figure 4. Comparison of average monthly temperature (°F) for Elwha Ranger Station in Water Year 2011 against monthly averages for the climatological normal 1971-2000.

Precipitation

Water Year 2011 was wetter than normal. Quillayute Airport received 118.2 inches of precipitation, 116% of normal. Elwha Ranger Station received 61.2 inches, 110% of normal (Table 4).

Precipitation for the fall season was near normal, however the typical pattern for the fall was reversed with October wetter than normal and a relatively dry November (Table 4). Winter months were near or slightly above normal (Quillayute +15% and Elwha Ranger Station -3% departure from normal). Spring months, however, experienced precipitation levels that were well above normal. Statewide, the months of March, April and May were the wettest in the 117 year record (NOAA, 2011a). On the Olympic Peninsula, sites on the coastal plains showed less deviation from normal (Quillayute Airport, 123% of normal) than sites in the mountainous interior (Elwha Ranger Station, 184% of normal) (Figures 5 and 6). March was particularly wet, with the Quillayute airport recording the fourth wettest March on record and the Elwha Ranger Station recording the fifth wettest March. Another way of emphasizing the unusual March precipitation is to compare March precipitation quantities to other months (Table 4). At various park weather stations, March precipitation nearly tied and sometimes exceeded December quantities, especially at Kalaloch and Quillayute Airport. December is typically the wettest month of the year park-wide, and December 2011 amounts were well above normal.

Precipitation amounts during the summer months averaged slightly below normal, however this varied between locations. The Elwha Ranger Station averaged 64% of normal for June, July and August (Figure 6). The Quinault Rainforest was 68% compared to the period of record at this site (Appendix H). In contrast, Quillayute was 91% of normal (Figure 5) and the Hoh Rainforest was 108% when compared to the period of record (Appendix E). Park-wide, the month of July was consistently much wetter than average while the months of June and August were drier than average. Variation between sites in the months of July and August showed consistent differences between coastal areas and the park interior. During the month of July, coastal sites were at or below average, while interior sites ranged from 124% to as high as 370% deviation from the period of record (Appendices A through I). This difference was also apparent during August, with coastal sites experiencing typical rainfall amounts (Quillayute 97% normal, Kalaloch 119% compared to the period of record) while interior sites were much drier (Elwha 10% of normal, Hoh Rainforest, 35% compared to the period of record). Wetter conditions returned by early September bringing to an end an already shortened summer season. Quillayute Airport and Elwha Ranger Station recorded well above normal precipitation, 185% and 154% of normal respectively.

Table 4. Total monthly precipitation (inches) from weather stations within or adjacent to Olympic National Park, in Water Year 2011.

Season	Month & Year	Buckinghorse Ridge SNOTEL	Deer Park Ranger Station	Deer Park Road	Elwha Ranger Station COOP	Hayes River Guard Station	Hoh Rainforest	Kalaloch Ranger Station	Ozette Ranger Station	Quillayute Airport COOP	Quinault Rainforest	Waterhole SNOTEL
Fall	October 2010	14.4	----[a]	3.2	7.0	10.2	12.7	11.9	9.9	12.3	18.5	6.6
	November 2010	12.9	----[a]	4.1	5.0	7.7	13.4	12.5	15.8[b]	12.3	16.8	10.1
Winter	December 2010	35.4	----[a]	9.9	9.9	17.3	23.4	16.6	15.9	19.0	32.8	14.7
	January 2011	16.7	----[a]	4.9	7.5	9.0	18.2	17.8	16.0	17.6	20.0	8.9
	February 2011	14.1	----[a]	3.2	6.9	5.9	12.8	9.6	8.6	10.5	14.8	10.0
Spring	March 2011	28.5	----[a]	6.9	11.3	15.2	21.4	18.3	15.4	18.0	28.8	19.3
	April 2011	11.9	----[a]	3.1	5.8	7.5	12.4	9.0	7.1	7.9	12.5	7.4
	May 2011	4.8	----[a]	5.3	3.6	3.8	7.4	6.8	5.0	5.6	6.7	4.5
Summer	June 2011	0.5	1.4	0.8	0.2	0.2	2.1	2.1	1.6	1.9	1.0	0.7
	July 2011	1.3	1.4	1.9	1.4	1.1	2.7	2.5	2.1	2.3	2.0	1.6
	August 2011	0.6	0.0	0.1	0.1	0.4	0.9	2.1	2.3	3.3	1.3	0.2
Fall	September 2011	7.8	1.5	1.1	2.5	3.7	5.0	5.2	7.0	7.7	7.9	3.0
Water Year		148.9	----[a]	44.3	61.2	82.0	132.3	114.4	106.6	118.2	163.0	87.0

[a] Non-heated tipping bucket. No winter values available.

[b] Ten days of missing data in November were replaced with values from Quillayute Airport COOP.

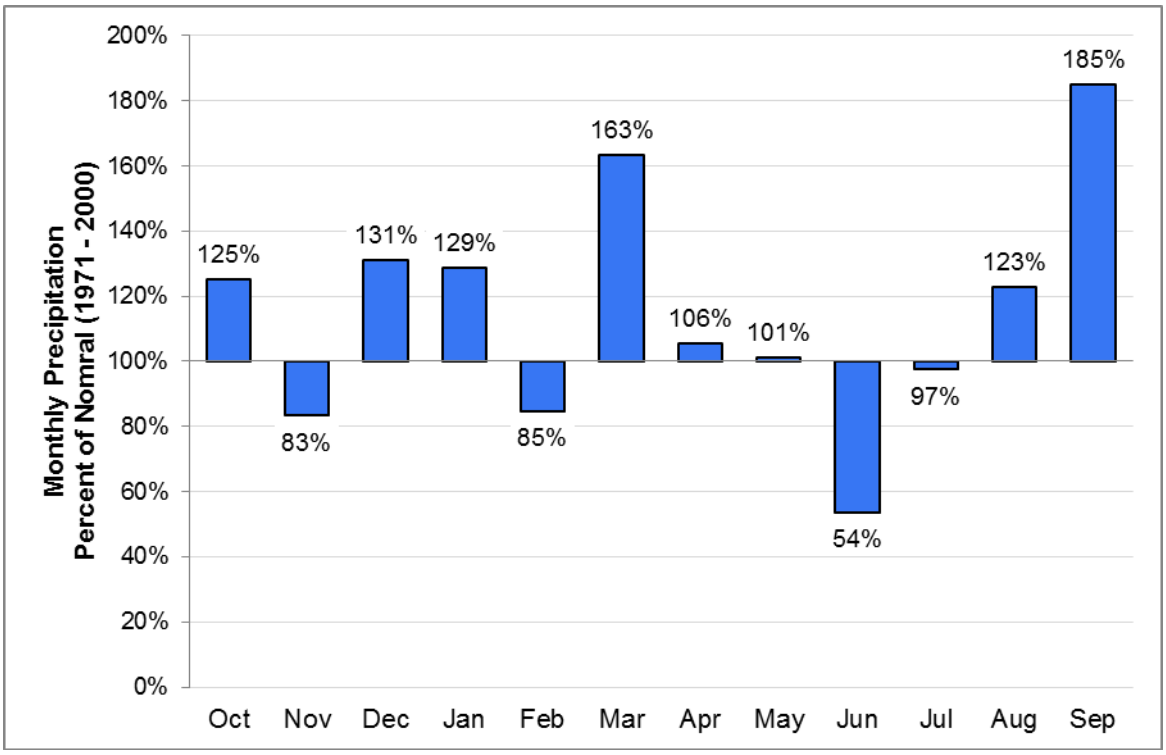

Figure 5. Comparison of monthly total precipitation (inches) as a percent of normal at Quillayute Airport in Water Year 2011 against the climatological normal 1971-2000.

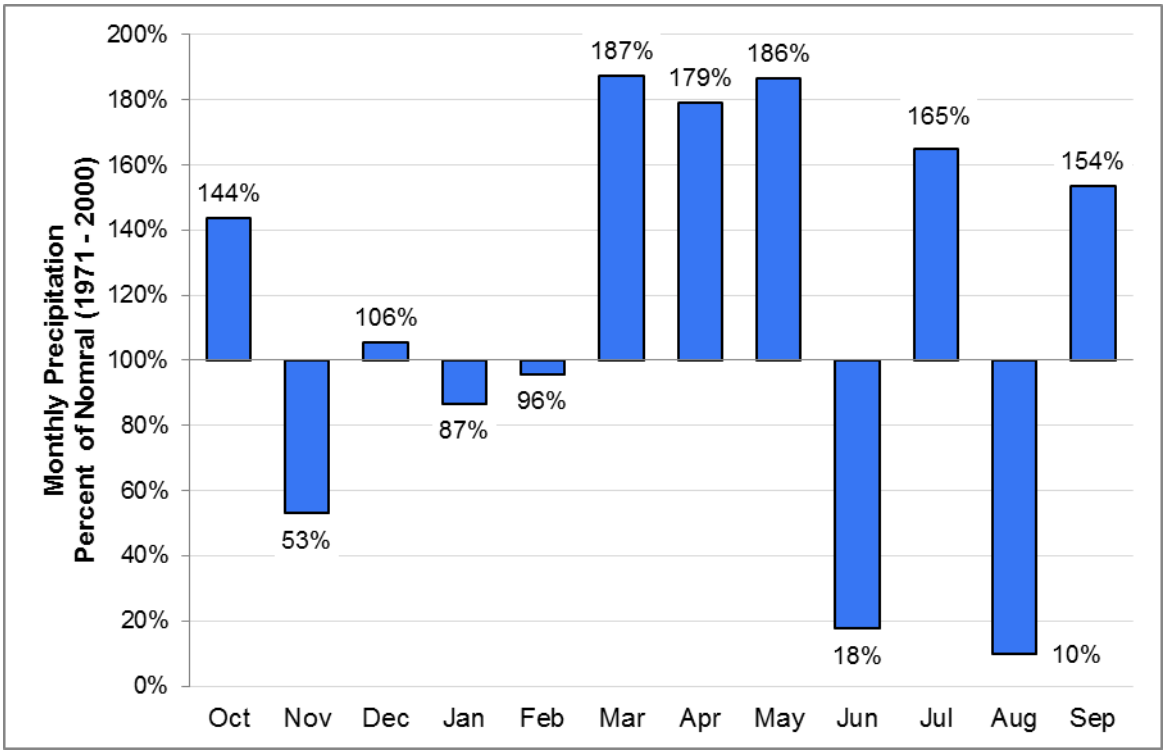

Figure 6. Comparison of monthly total precipitation (inches) as a percent of normal at the Elwha Ranger Station in Water Year 2011 against the climatological normal 1971-2000.

Snow

Below normal temperatures in late November and several large precipitation events combined to build an above normal snowpack in the Olympic Mountains by December 1 (Figure 7). Supported by colder than normal temperatures and slightly above normal precipitation, snowpack continued on a slightly above average trend. On March 1, the Waterhole SNOTEL had 110 inches of snow with a water equivalent of 124% greater than normal (Table 5; Figure 7; and Appendix I, Figure I-8). This trajectory changed dramatically during the month of March, when double the normal precipitation fell, burying the mountains in snow. By April 1, snowpack was nearly 160% of normal at the Waterhole SNOTEL. Unusually cool conditions through the remainder of spring helped to build and preserve this deep snowpack. At Waterhole SNOTEL, the maximum snowpack was not reached until May 1 (Table 5 and Appendix I, Figure I-7), a month later than the normal maximum. Historic Snow Courses on May 1, ranged from 154% at Hurricane to 203% at Deer Park (Figure 8).

Unusually cool summer temperatures preserved the snowpack throughout high elevation areas. On June 1, the Waterhole SNOTEL was 390% of normal and the site did not melt out until July 24, more than a month beyond the average melt date for this site. Subalpine areas deeper in the interior were not snow free until well into August. For example the Buckinghorse SNOTEL, near the headwaters of the Elwha and deep within the park interior, was not snow free until August 12, having been buried for a period of 294 days (Appendix A, Figure A-4).

Table 5. Snow Depth (inches) measured on the first day of the month at SNOTEL and snow courses within Olympic National Park during Water Year 2011.

Month & Year	Buckinghorse Ridge SNOTEL	Waterhole SNOTEL	Cox Valley Snow Course[1]	Deer Park Snow Course[1]	Hurricane Snow Course[1]
November 1, 2010	20.0	12.0			
December 1, 2010	49.0	29.0			
January 1, 2011	109.0	61.0			
February 1, 2011	101.0	58.0	56.0	25.0	27.0
March 1, 2011	162.0	110.0	98.0	53.0	50.0
April 1, 2011	-----[2]	130.0	129.0	72.0	75.0
May 1, 2011	-----[2]	143.0	142.0	77.0	74.0
June 1, 2011	-----[2]	109.0			
July 1, 2011	-----[2]	55.0			

[1] Snow courses are manually measured four times annually, from February 1 to May 1.

[2] Snow depth data are missing due to the sensor becoming buried by an unusually deep snow pack. The height of the sensor was raised during the summer of 2012.

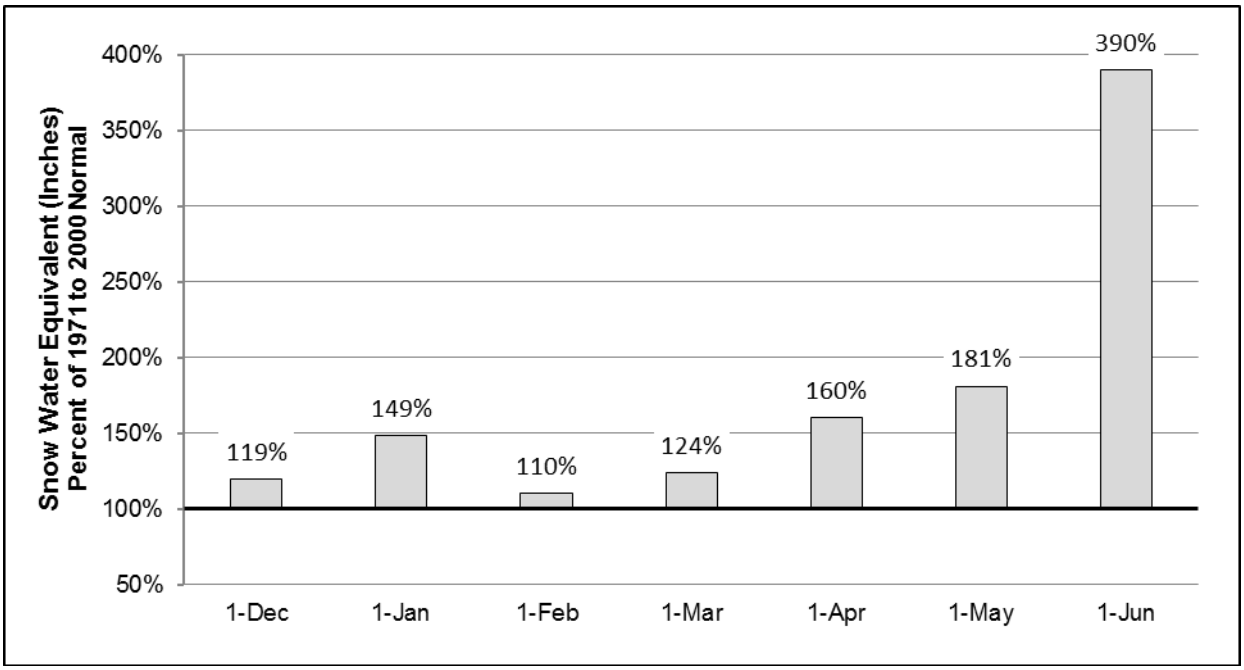

Figure 7. Comparison of snow water equivalent (inches) at the Waterhole SNOTEL in Water Year 2011 against the climatological normal 1971-2000.

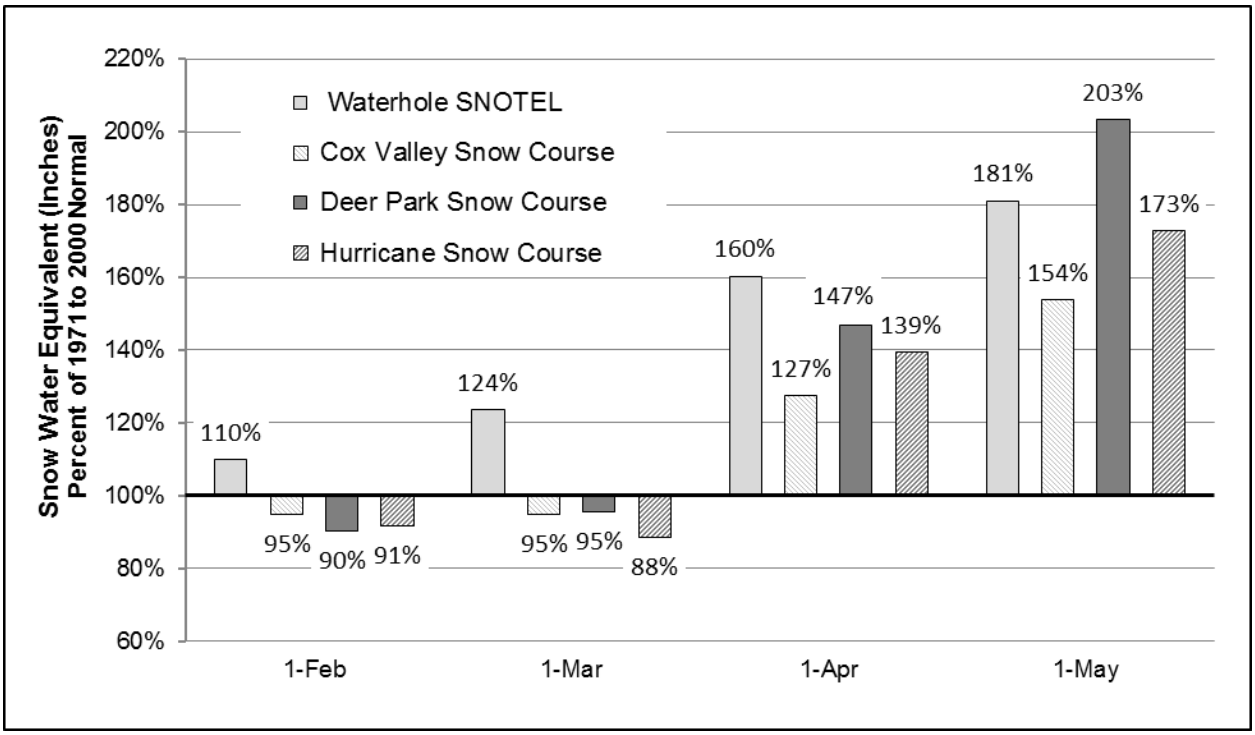

Figure 8. Comparison of snow water equivalent (inches) at long-term SNOTEL and Snow Courses within Olympic National Park in Water Year 2011 against the climatological normal 1971-2000.

2011 Water Year in Review

Significant Weather Events and Patterns

An arctic air mass in late November blanketed lowlands with snow and contributed to an early above normal snowpack in the Olympic Mountains. A major rain storm occurred between December 11 and 12. This storm was the largest precipitation event of the water year at all but one of the park's interior weather stations and triggered debris flows in many lowland areas.

A warm and wet frontal system impacted the Pacific Northwest in mid-January. January 15 (Martin Luther King Day) was the wettest single day of the year at the Hoh Rainforest and dropped heavy rainfall at low and high elevations. This rainfall affected the mountain snow pack, forming a weak layer dubbed by the skiing community "the MLK crust". This layer would play a significant role as an avalanche failure surface in future months.

Heavy rains occurred on February 12 and 14, followed by a cold period with lowland snow between Feb 22 and 26. A storm event with warm temperatures and heavy rains hit the Olympics on March 30 and 31. While the precipitation was most pronounced in coastal areas (the single wettest day of the year at Kalaloch, second wettest at Ozette), the heavy amounts of mountain rainfall combined with a weak snowpack layer from mid-January, triggered multiple avalanches of a massive scale in many interior areas of the park (Figure 9).

Figure 9. A massive avalanche leveled a swath of forest from ridge top to river bottom in the upper Hayes River during the winter of 2011.

Persistent wet and cool weather continued through the months of April, May and June. Statewide, this period was the second coolest in the 117 year record (NOAA, 2011b) and snow continued to accumulate in the mountains until early May. July remained cool and had a stretch of wet, showery days, especially on the west side. These conditions preserved an already deep snowpack. Conditions in the high country remained snow covered through much of the summer with many north facing cirques and high elevation lakes never melting out.

A long, dry stretch of weather finally settled in during the month of August. A notable rain event occurred on August 22, dropping heavy rain on coastal and west side locations, but with limited precipitation in the northeastern rain shadow areas. Early September had two weeks of warm, dry conditions before an early return to wet and cold conditions by mid-month.

Parkwide Precipitation Summary

The southwestern slopes of the Olympic Mountains receive among the highest precipitation in the United States. Precipitation at four park weather stations exceeded 100 inches for the 2011 water year, with the highest amount occurring at the Quinault Rainforest, 163.0 inches (Figure 10). With a dramatic mountain rain shadow effect on the Olympic Peninsula from southwest to northeast, precipitation at the Elwha Ranger Station COOP and Deer Park Road weather stations was two to three times lower than stations on the southwest-side (Figure 10).

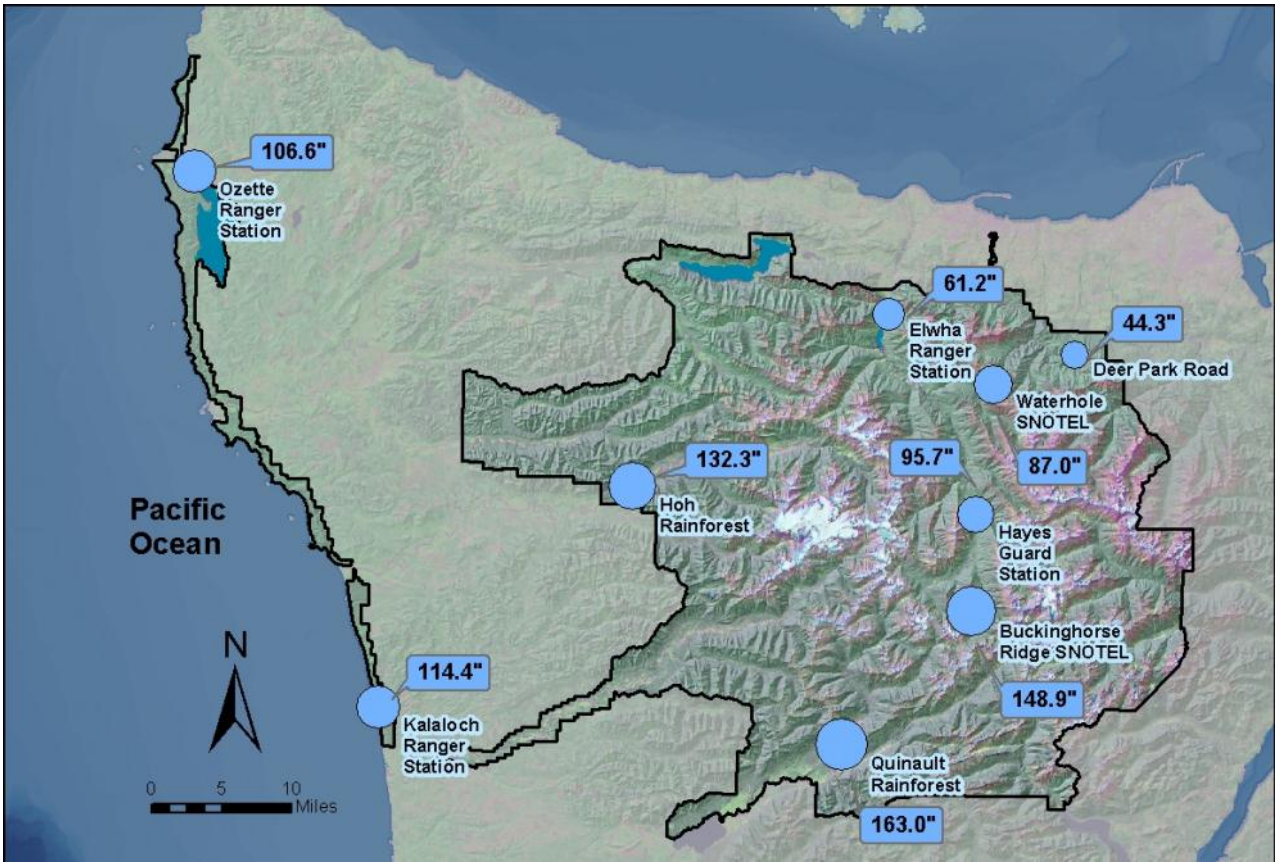

Figure 10. Total precipitation measured at weather stations located within Olympic National Park during Water Year 2011. Blue circles are proportional to the total amount of precipitation measured at each site.

Literature Cited

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

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.

Johnstone, J. 2011. A review of a 'San Francisco Summer' for the Pacific Northwest. Presentation at the Pacific Northwest Weather Workshop, 2011. Available online at: http://www.wrh.noaa.gov/sew/2011pnwww/Johnstone.pdf (accessed 24 October 2011).

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.

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

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

Mantua, N. 2010. The Pacific Decadal Oscillation. The Joint Institute for the Study of the Atmosphere and Oceans, University of Washington. Available at: http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_egec.htm (accessed 16 February 2012).

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.

National Water and Climate Center. 2012. SNOTEL data and products. Available online: http://www.wcc.nrcs.usda.gov/snotel/Washington/washington.html (accessed 12 December, 2012).

NOAA National Climatic Data Center, State of the Climate, 2011a. Washington precipitation time series plot, March-May 1895-2011. Available online: http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php (accessed 16 November, 2012).

NOAA National Climatic Data Center, State of the Climate, 2011b. Washington temperature time series plot, April-June 1895-2011. Available online: http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php (accessed 16 November, 2012).

Redmond, K. 1998. El Niño, La Nina, and the Western U.S., Alaska and Hawaii: Frequently Asked Questions. Western Regional Climate Center, Desert Research Institute. Available at: http://www.wrcc.dri.edu/enso/ensofaq.html (accessed 30 March, 2011).

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.

Western Regional Climate Center. 2012. Cooperative climatological data summaries. Available at: http://www.wrcc.dri.edu/climatedata/climsum/ (accessed 12 December, 2012).

Appendix A: Buckinghorse Ridge SNOTEL - Water Year 2011

Average annual temperature at the Buckinghorse Ridge SNOTEL weather station was 38.5°F (Table A-1). Temperatures ranged from an extreme low of -2.6°F during a particularly cold period in late-November, to a maximum of 78.6°F in early-September (Table A-2). A prolonged period of below freezing temperatures was recorded from early February to late April (Figure A-1). These unusual conditions were a contributing factor to a late developing, deep snowpack in late spring.

The Buckinghorse SNOTEL, with 148.9 inches of total precipitation, was the second wettest station in the park during 2011 (Table 4). This site also recorded the highest monthly precipitation of any site, with 35.4 inches of precipitation recorded during the month of December (Figure A-2). The highest daily precipitation of the year was recorded here (6.6 inches) during a major storm on December 12 (Figure A-3).

Snowpack began developing on October 24, 2010 and finally melted on August 11, 2011. The snowpack persisted for 292 days. Maximum snowpack occurred on April 27, with a snow water equivalent of 95.5 inches (Figure A-4). Snow depth data are missing from early March through August, due to the sensor becoming buried by an unusually deep snow pack. The height of the sensor was extended during the summer of 2012.

Table A-1. Monthly summary data, Buckinghorse Ridge 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	43.1	49.5	37.8	14.4
	November 2010	31.4	37.1	26.4	12.9
Winter	December 2010	29.4	34.0	26.1	35.4
	January 2011	32.9	39.1	28.2	16.7
	February 2011	27.6	35.1	22.3	14.1
Spring	March 2011	29.3	35.7	24.5	28.5
	April 2011	30.7	40.2	23.6	11.9
	May 2011	37.4	46.3	30.7	4.8
Summer	June 2011	44.5	53.3	37.8	0.5
	July 2011	48.9	57.6	41.9	1.3
	August 2011	53.6	63.2	46.5	0.6
Fall	September 2011	53.1	61.1	46.5	7.8
Water Year		38.5	46.0	32.7	148.9

Table A-2. Air temperature extremes, Buckinghorse SNOTEL, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 12, 2011	78.6	November 24, 2010	-2.6
September 11, 2011	76.8	November 23, 2010	2.3
September 10, 2011	75.9	February 26, 2011	2.7
September 8, 2011	75.9	November 25, 2010	7.2
August 21, 2011	74.8	February 25, 2011	7.3

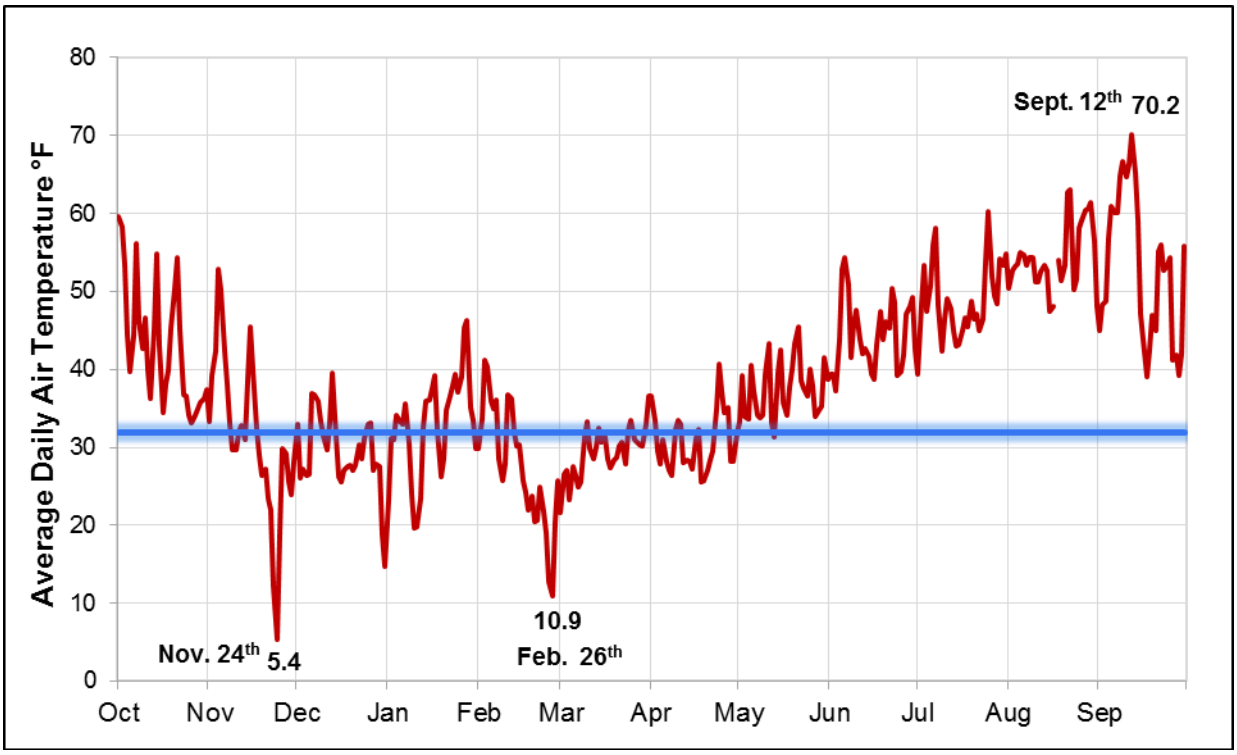

Figure A-1. Daily average air temperature (°F) at Buckinghorse Ridge SNOTEL, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

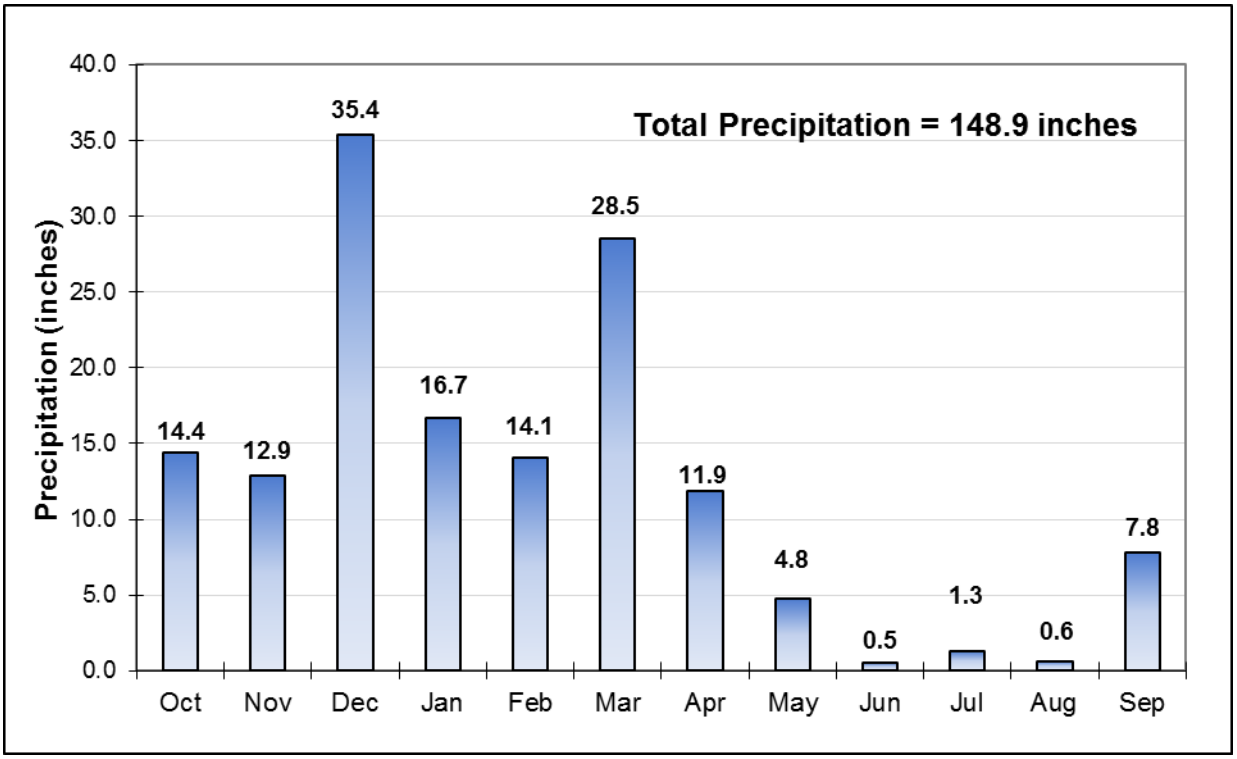

Figure A-2. Monthly precipitation values (inches) at Buckinghorse Ridge SNOTEL, Water Year 2011.

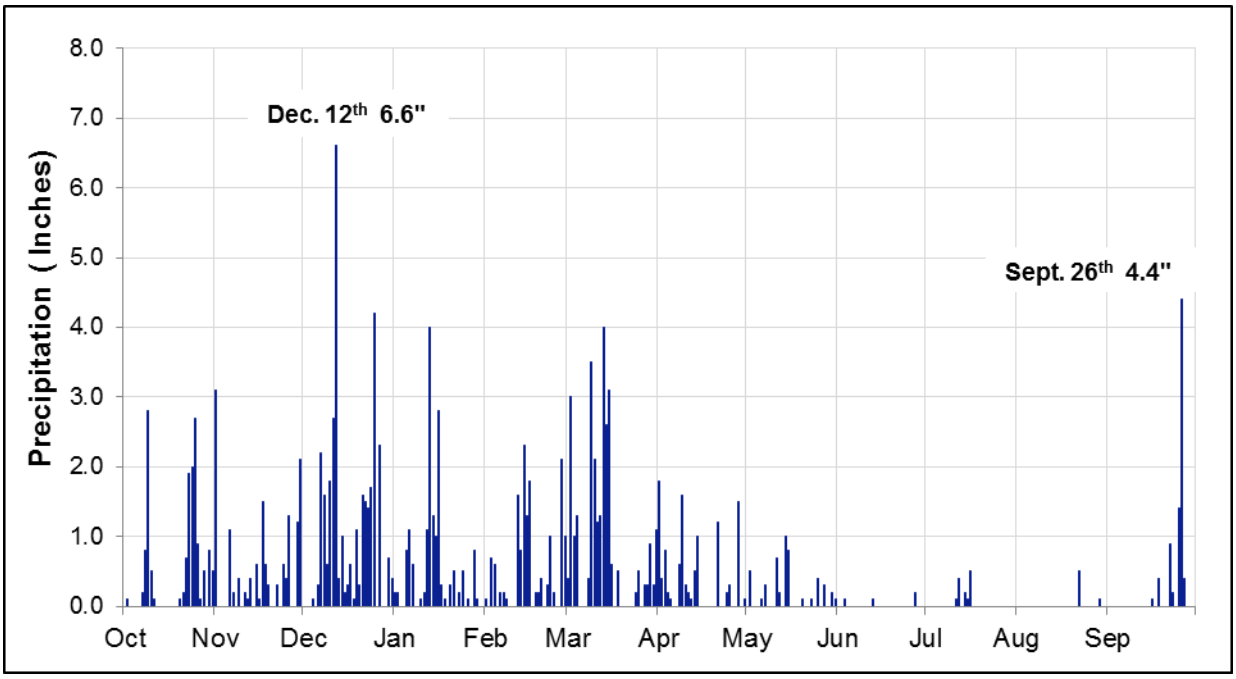

Figure A-3. Daily precipitation (inches) at Buckinghorse Ridge SNOTEL, Water Year 2011.

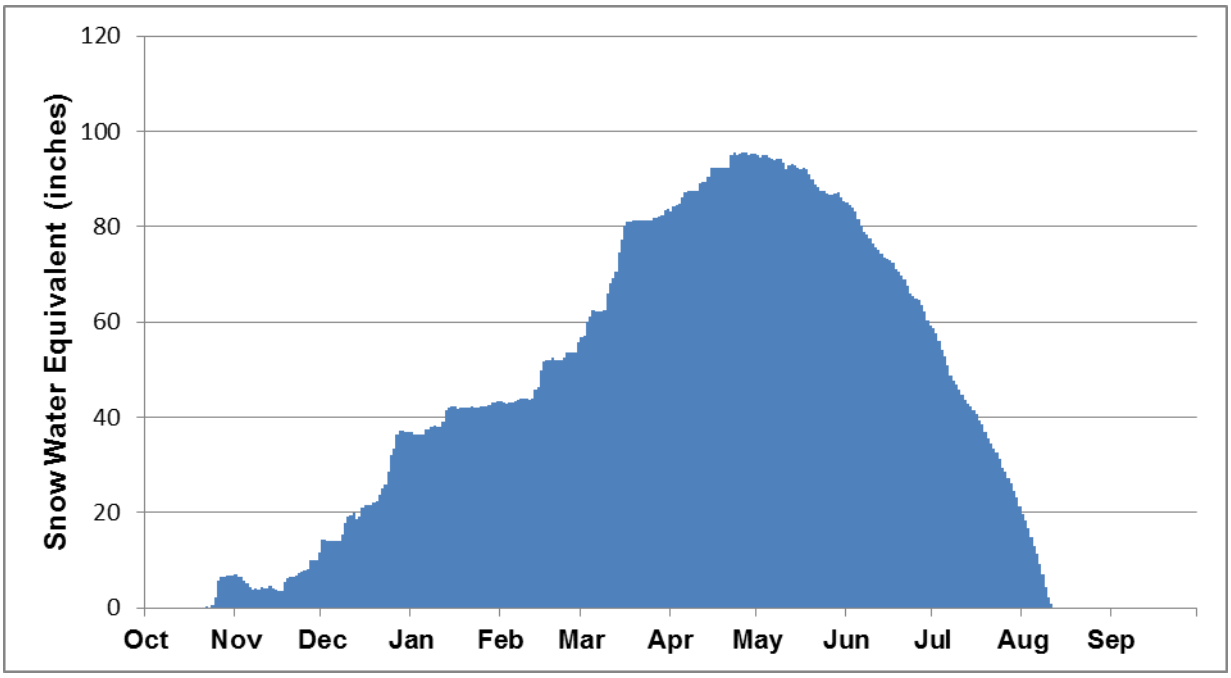

Figure A-4. Daily snow water equivalent (SWE) at Buckinghorse Ridge SNOTEL, Water Year 2011.

Appendix B: Deer Park Ranger Station - Water Year 2011

Average annual temperature at the Deer Park Ranger Station was 35.8°F (Table B-1). Daily air temperatures ranged from an extreme low of -6.1°F during a cold period in late-November, to a maximum of 79.7°F on September 10 (Table B-2). A prolonged period of below freezing temperatures is seen in data from mid-November extending to the end of April (Figure B-1).

Deer Park Ranger Station received 35.9 inches of total precipitation (Figure B-2). The highest daily precipitation of the year was recorded during a major "rain on snow" storm event on December 12, depositing 3.08 inches of rain (Figure B-3). It should be noted that some of the recorded precipitation from this event was melting snow in the non-heated rain gage.

Snowpack began developing on October 25, 2010 and melted on June 30, 2011, persisting for 250 days (Figure B-4). Maximum snow depth was 93.8 inches on March 18, 2011 (Figure B-4). Snowpack as measured at the Deer Park snow course was near average through the months of December and January, before rapidly increasing to 225% of normal by May 1 (Figure B-5). This was due to unusually cold and snowy conditions in the months of April and May. When compared to the historic record, April 1 snowpack in WY 2011 was one of the highest in the last three decades (Figure B-6).

Table B-1. Monthly summary data, Deer Park Ranger 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	39.0	47.6	32.7	2.9 [a]
	November 2010	26.9	34.1	20.8	2.5 [a]
Winter	December 2010	23.5	29.4	19.6	7.1 [a]
	January 2011	28.1	34.1	23.5	4.1 [a]
	February 2011	22.2	30.6	16.1	2.2 [a]
Spring	March 2011	25.3	34.3	18.6	5.3 [a]
	April 2011	25.3	35.3	16.9	3.2 [a]
	May 2011	33.9	42.3	26.6	4.3 [a]
Summer	June 2011	40.6	49.2	33.2	1.4
	July 2011	46.3	55.4	38.3	1.4
	August 2011	50.7	61.2	42.3	0.0
Fall	September 2011	51.1	61.1	43.6	1.5
Water Year		**35.8**	**42.9**	**27.7**	**35.9** [a]

[a] Non-heated rain gauge underestimates precipitation amounts during snow dominated periods.

Table B-2. Air temperature extremes, Deer Park Ranger Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 10, 2011	79.7	November 23, 2010	-6.1
September 11, 2011	78.4	February 25, 2011	-4.8
September 7, 2011	76.4	November 22, 2010	-4.5
September 8, 2011	75.9	November 24, 2010	-1.3
August 21, 2011	73.8	February 26, 2011	1.6

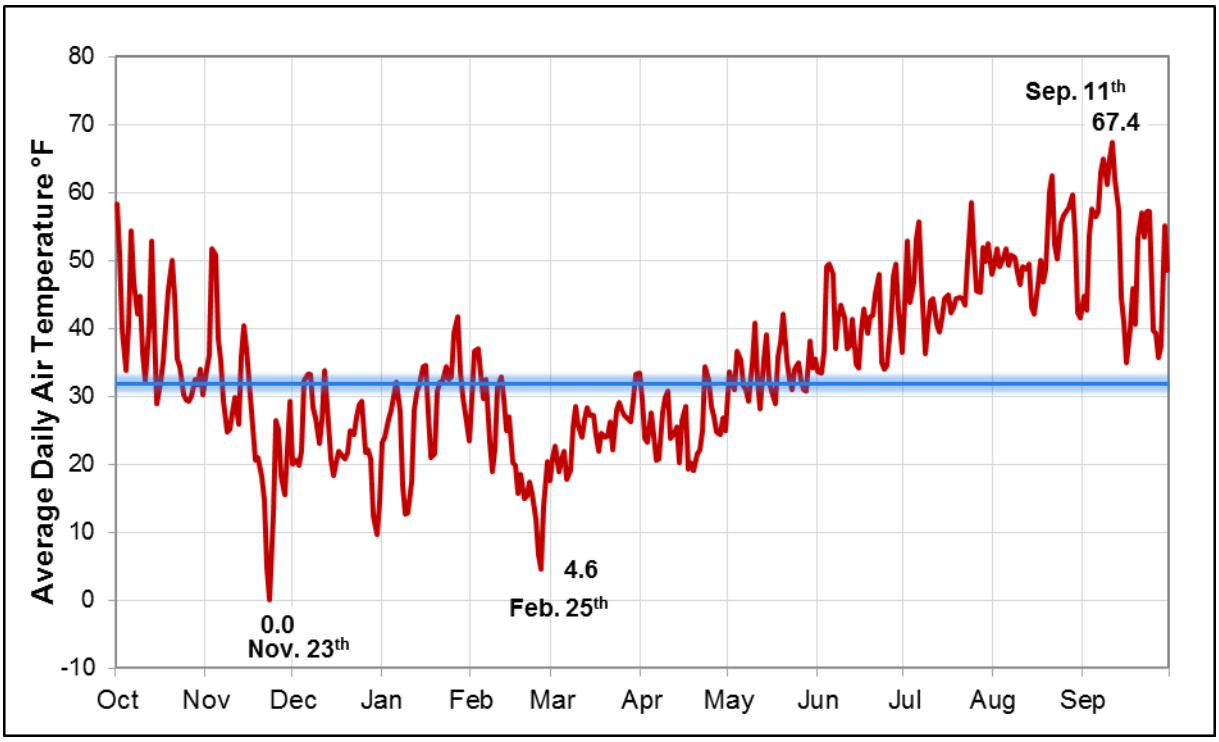

Figure B-1. Daily average air temperature (°F) at Deer Park Ranger Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

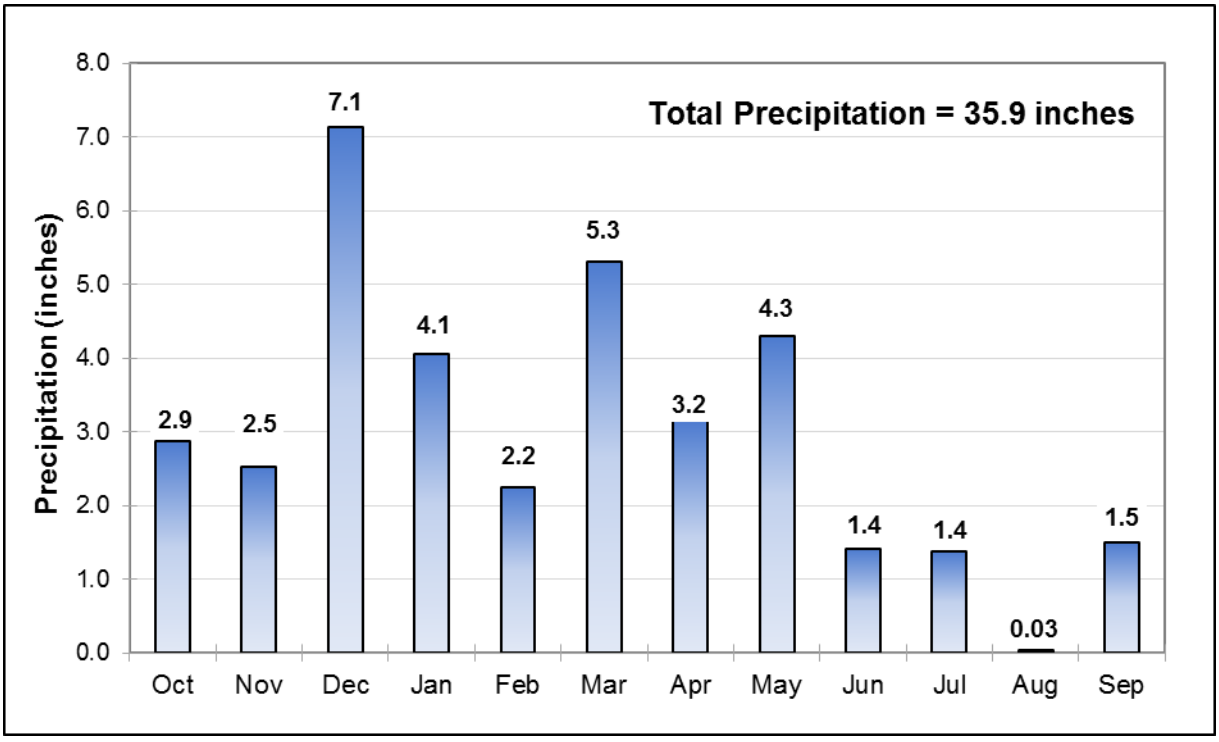

Figure B-2. Monthly precipitation values (inches) at Deer Park Ranger Station, Water Year 2011. The non-heated rain gauge at this station underestimates precipitation amounts during snow dominated periods.

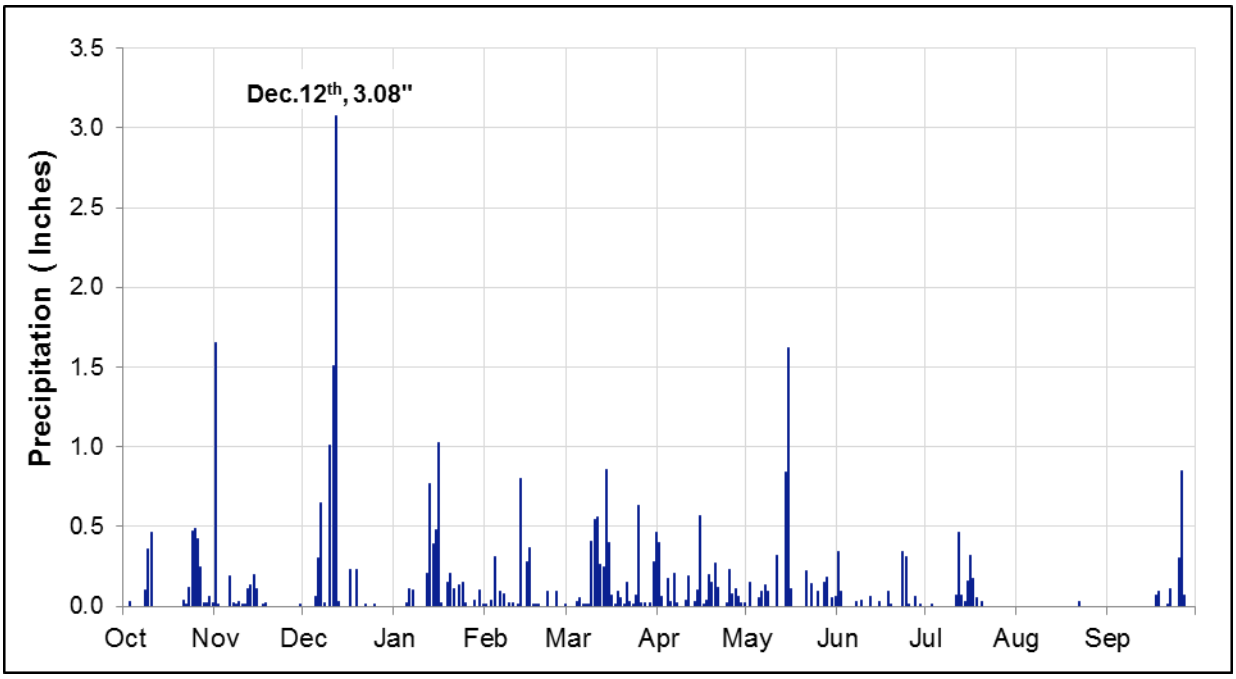

Figure B-3. Daily precipitation (inches) at Deer Park Ranger Station, Water Year 2011.

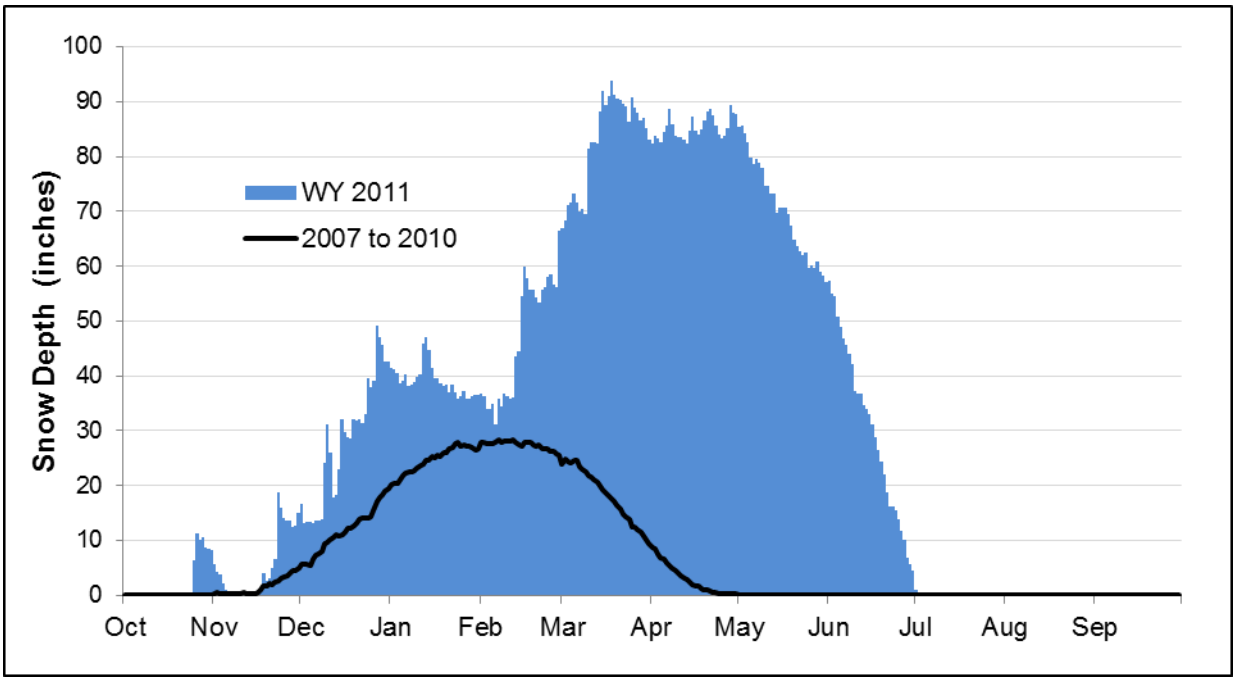

Figure B-4. Daily snow depth (inches) at Deer Park Ranger Station, Water Year 2011.

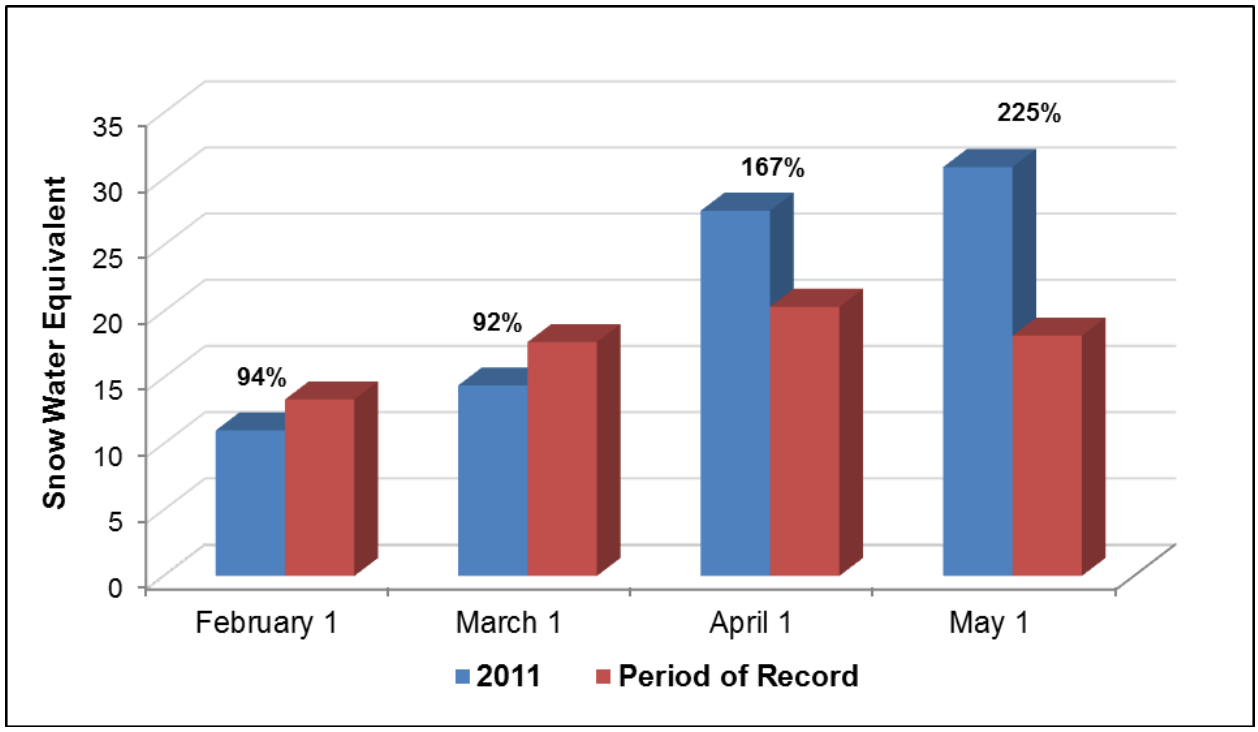

Figure B–5. First of the month snow water equivalent (inches) at Deer Park Snow Course in Water Year 2011, compared with the period of record (1949-2010).

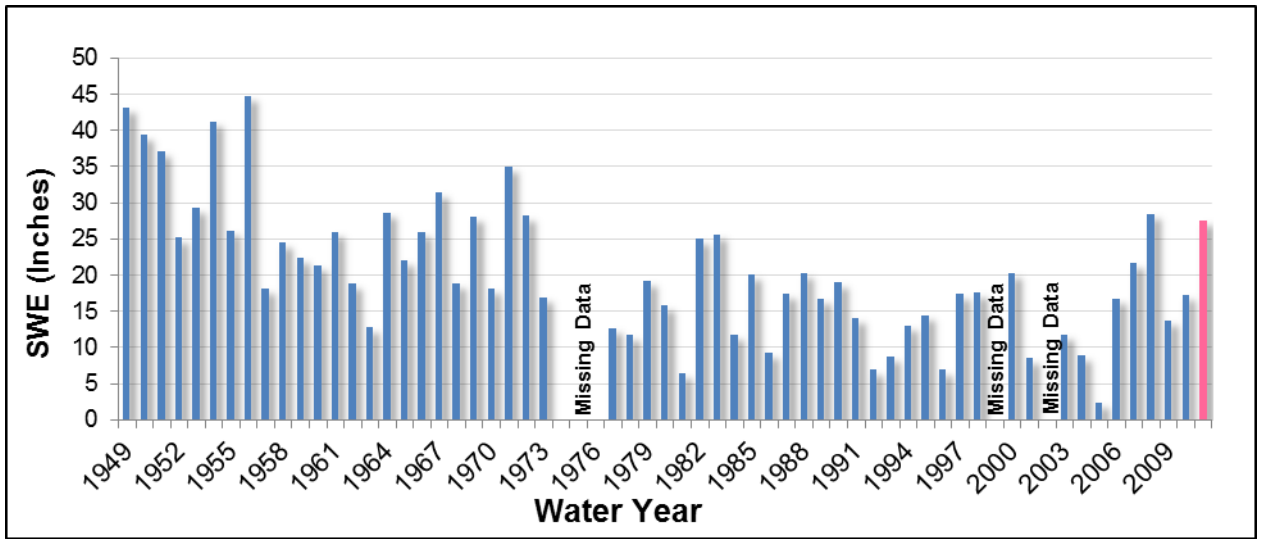

Figure B-6. April 1st snow water equivalent (inches) at the Deer Park Snow Course for the period of record (1949 -2011). Highlighted column indicates Water Year 2011. No data were available for water years 1974-1976, 1999 and 2002.

Appendix C: Deer Park Road - Water Year 2011

Average annual temperature at the Deer Park Road weather station was 42.5°F (Table C-1). Temperatures ranged from an extreme low of 6.6°F during a particularly cold period in late-November, to a high of 86.6°F on September 11 (Table C-2, Figure C-1). The extreme low, recorded on November 23 was the second coldest temperature on record for this site (1998 to 2011). Data from this station reflected the colder than average conditions for most of the year. Only the months of October, January and September were warmer than average. Spring and summer months were 2.4°F below average (Figure C-2).

Precipitation at the Deer Park Road weather station was 44.3 inches, 150% compared to the period of record (1999 to 2010). This was the highest annual precipitation recorded at this site since installation. The wettest month of Water Year 2011 was December, with 9.9 inches (Figure C-3). Five months exceeded average rainfall by over 200%. The months with the greatest positive deviation from average were March and July (Figure C-4). The month of August was particularly dry receiving only 9% of average precipitation. The wettest day was December 12, with 3.0 inches of rain (Figure C-5).

Table C-1. Monthly summary data, Deer Park Road, 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	47.3	53.7	42.3	3.2
	November 2010	35.6	41.3	30.7	4.1
Winter	December 2010	34.7	39.6	31.0	9.9
	January 2011	36.6	42.0	31.9	4.9
	February 2011	31.7	37.0	27.2	3.2
Spring	March 2011	35.2	40.3	31.2	6.9
	April 2011	34.9	40.8	30.4	3.1
	May 2011	42.3	47.6	37.6	5.3
Summer	June 2011	49.1	54.8	44.2	0.8
	July 2011	53.8	59.9	49.1	1.9
	August 2011	58.4	65.5	52.8	0.1
Fall	September 2011	59.2	67.4	53.3	1.1
Water Year		**42.5**	**67.4**	**27.2**	**44.3**

Table C-2. Air temperature extremes, Deer Park Road, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 11, 2011	86.6	November 23, 2010	6.6
September 8, 2011	81.3	November 22, 2010	8.0
September 10, 2011	81.1	February 25, 2011	10.3
September 9, 2011	81.0	November 24, 2010	10.7
August 20, 2011	78.2	February 24, 2011	14.4

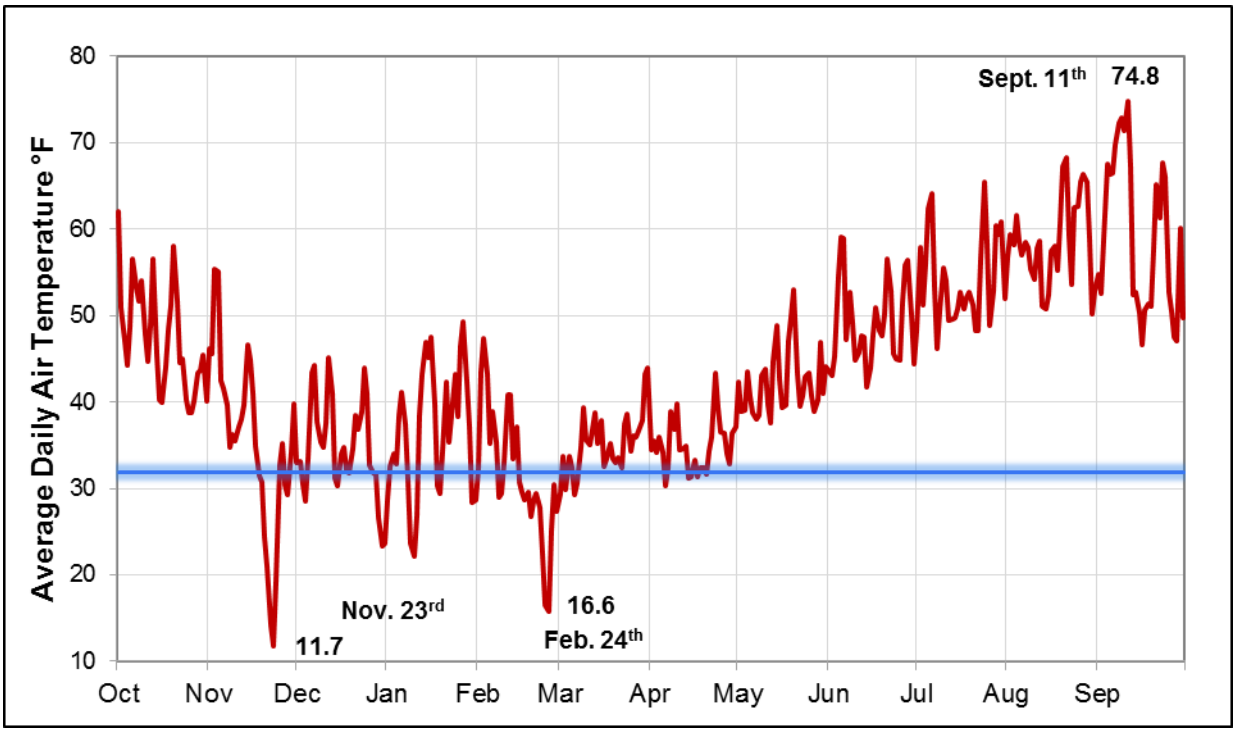

Figure C-1. Daily average air temperature (°F) at Deer Park Road, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

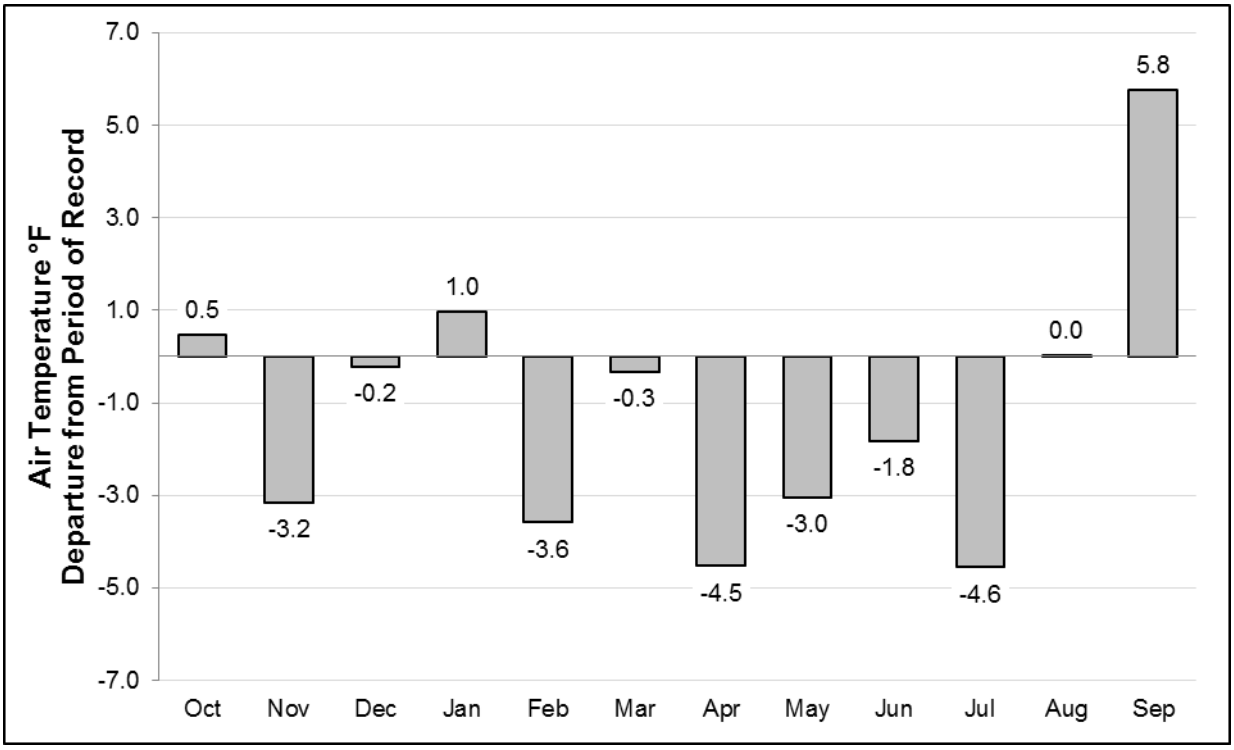

Figure C-2. Comparison of average monthly temperature (°F) for Deer Park Road in Water Year 2011 against monthly averages for the period of record (1999-2010).

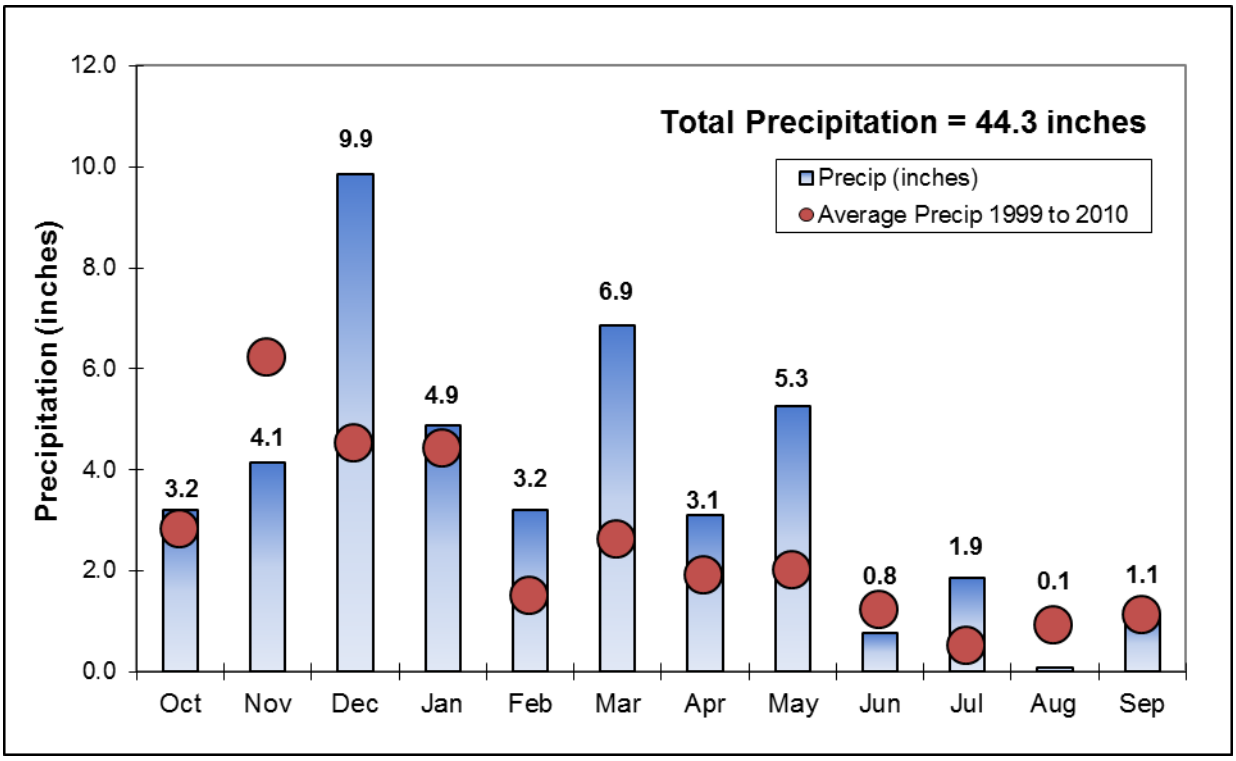

Figure C-3. Monthly precipitation values (inches) at Deer Park Road, Water Year 2011 compared to the monthly averages for the period of record (1999-2010).

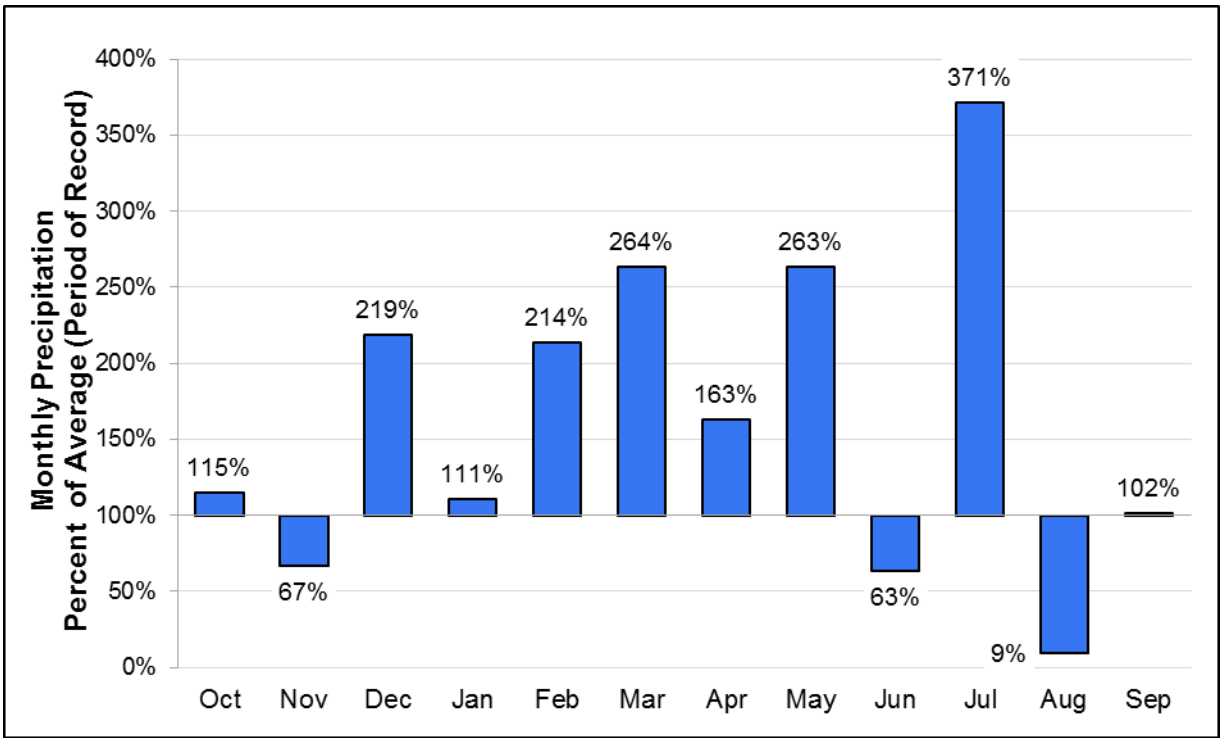

Figure C-4. Percent of average precipitation for the period of record (1999-2010) at Deer Park Road in Water Year 2011.

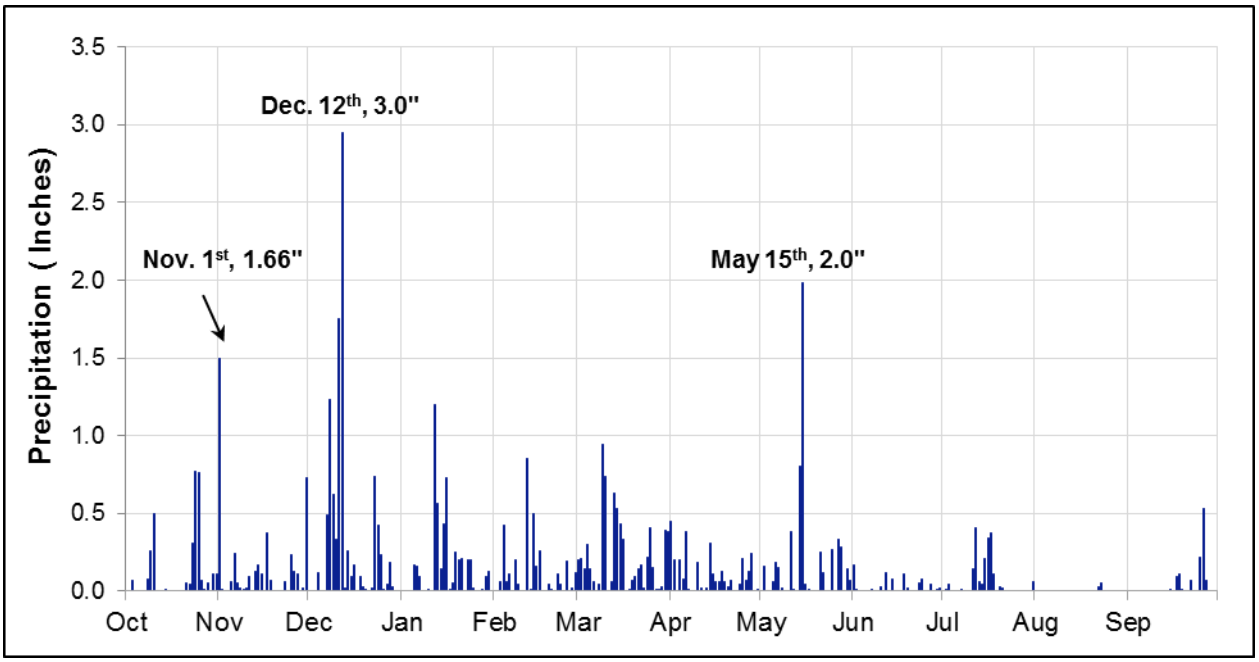

Figure C-5. Daily precipitation (inches) at Deer Park Road, Water Year 2011.

Appendix D: Hayes River Guard Station - Water Year 2011

Average annual temperature at the Hayes River Guard Station was 42.5°F (Table D-1). Temperatures ranged from an extreme low of 9.5°F on November 24 to a high of 84.0°F on July 6 (Table D-2). This is the only park weather station during the summer of 2011 to record its highest extreme temperatures during July and August. All other sites recorded the highest summer temperatures during the first two weeks of September. This may indicate a problem with the temperature sensor or a unique siting characteristic of this weather station. Figure D-1 compares Hayes River air temperature a nearby station on Deer Park Road. While high temperature data compares closely during the months of April to August, high temperatures in winter months and early September show a pattern of lower temperature signatures. This may be associated with shading during winter months, the settling of cold air in this deep river valley or a possible issue with the sensor.

Three prolonged periods of below freezing temperatures were recorded at Hayes Guard Station, the first in the latter half of November, the second covers most December to early January and the final, a solid period from mid-February to mid-March (Figure D-2).

The station received 82.0 inches of total precipitation (Table D-1). The wettest month was December with 17.3 inches of precipitation (Figure D-3). The highest daily rainfall was 3.4 inches, occurring on October 25 and on December 12 (D-4). Precipitation totals for this site may be underestimated, as much of the winter's precipitation fell as snow and this site relies on an unheated tipping bucket.

Table D-1. Monthly summary data, Hayes River Guard 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	43.1	49.0	38.2	10.2
	November 2010	34.7	37.9	31.5	7.7
Winter	December 2010	32.5	34.4	30.8	17.3
	January 2011	32.3	34.9	29.8	9.0
	February 2011	31.5	34.8	28.2	5.9
Spring	March 2011	34.1	38.0	31.3	15.2
	April 2011	35.9	43.5	30.8	7.5
	May 2011	44.5	54.9	37.1	3.8
Summer	June 2011	52.8	65.6	43.3	0.2
	July 2011	56.6	70.2	47.0	1.1
	August 2011	58.2	72.7	48.3	0.4
Fall	September 2011	54.0	65.0	45.8	3.7
Water Year		**42.5**	**50.1**	**36.8**	**82.0**

Table D-2. Air temperature extremes, Hayes River Guard Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
July 6, 2011	84.0	November 24, 2010	9.5
July 24, 2011	82.3	November 23, 2010	9.7
August 21, 2011	81.6	February 26, 2011	11.0
July 2, 2011	81.1	February 25, 2011	12.8
August 20, 2011	80.9	November 22, 2010	14.5

Figure D-1. Daily average air temperature (°F) at Hayes River Guard Station (Red) compared to daily average air temperature at Deer Park Road (Green), Water Year 2011.

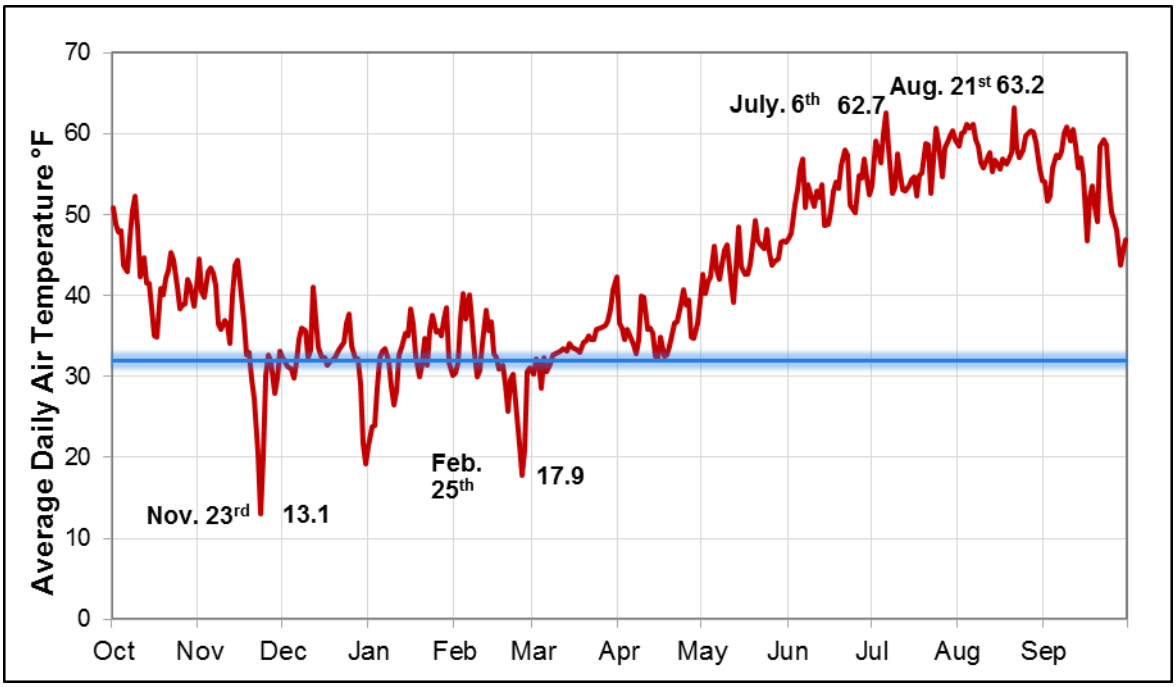

Figure D-2. Daily average air temperature (°F) at Hayes River Guard Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

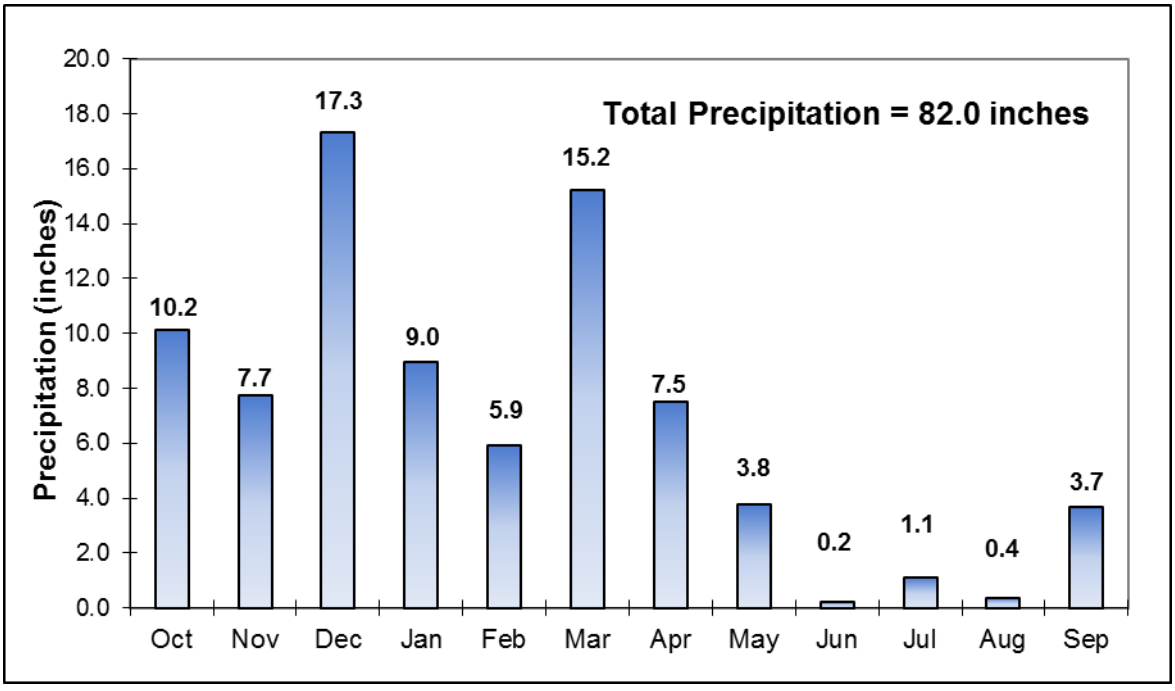

Figure D-3. Monthly precipitation values at Hayes River Guard Station, Water Year 2011.

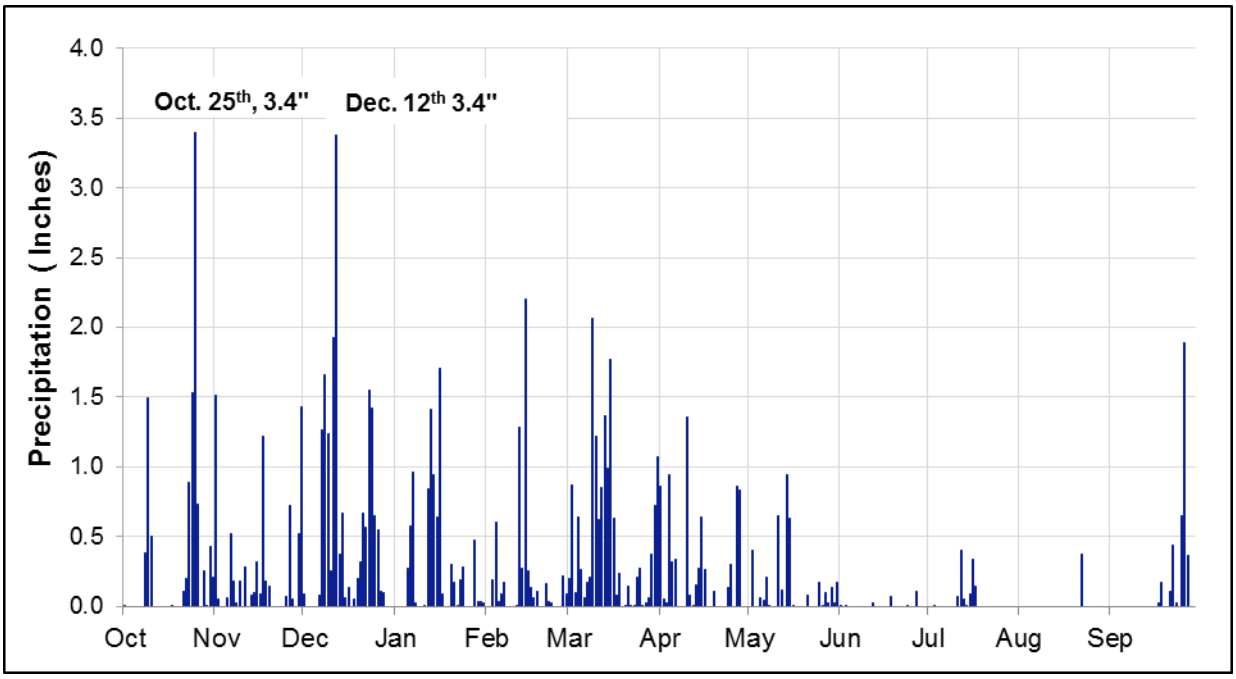

Figure D-4. Daily precipitation (inches) at Hayes River Guard Station, Water Year 2011.

Appendix E: Hoh Rainforest - Water Year 2011

Average annual temperature at the Hoh Rainforest weather station was 47.6°F (Table E-1). Temperatures ranged from an extreme low of 16.6°F on November 23, to a high of 86.2°F on September 7, 2010 (Table E-2). Data from this site reflected the unusually cool conditions throughout the year. Most months were well below the average, with April the most extreme example at 5.3°F below average (Figure E-1). The winter, spring and summer seasons were 1.6°, 3.1° and 1.7° below average respectively. These unusually cool conditions are also reflected in daily temperatures; there were three prolonged periods with below freezing temperatures (Figure E-2). The only month with above average temperatures was September (Figure E-1).

The Hoh Rainforest received 132.4 inches of rainfall in Water Year 2011 (Figure E-3), 119% of the annual average. Fall months were slightly drier than average (92%), while winter and spring months were well above average (128% and 152% respectively). The month of July experienced the greatest deviation, with 193% of average rainfall (Figure E-4). August was unusually dry (35% of average), and these conditions continued through mid-September. During a 45 day period, little appreciable precipitation fell and nearly all precipitation measured in August occurred on a single day when .83 inches of rain fell. The heaviest precipitation event of the year occurred on January 16, with 3.7 inches (Figure E-5).

Table E-1. Monthly summary data, Hoh Rainforest, 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	47.6	58.5	39.9	12.7
	November 2010	39.0	45.3	34.4	13.4
Winter	December 2010	38.1	43.8	34.3	23.4
	January 2011	37.9	43.2	34.1	18.2
	February 2011	36.3	43.2	31.8	12.8
Spring	March 2011	40.1	47.7	34.5	21.4
	April 2011	40.0	48.1	33.2	12.4
	May 2011	46.9	55.7	38.7	7.4
Summer	June 2011	53.4	61.8	45.8	2.1
	July 2011	57.1	67.6	47.4	2.7
	August 2011	59.2	70.5	49.7	0.9
Fall	September 2011	58.2	70.6	48.8	5.0
Water Year		**46.2**	**54.7**	**39.4**	**132.4**

Table E-2. Air temperature extremes, Hoh Rainforest, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 7, 2011	86.2	November 23, 2010	16.6
September 11, 2011	85.6	February 25, 2011	18.2
September 10, 2011	84.4	February 26, 2011	18.9
August 20, 2011	84.1	November 24, 2010	20.2
September 8, 2011	82.6	December 31, 2010	20.3

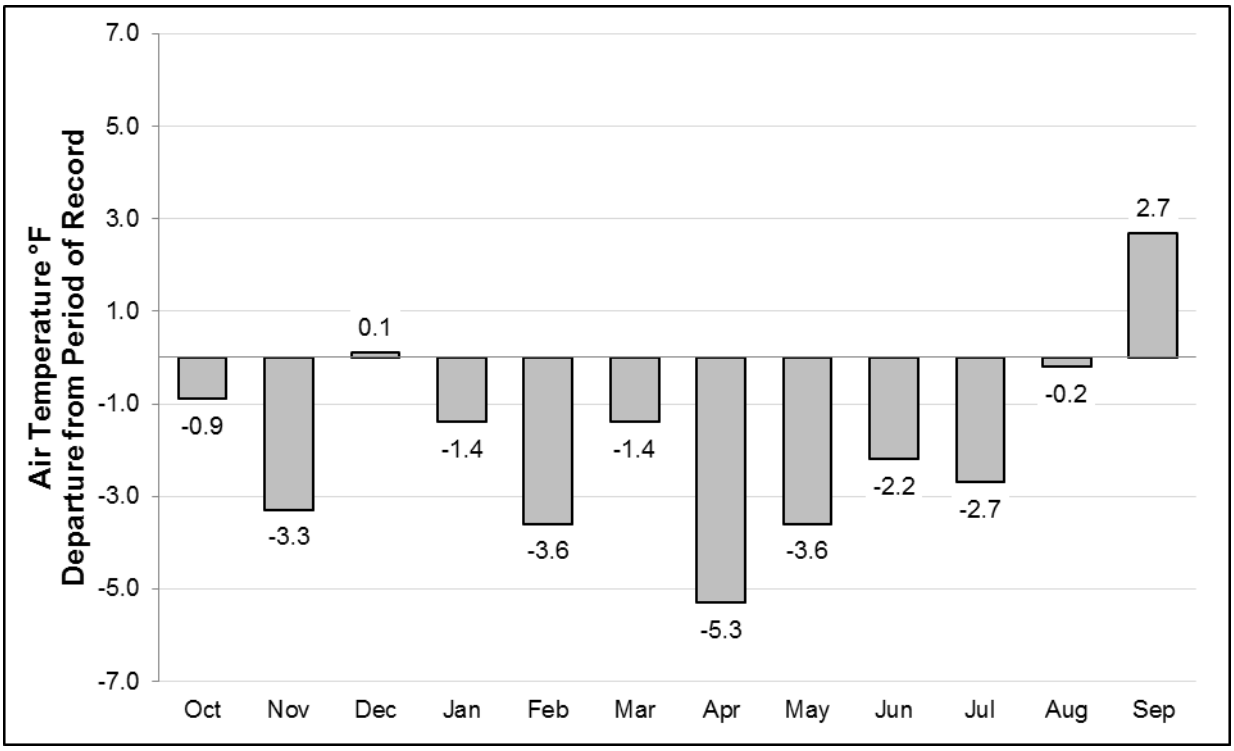

Figure E-1. Comparison of average monthly temperature (°F) for the Hoh Rainforest in Water Year 2011 against monthly averages for the period of record (1999-2010).

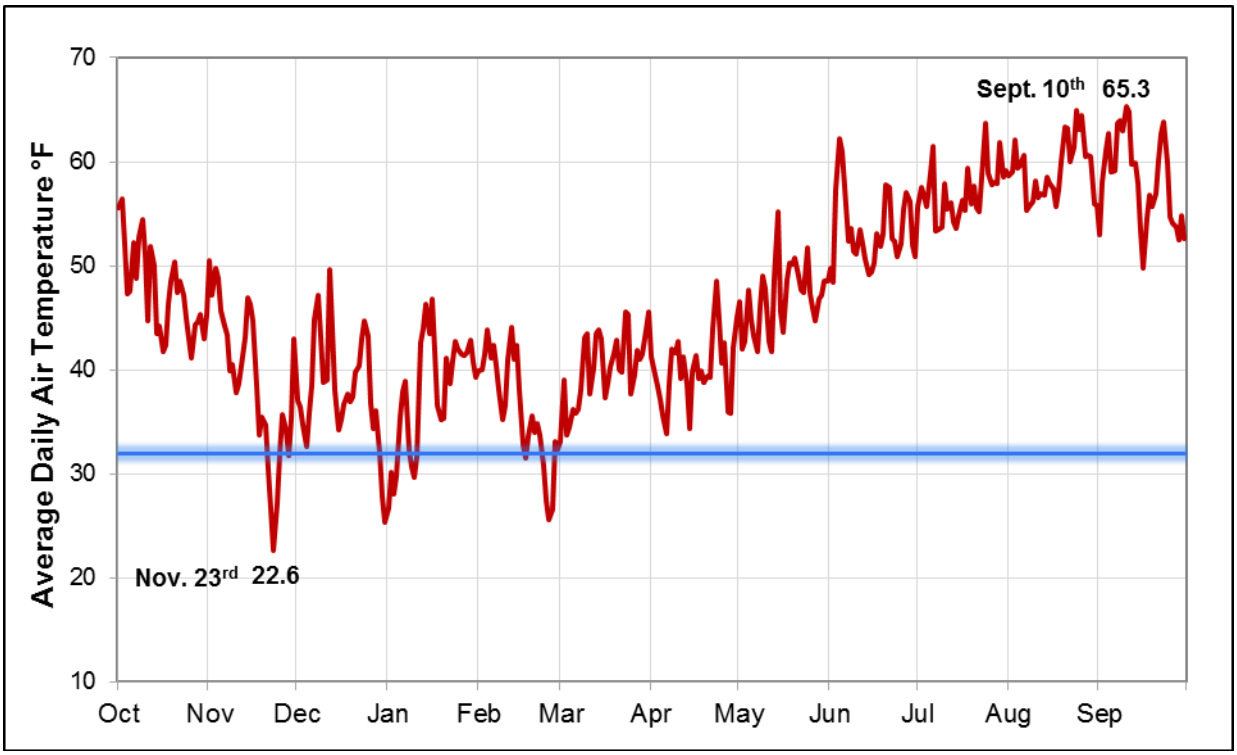

Figure E-2. Daily average air temperature (°F) at the Hoh Rainforest, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

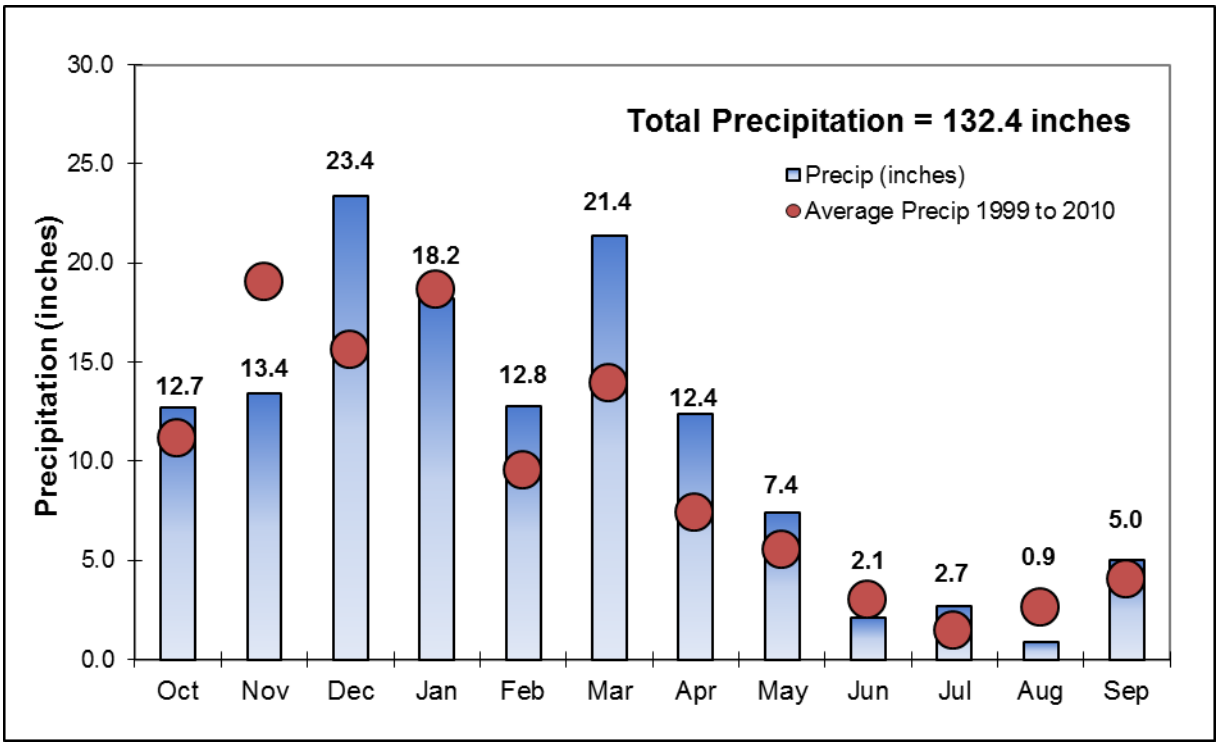

Figure E-3. Monthly precipitation values (inches) at the Hoh Rainforest, Water Year 2011 compared to the monthly averages for the period of record (1999-2010).

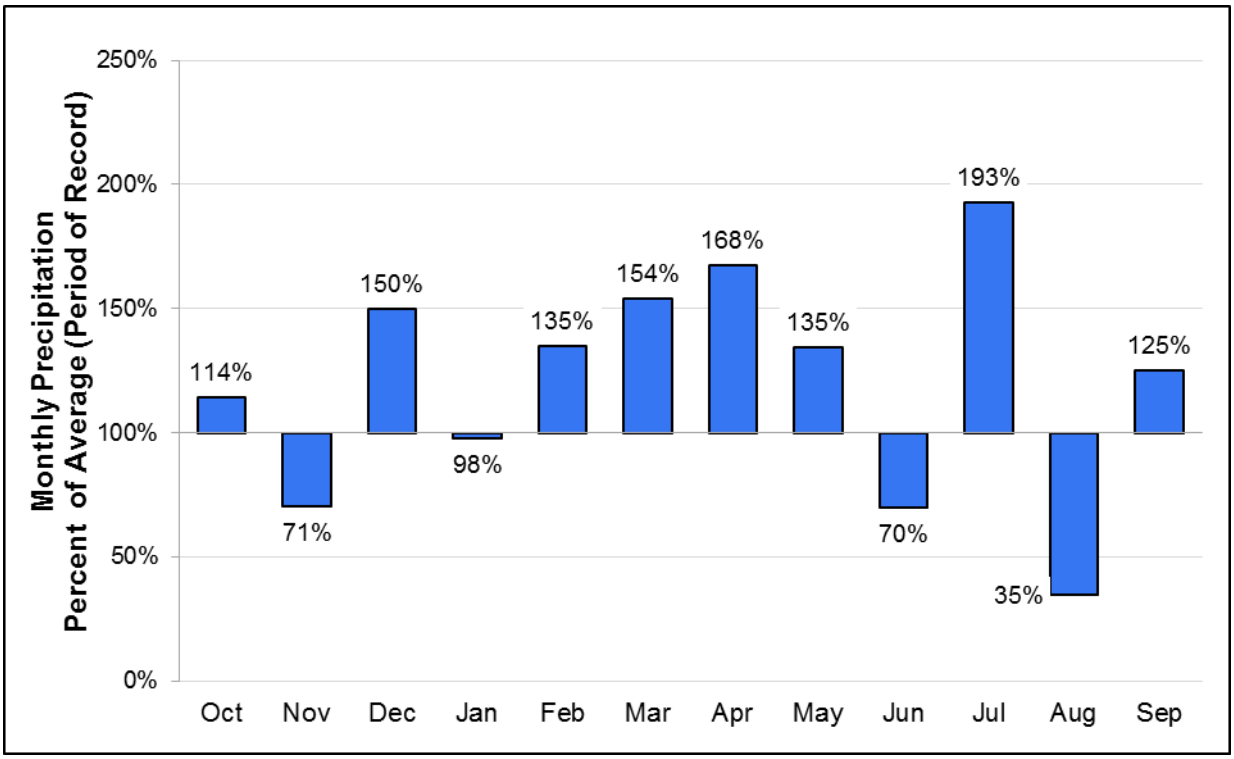

Figure E-4. Percent of average precipitation for the period of record (1999-2010) at the Hoh Rainforest in Water Year 2011.

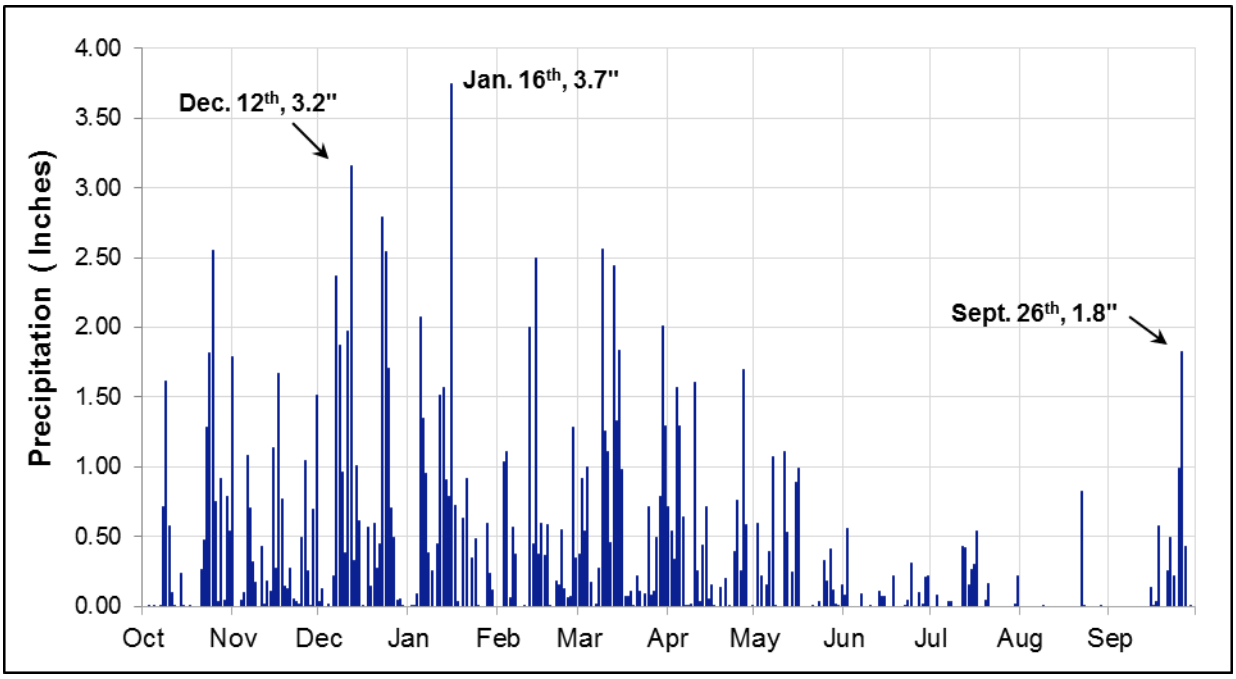

Figure E-5. Daily precipitation (inches) at the Hoh Rainforest, Water Year 2011.

Appendix F: Kalaloch Ranger Station - Water Year 2011

Temperature data from the Kalaloch Ranger Station are incomplete for this water year, due to the failure of a temperature sensor (Table F-1). The failure likely relates to high humidity conditions which have plagued the Vaisala HMP 45C temperature and relative humidity probes installed at many NPS weather stations. This probe was replaced with a Campbell Scientific 109 temperature probe on December 20, 2010. Minimum low temperature likely occurred in late November of 2010 when the original sensor was inoperable. A maximum summer temperature of 72.6ºF occurred on September 11 (Table F-2). The warmest average temperature of the year was 62.8 ºF on September 24, 2011 (Figure F-1)

The Kalaloch Ranger Station received 114.3 inches of rainfall in Water Year 2011 (Figure F-2), 115% of average. Winter and spring seasons were unusually wet, at 113% and 132% respectively. March was the wettest month with 18.3 inches, a 156% departure from average (Figure F-3). Summer months were slightly drier than normal (87%) (Figure F-3). The highest rainfall amount occurred on March 30, a total of 2.7 inches (Figure F-4). While this significant spring event was evidenced across the park, it was most obvious in the form of precipitation extremes at the coastal stations (Kalaloch, Ozette and Quillayute).

Table F-1. Monthly summary data, Kalaloch Ranger 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	---- [1]	---- [1]	---- [1]	11.9
	November 2010	---- [1]	---- [1]	---- [1]	12.5
Winter	December 2010	---- [1]	---- [1]	---- [1]	16.6
	January 2011	42.1	46.1	38.5	17.8
	February 2011	39.5	44.4	35.3	9.6
Spring	March 2011	43.7	49.1	39.1	18.3
	April 2011	43.9	50.7	37.8	9.0
	May 2011	49.1	55.9	42.6	6.8
Summer	June 2011	55.2	60.9	50.0	2.1
	July 2011	57.0	62.8	51.5	2.5
	August 2011	57.2	63.4	51.4	2.1
Fall	September 2011	55.9	62.5	50.3	5.2
Water Year		---- [1]	---- [1]	---- [1]	**114.3**

Table F-2. Air temperature extremes, Kalaloch Ranger Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 11, 2011	72.6	Not Available [1]	
August 24, 2011	68.8		
June 4, 2011	68.5		
June 5, 2011	68.1		
September 24, 2011	66.9		

[1] A minimum temperature was not available due to the failure of the temperature sensor.

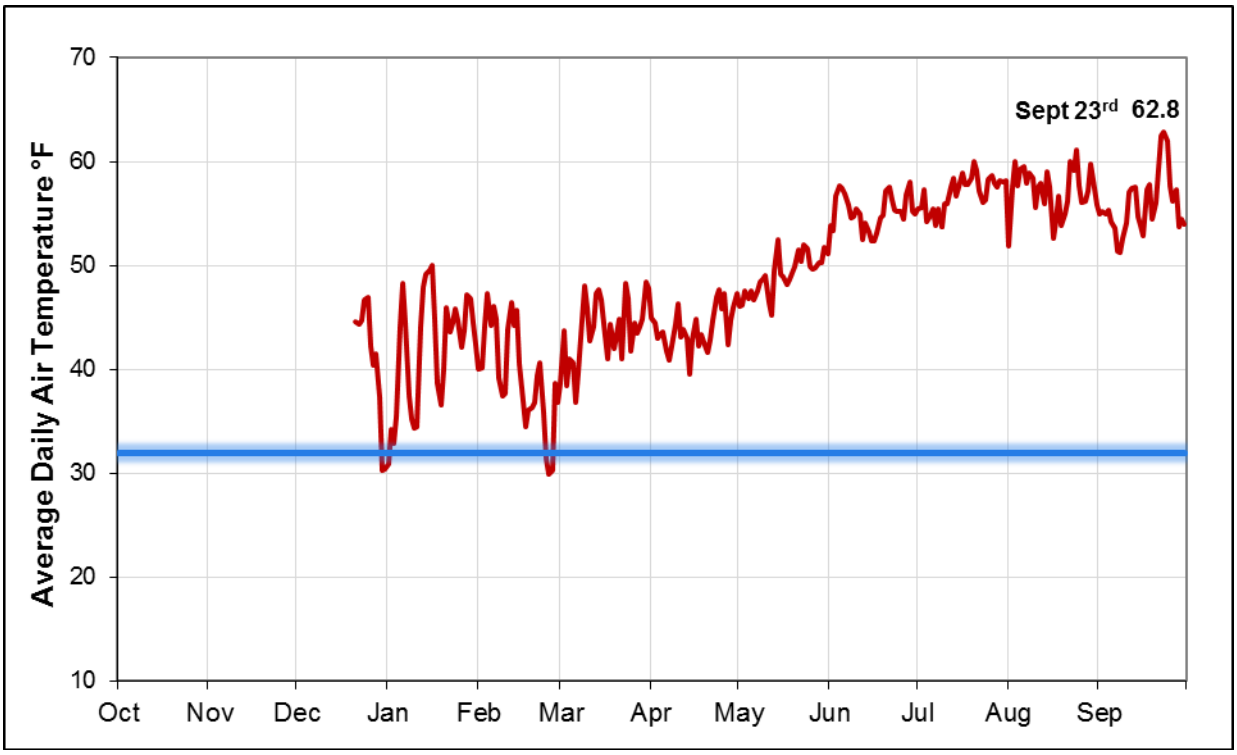

Figure F-1. Daily average air temperature (°F) at the Kalaloch Ranger Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

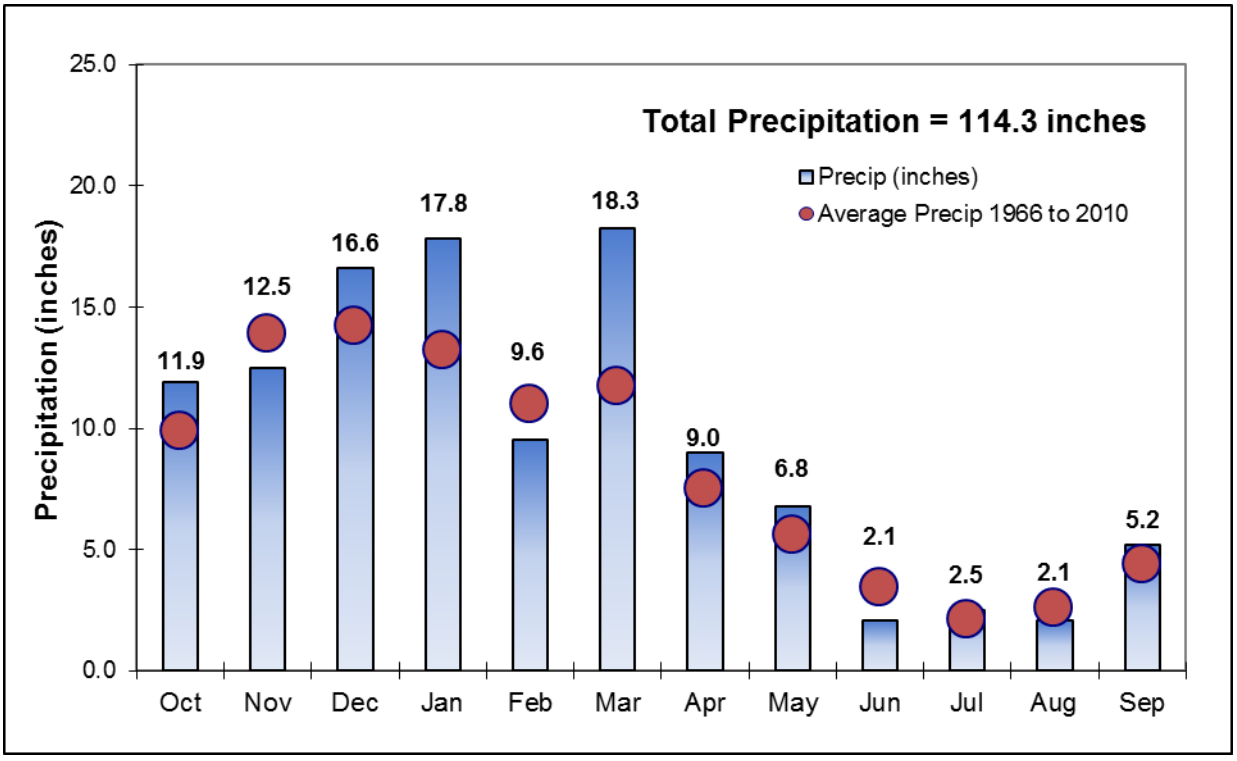

Figure F-2. Monthly precipitation values (inches) at the Kalaloch Ranger Station, Water Year 2011 compared to the monthly averages for the period of record (1966-2010).

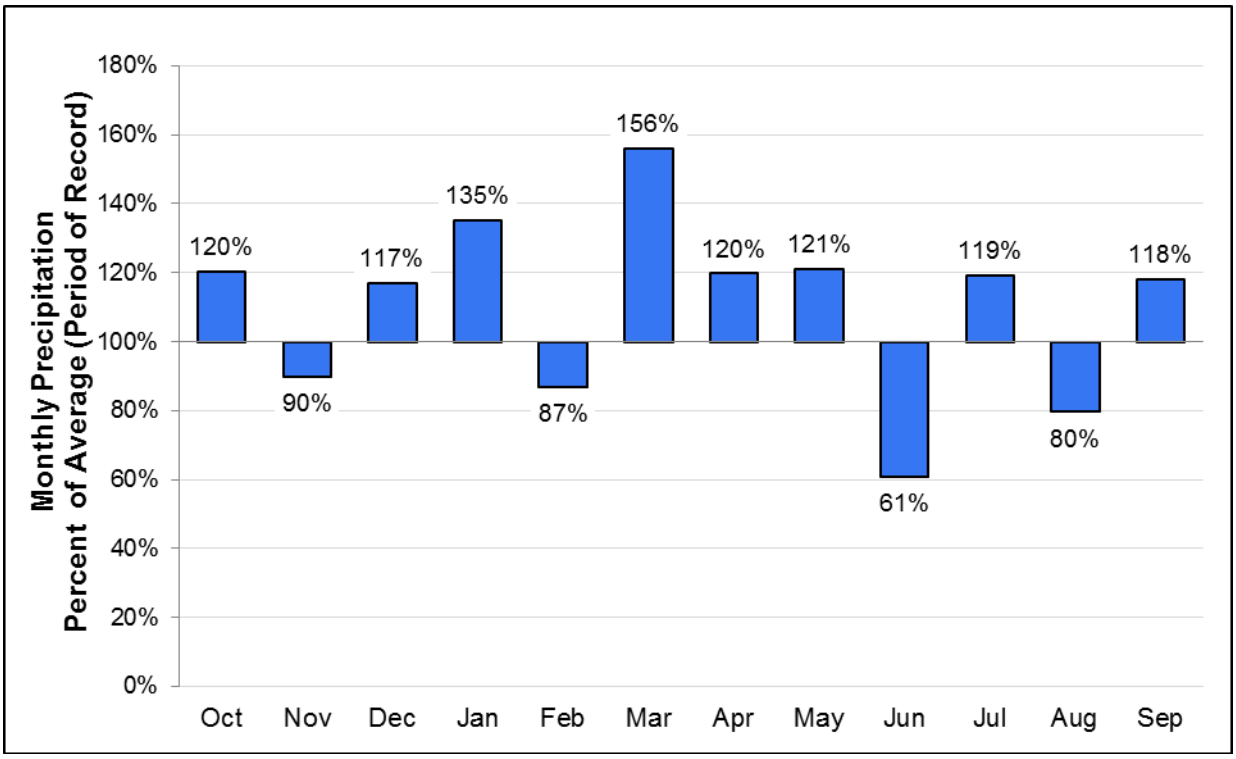

Figure F-3. Percent departure of precipitation from the period of record (1966-2010) at the Kalaloch Ranger Station in Water Year 2011.

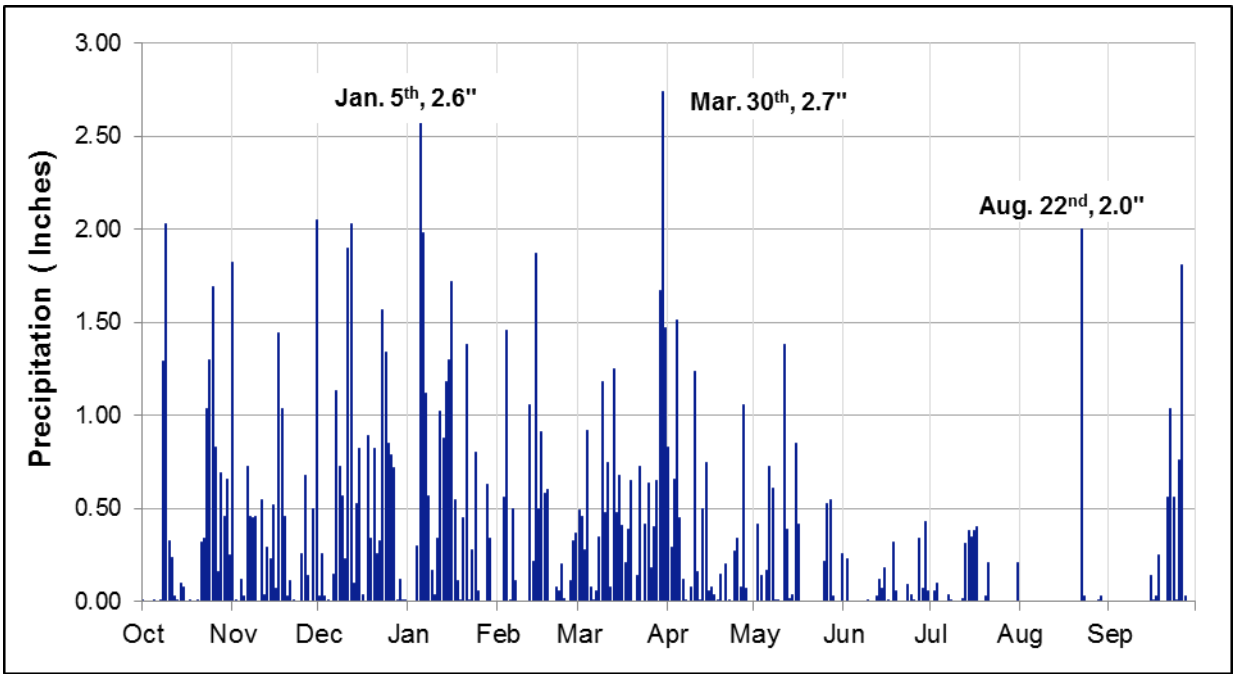

Figure F-4. Daily precipitation (inches) at the Kalaloch Ranger Station, Water Year 2011.

Appendix G: Ozette Ranger Station - Water Year 2011

Average annual temperature at the Ozette Ranger Station was 46.2°F (Table G-1). Temperatures ranged from a low of 19.9°F in mid-November, to a high of 82.9°F in early September (Table G-2). Temperature departure (from the relatively short period of record) reflects the colder than average conditions this year, with all months below average with the exception of September (Figure G-1). Late winter and early spring months showed the most extreme negative departures. Several days in both late December and February were below freezing (Figure G-2).

It was a wetter than average year at Ozette, with annual precipitation 126% of average and eight of twelve months receiving above average precipitation (Figures G-3 and G-4). The exceptions were summer months, especially June with 55% of average rainfall (Figure G-4). The greatest positive departure was March, with 15.4 inches of rainfall (171% of the average). The single heaviest day of rainfall was on November 17 with 4.2 inches of precipitation (Figure G-5).

Data logger memory problems led to a small loss of data in late November. Memory issues were mitigated by replacing the datalogger in late April of 2011.

Table G-1. Monthly summary data, Ozette Ranger 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	50.5	57.9	43.9	9.9
	November 2010	42.5[a]	50.9[a]	41.7[a]	15.8[a]
Winter	December 2010	38.6	45.6	38.7	15.9
	January 2011	37.5	45.3	37.8	16.0
	February 2011	34.2	44.0	33.7	8.6
Spring	March 2011	37.8	48.6	38.0	15.4
	April 2011	38.8	49.8	37.4	7.1
	May 2011	48.6	55.4	41.8	5.0
Summer	June 2011	54.8	60.8	49.4	1.6
	July 2011	56.7	62.7	50.4	2.1
	August 2011	58.1	65.0	51.8	2.3
Fall	September 2011	56.9	65.8	49.7	7.0
Water Year		**46.2**[a]	**54.3**[a]	**42.9**[a]	**106.6**[a]

[a] Ten days of missing data in November were replaced with values from the Quillayute Field COOP.

Table G-2. Air temperature extremes, Ozette Ranger Station, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 7, 2011	82.9	November 24, 2010	19.9 [a]
September 3, 2011	80.3	November 23, 2010	21.0 [a]
September 11, 2011	78.6	February 26, 2011	22.4
June 4, 2011	77.2	February 25, 2011	23.9
August 20, 2011	76.9	December 30, 2010	24.8

[a] Missing daily data were replaced with values from the nearby Quillayute Field COOP.

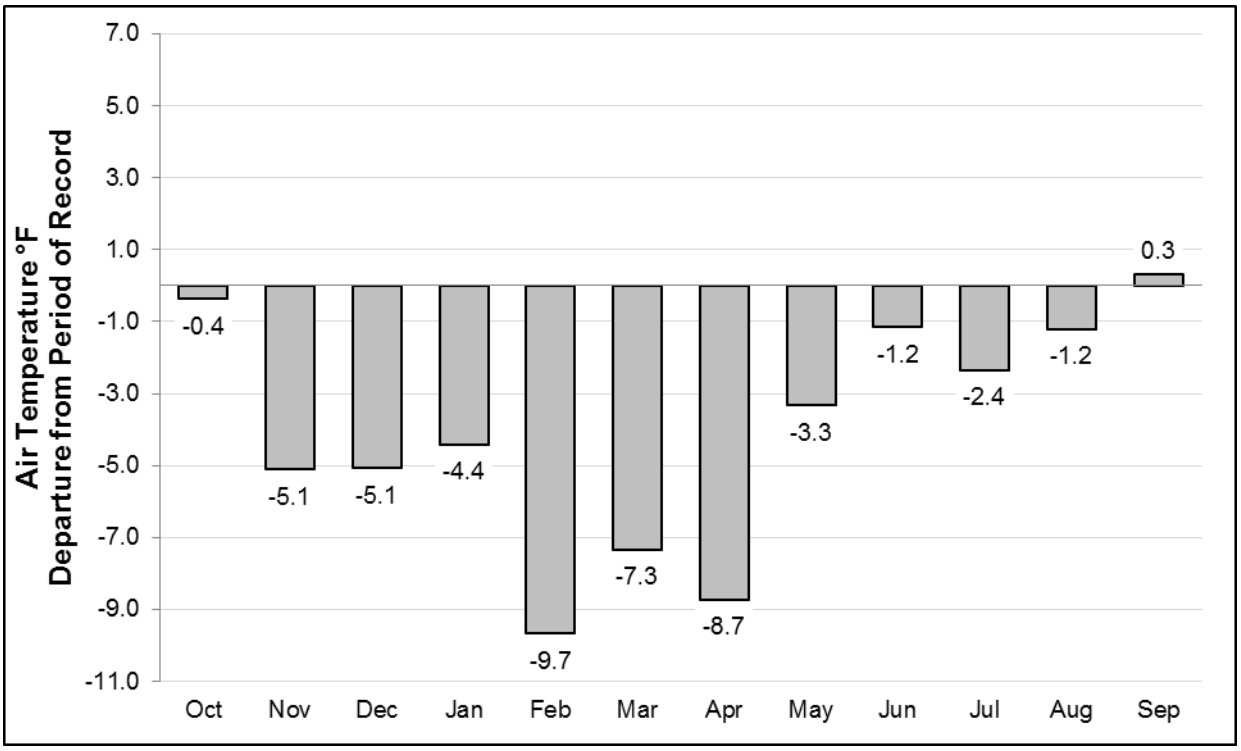

Figure G-1. Comparison of average monthly temperature (°F) for the Ozette Ranger Station in Water Year 2011 against monthly averages for the period of record (2004-2010).

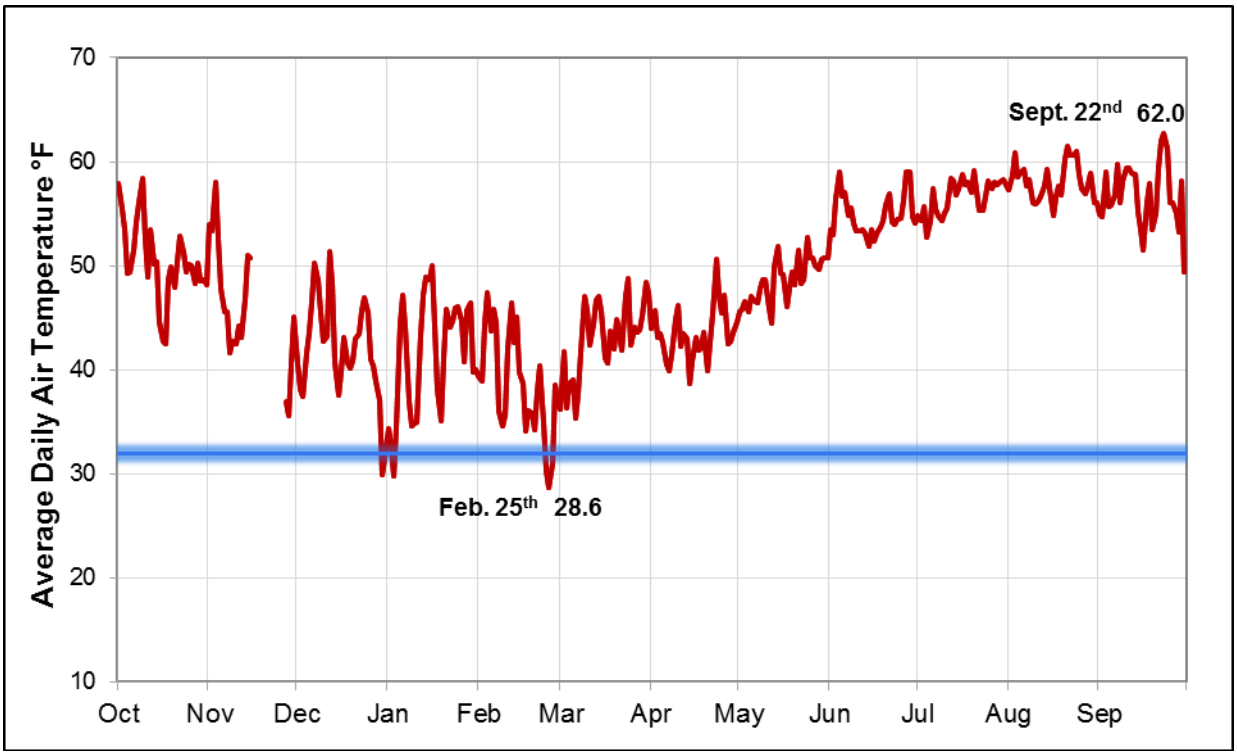

Figure G-2. Daily average air temperature (°F) at the Ozette Ranger Station, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

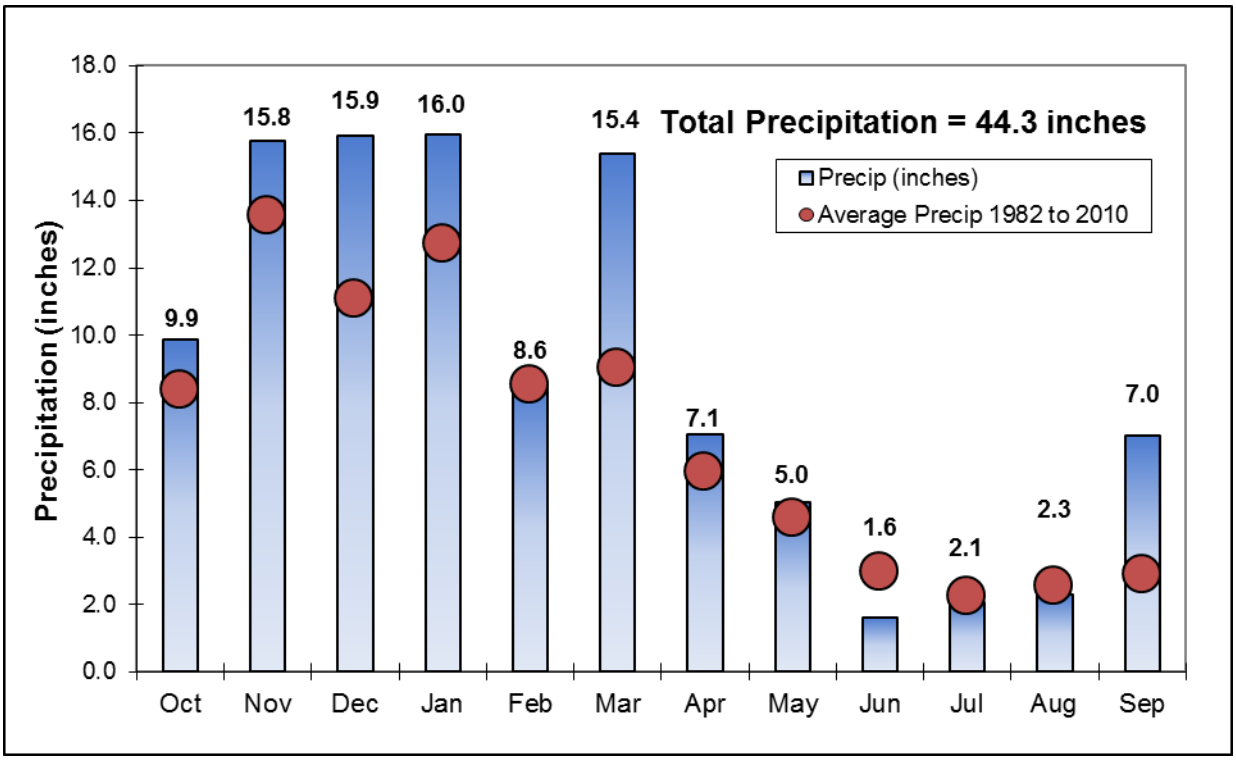

Figure G-3. Monthly precipitation values (inches) at the Ozette Ranger Station, Water Year 2011 compared to the monthly averages for the period of record (1982-2010).

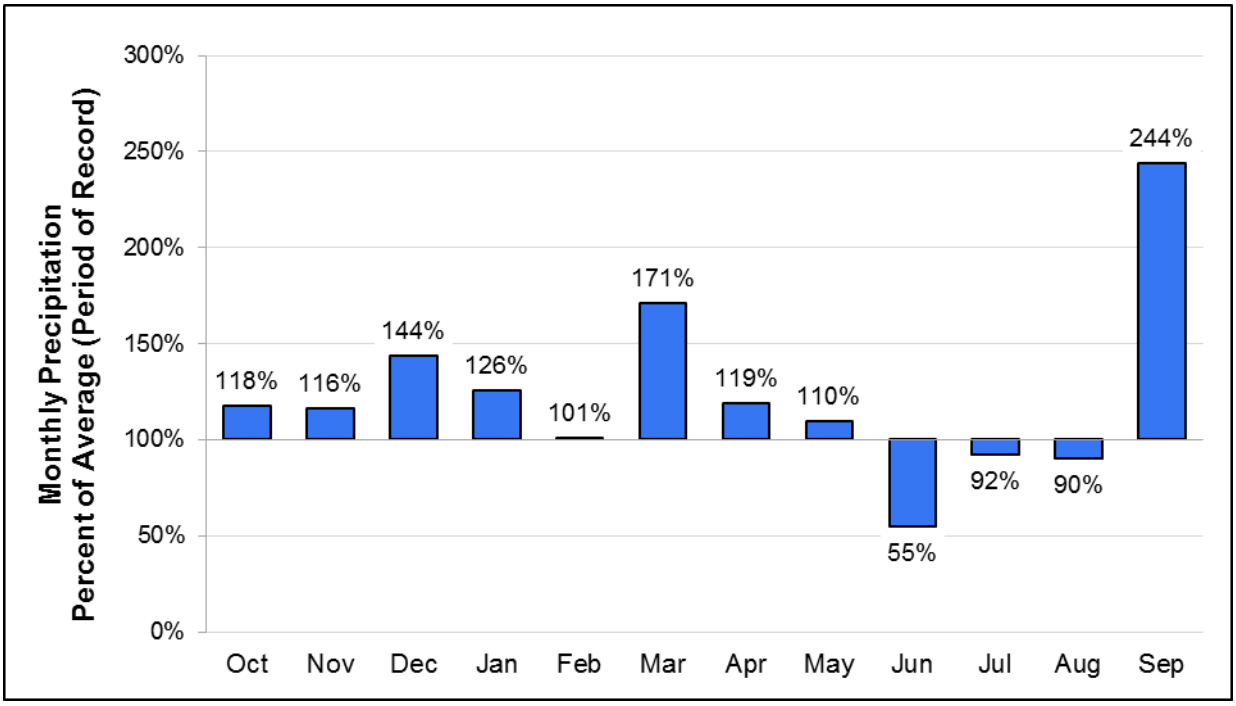

Figure G-4. Percent departure from the period of record (1982-2010) for precipitation at the Ozette Ranger Station in Water Year 2011.

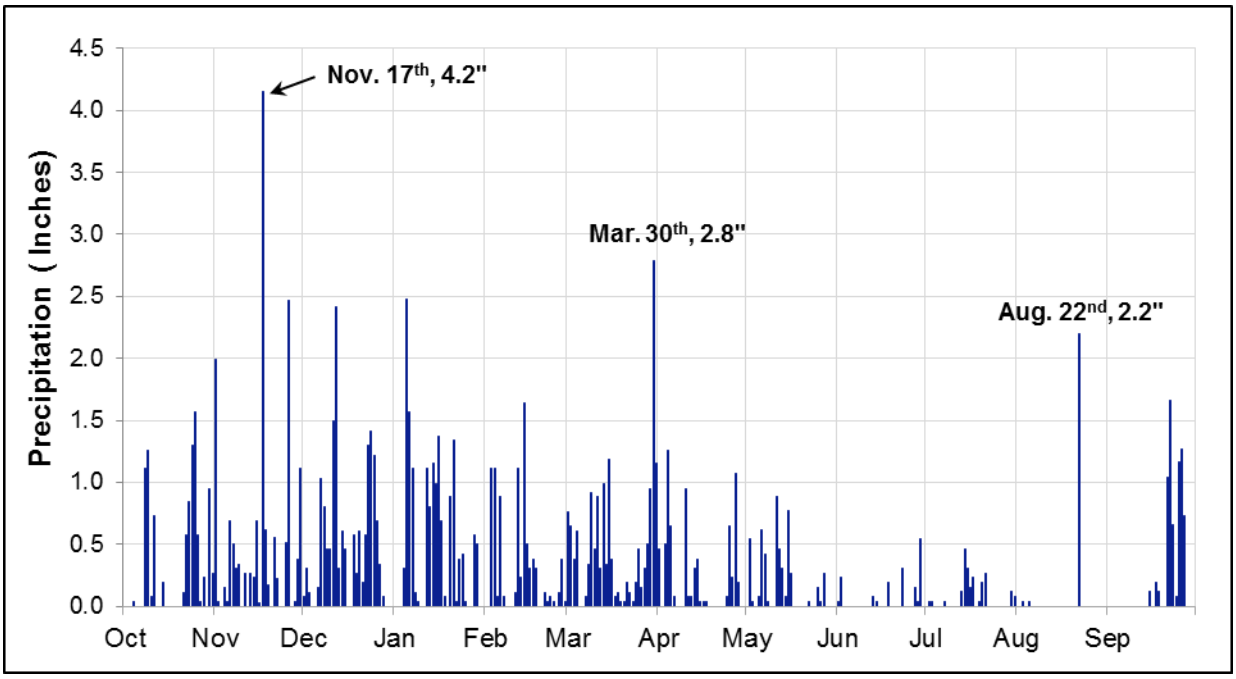

Figure G-5. Daily precipitation (inches) at the Ozette Ranger Station, Water Year 2011.

Appendix H: Quinault Rainforest - Water Year 2011

Average annual temperature at the Quinault Rainforest weather station was 47.7°F (Table H-1). Temperatures ranged from an extreme low of 18.1°F in late November, to a high of 89.4°F on September 11 (Table H-2). Data from this site reflected the colder than average conditions in spring and early summer. The coldest month during this period was April, at 4.9°F below average (Figure H-1). Three distinct periods of below freezing temperatures were recorded in late November, December and February (Figure H-2).

The Quinault Rainforest received 163.2 inches of rainfall in Water Year 2011, 135% greater than average (Figure H-3). Five months were >165% above average, the most extreme being March (201% of average) and September (231% of average) (Figure H-4). The greatest period of rain occurred during several major storms between December 6 and 12, when 16.7 inches of rain fell. The single heaviest day of rainfall was during this event on December 12, with 5.8 inches (Figure H-5).

Table H-1. Monthly summary data, Quinault Rainforest, 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	49.9	58.6	44.0	18.5
	November 2010	40.4	44.7	36.5	16.8
Winter	December 2010	38.6	41.8	35.6	32.8
	January 2011	38.4	42.2	35.1	20.0
	February 2011	36.7	42.3	33.1	14.8
Spring	March 2011	40.5	46.9	36.2	28.8
	April 2011	41.2	49.3	34.3	12.5
	May 2011	49.6	58.4	42.0	6.7
Summer	June 2011	56.4	65.8	48.1	1.0
	July 2011	60.3	71.2	50.8	2.0
	August 2011	61.4	74.2	52.0	1.3
Fall	September 2011	59.4	72.0	50.3	7.9
Water Year		**47.7**	**55.6**	**41.5**	**163.0**

Table H-2. Air temperature extremes, Quinault Rainforest, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 11, 2011	89.4	November 23, 2010	18.1
September 10, 2011	88.2	November 24, 2010	19.9
August 20, 2011	88.2	November 22, 2010	22.0
September 7, 2011	87.7	February 26, 2011	22.3
September 8, 2011	86.3	December 31, 2010	22.5

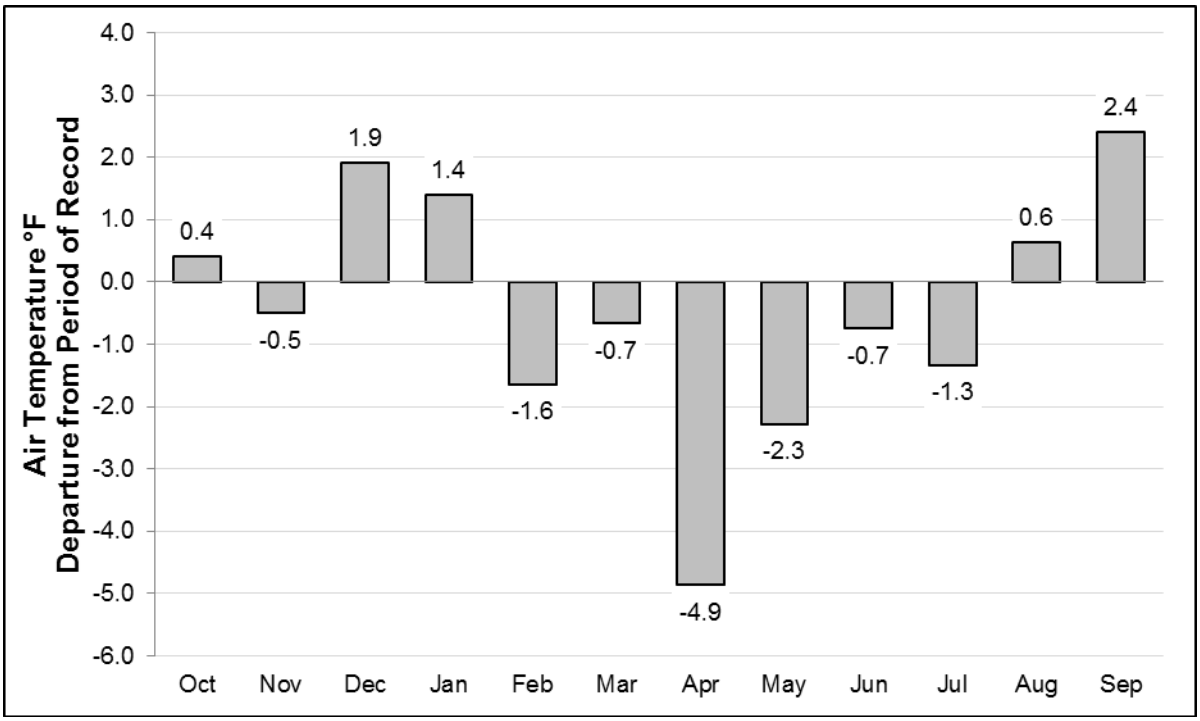

Figure H-1. Comparison of average monthly temperature (°F) for the Quinault Rainforest in Water Year 2011 against monthly averages for the period of record (1999-2010).

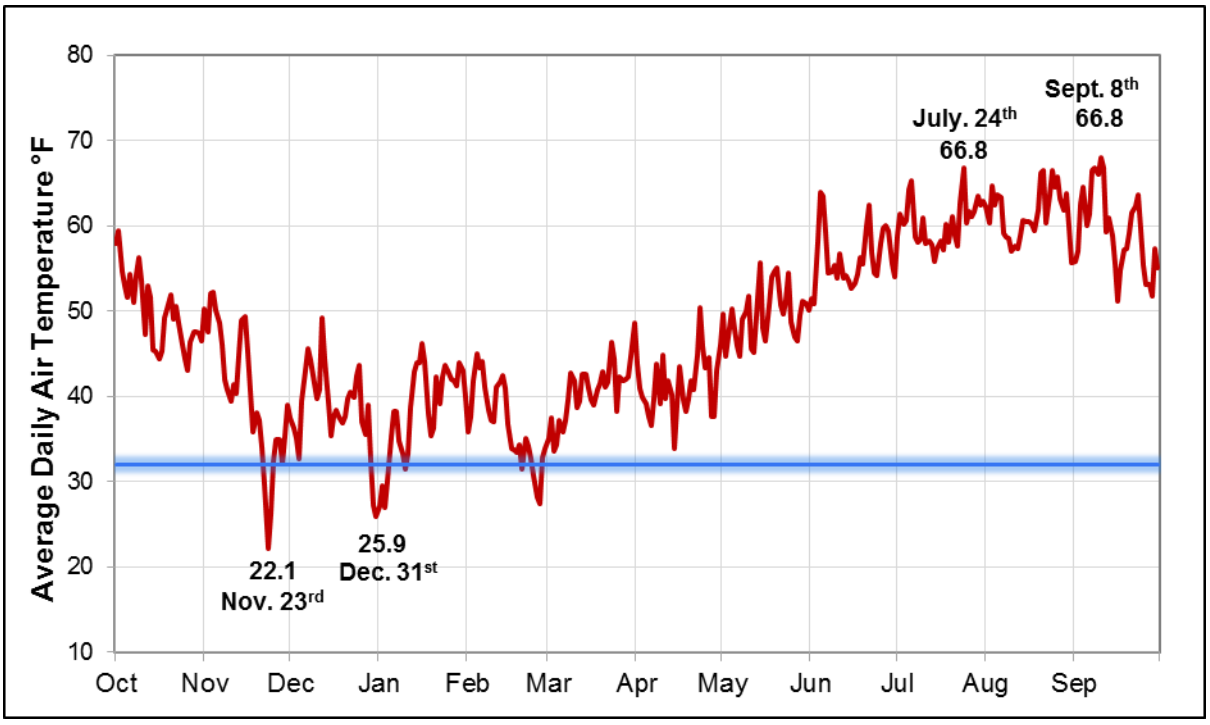

Figure H-2. Daily average air temperature (°F) at the Quinault Rainforest, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

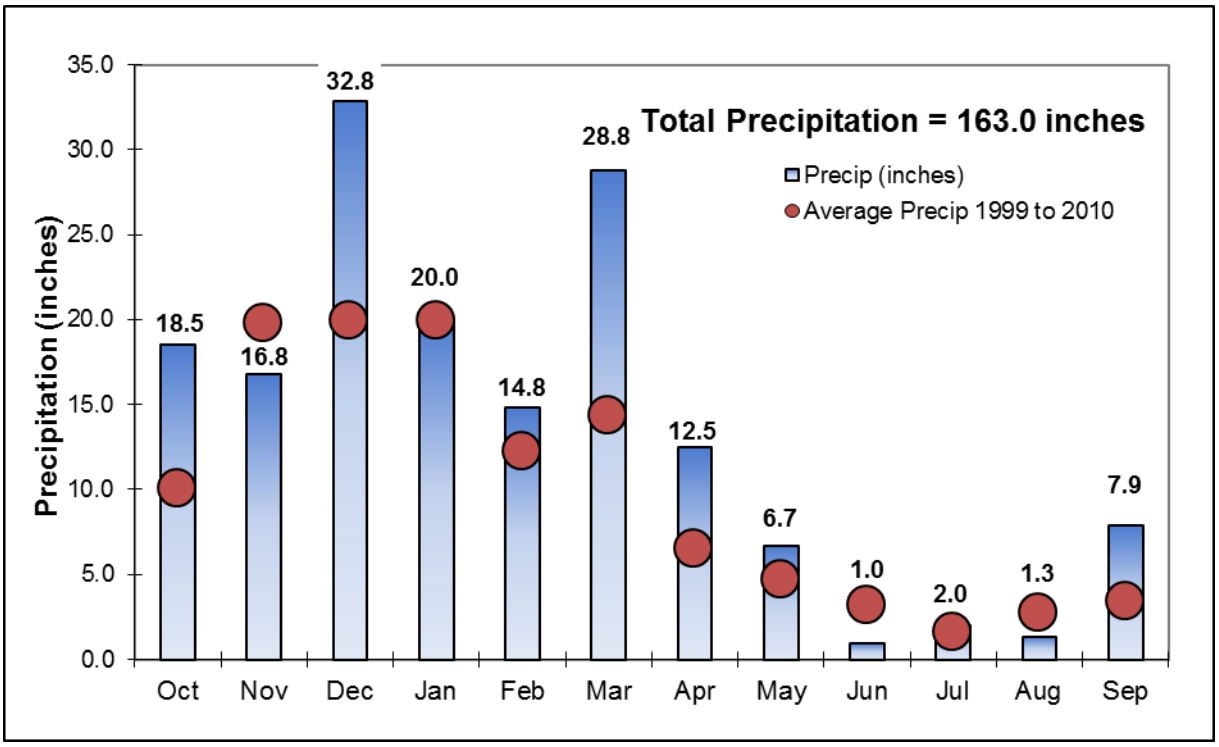

Figure H-3. Monthly precipitation values (inches) at the Quinault Rainforest, Water Year 2011 compared to the monthly averages for the period of record (1999-2010).

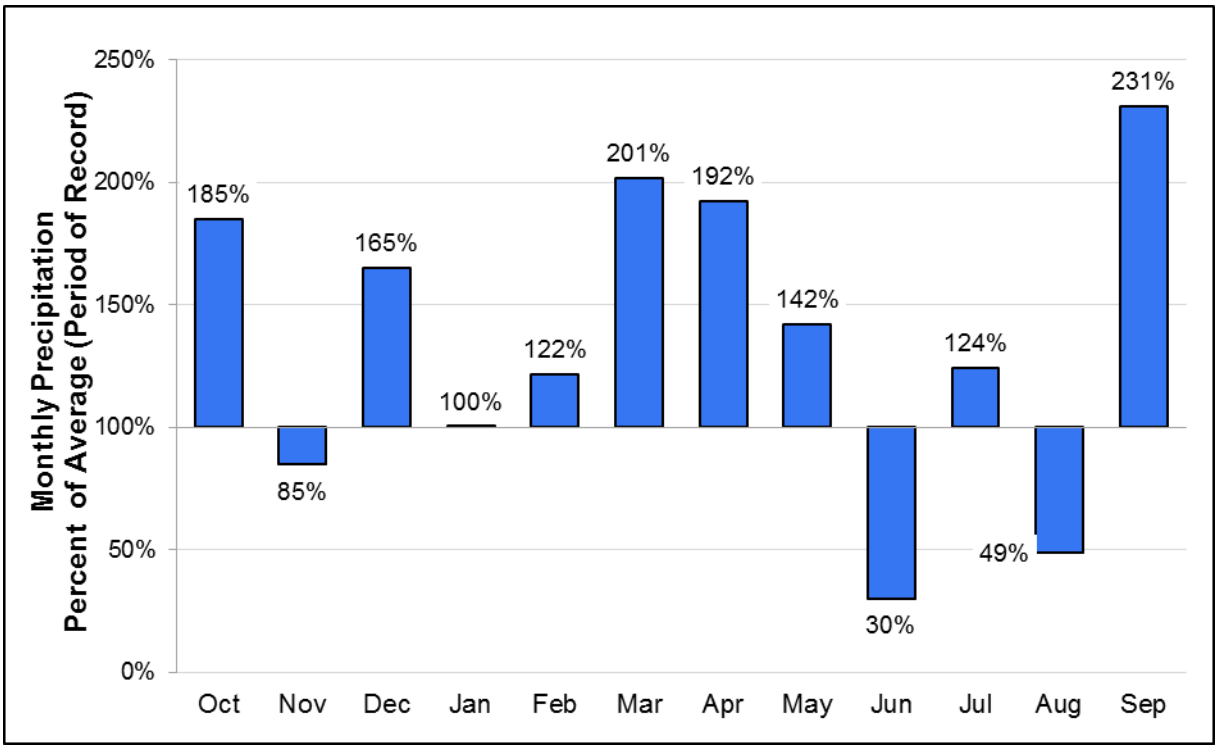

Figure H-4. Percent departure of precipitation from the period of record (1999-2010) at the Quinault Rainforest in Water Year 2011.

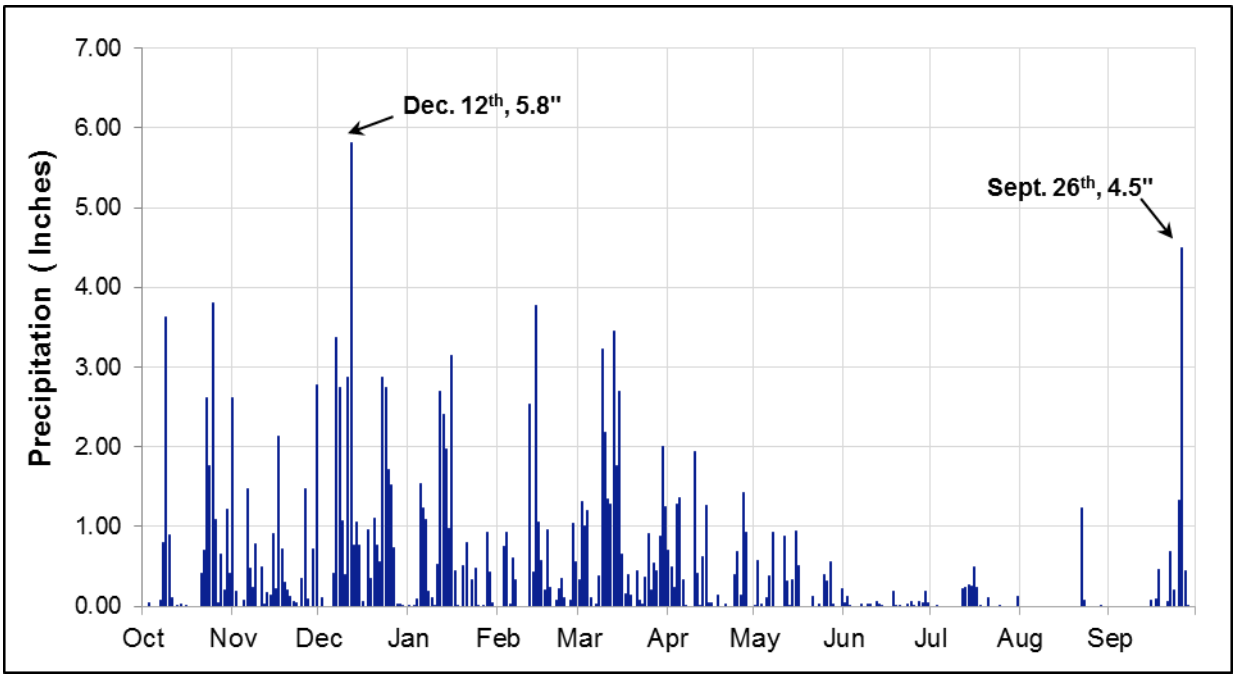

Figure H-5. Daily precipitation (inches) at the Quinault Rainforest, Water Year 2011.

Appendix I: Waterhole SNOTEL - Water Year 2011

Average annual temperature at the Waterhole SNOTEL weather station was 36.2°F (Table I-1). Temperatures ranged from an extreme low of -1.7°F on November 23, 2010 to a high of 75.9°F on September 11, 2011 (Table I-2). Late winter and spring months were much colder than average (2.2°F below). This departure was even more pronounced during the summer season (3.3°F below). July showed the most extreme negative departure from average, with a negative departure of 6.1°F (Figure I-2). An extensive period of above freezing temperatures occurred in the latter half of January (Figure I-3), including a major rain event which created a distinct surface layer that was prone to avalanches later in the winter.

The Waterhole SNOTEL received 86.2 inches of precipitation in Water Year 2011 (Figure I-4), 126% of average. Late winter and spring months were unusually wet (Figure I-5). The typically dry month of July was quite wet with 1.6 inches of rain, 256% of average. August was unusually dry (19% of average) but wet conditions returned in September (172% of average) (Figure I-5). The highest precipitation day was December 11, 2010 with 3.0 inches, followed by March 15 with 2.8 inches (Figure I-6).

Below average temperatures throughout the year and especially in spring and summer months contributed to an above normal and long-lasting mountain snowpack. Snowpack began developing in late October 2010 and melted out on July 24, 2011, persisting for 273 days (Figure I-7). Maximum snow water equivalent was 65.9 inches on May 5, 2010. This was the second year in a row with a large and well preserved snowpack. The snowpack was at or slightly above normal for winter months, but grew progressively over the colder and wetter than normal spring season, to reach 246% of normal by June 1, 2010 (Figure I-8). The April 1 snowpack was the largest recorded at the SNOTEL since being installed in 1999 (Figure I-9).

Figure I-1. Late April snowpack buries a park backcountry shelter. Photograph by: Bill Baccus.

Table I-1. Monthly summary data, Waterhole 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	40.4	47.4	35.2	6.6
	November 2010	29.3	33.9	24.4	10.1
Winter	December 2010	27.8	31.3	24.5	14.7
	January 2011	30.6	35.2	26.0	8.9
	February 2011	25.2	30.9	19.9	10.0
Spring	March 2011	28.0	33.8	22.8	19.3
	April 2011	28.3	36.3	20.6	7.4
	May 2011	35.5	43.3	29.0	4.5
Summer	June 2011	41.9	51.1	34.9	0.7
	July 2011	46.4	54.9	39.0	1.6
	August 2011	50.9	59.9	43.2	0.2
Fall	September 2011	50.1	58.8	43.1	3.0
Water Year		**36.2**	**43.1**	**30.2**	**87.0**

Table I-2. Air temperature extremes, Waterhole SNOTEL, Water Year 2011.

Date	Max Air Temp °F	Date	Min Air Temp °F
September 11, 2011	75.9	November 24, 2010	-1.7
September 12, 2011	74.1	February 26, 2011	-1.5
August 22, 2011	72.1	November 23, 2010	0.9
September 13, 2011	72.1	November 25, 2010	3.6
August 21, 2011	70.2	December 31, 2010	6.1

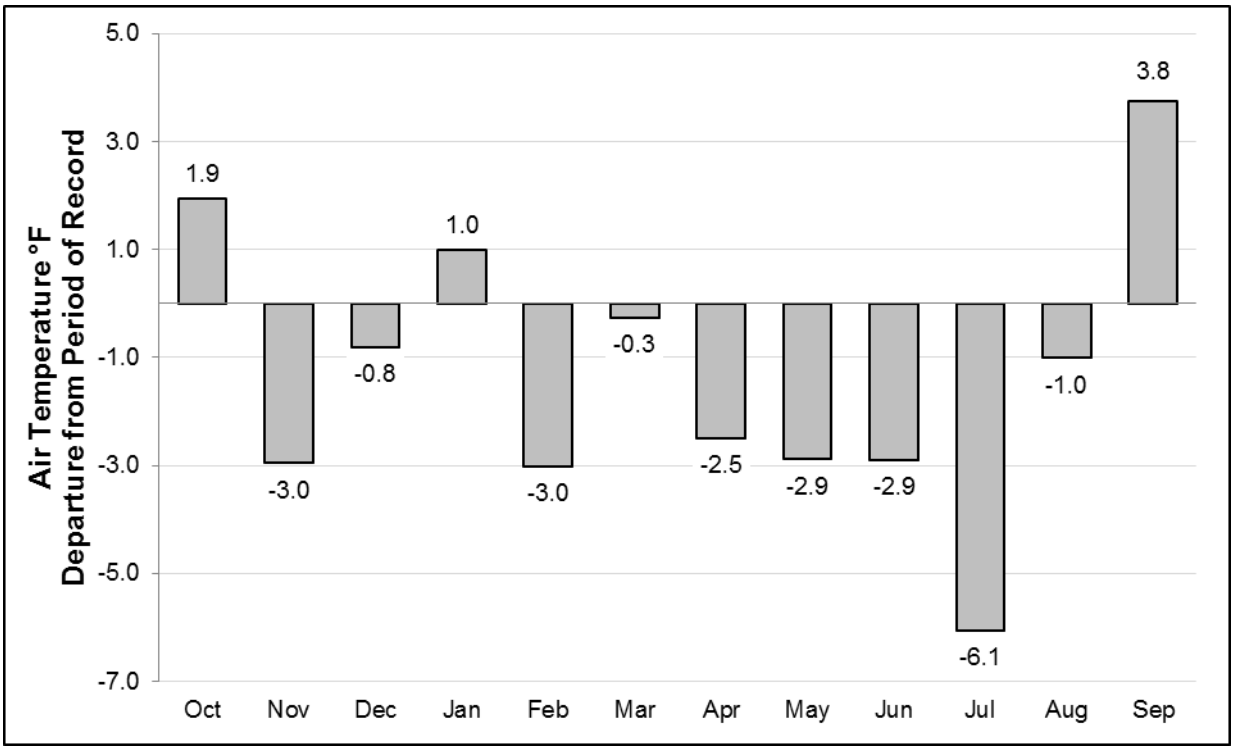

Figure I-2. Comparison of average monthly temperature (°F) for Waterhole SNOTEL in Water Year 2011 against monthly averages for the period of record (2000-2010).

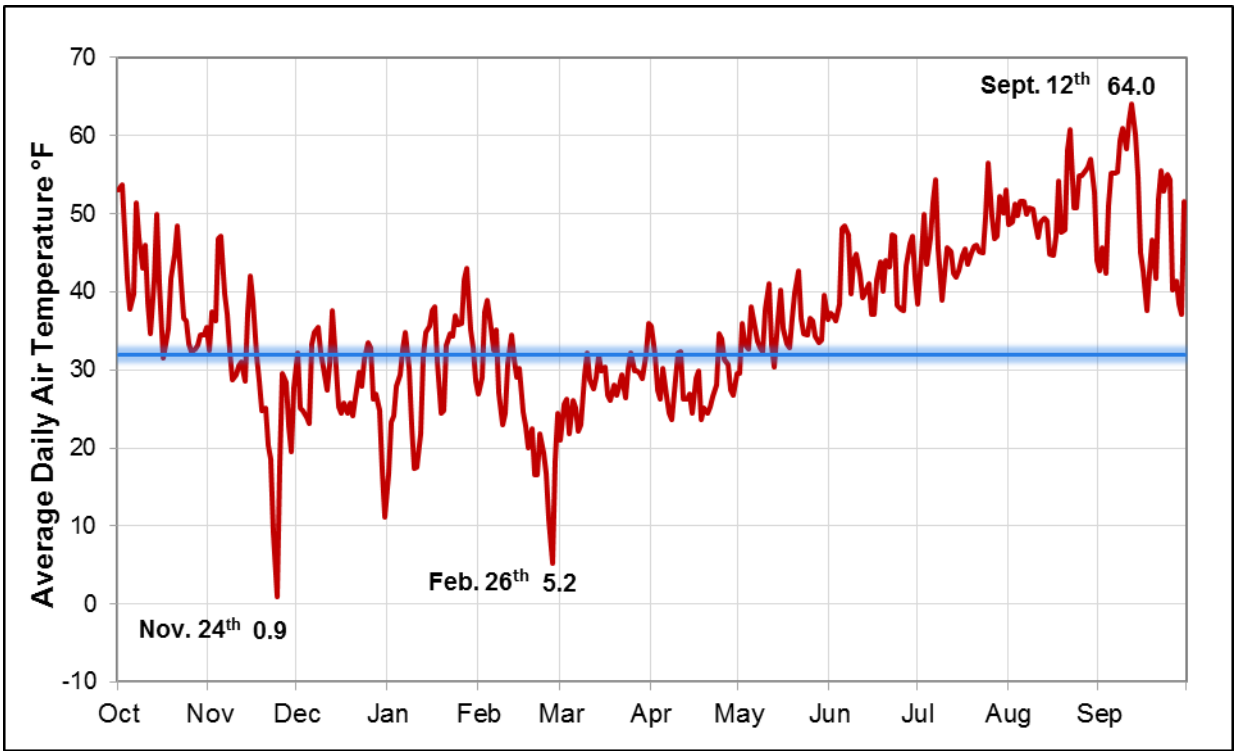

Figure I-3. Daily average air temperature (°F) at the Waterhole SNOTEL, Water Year 2011. Blue line indicates 32ºF, the freezing point of water.

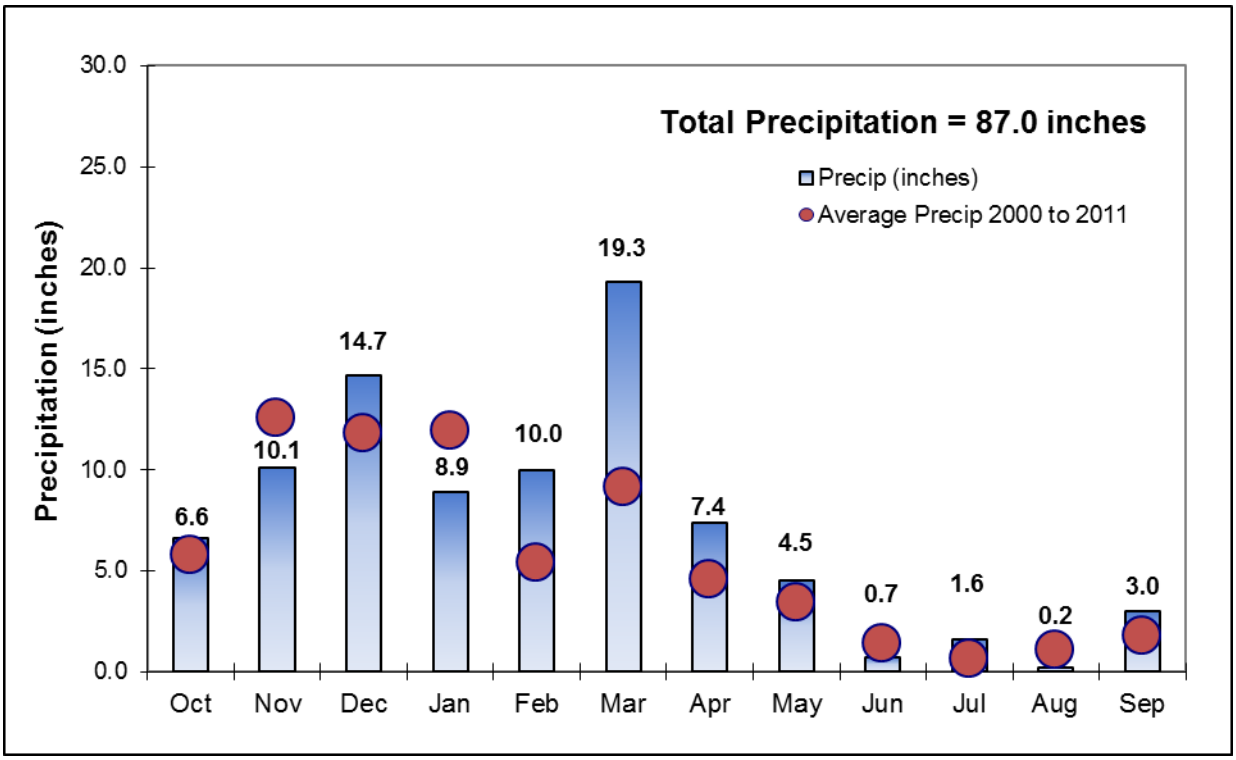

Figure I-4. Monthly precipitation values (inches) at the Waterhole SNOTEL, Water Year 2011 compared to the monthly averages for the period of record (2000-2010).

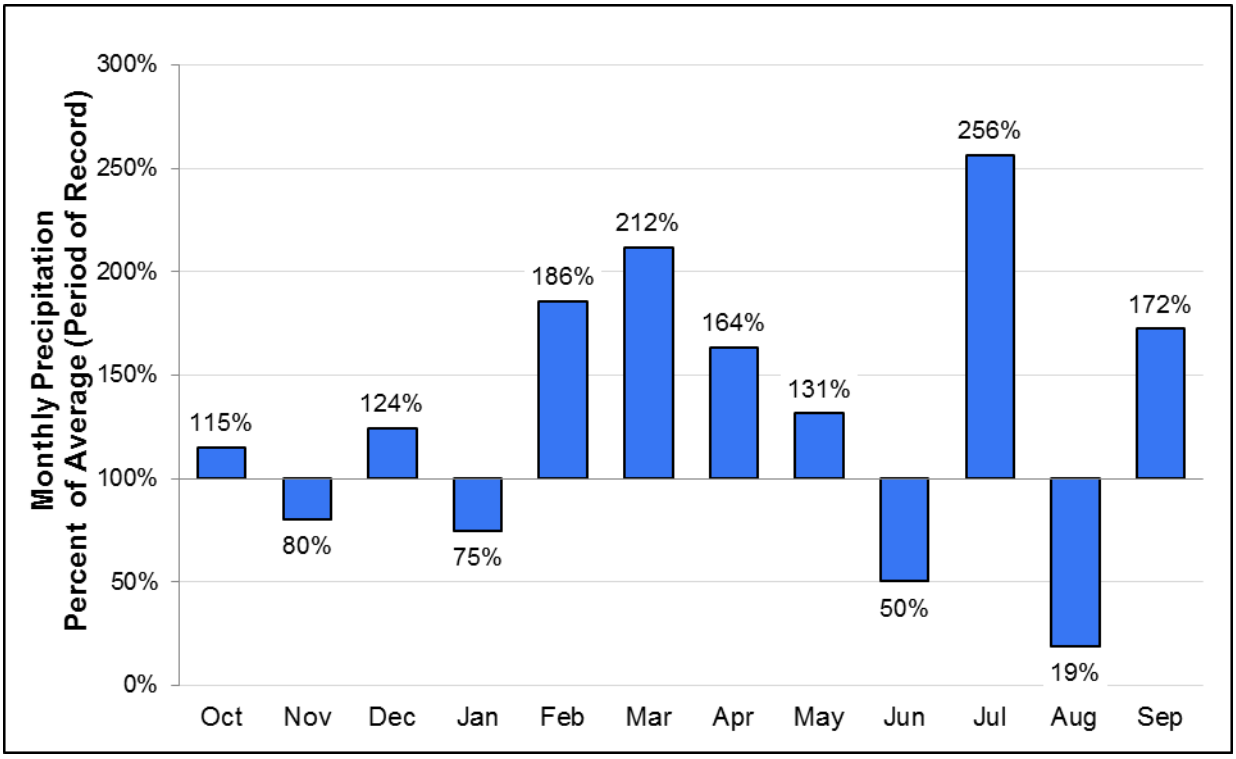

Figure I-5. Percent departure of precipitation from the period of record (2000-2010) at the Waterhole SNOTEL in Water Year 2011.

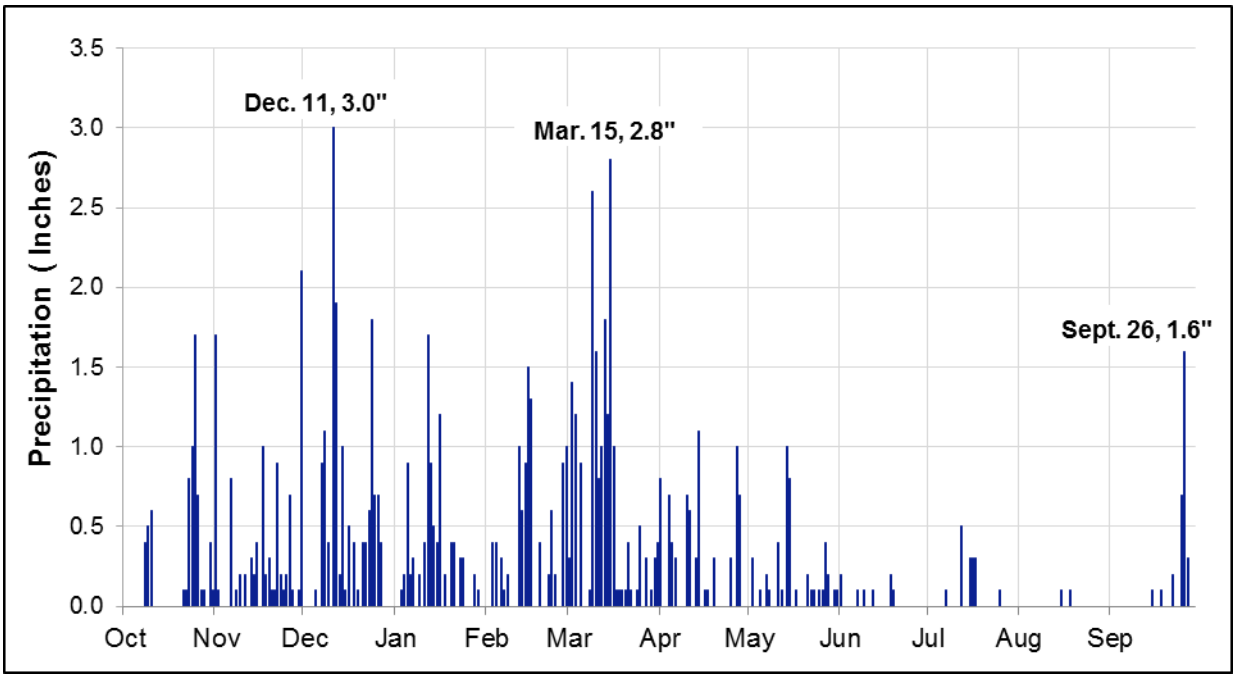

Figure I-6. Daily precipitation (inches) at the Waterhole SNOTEL, Water Year 2011.

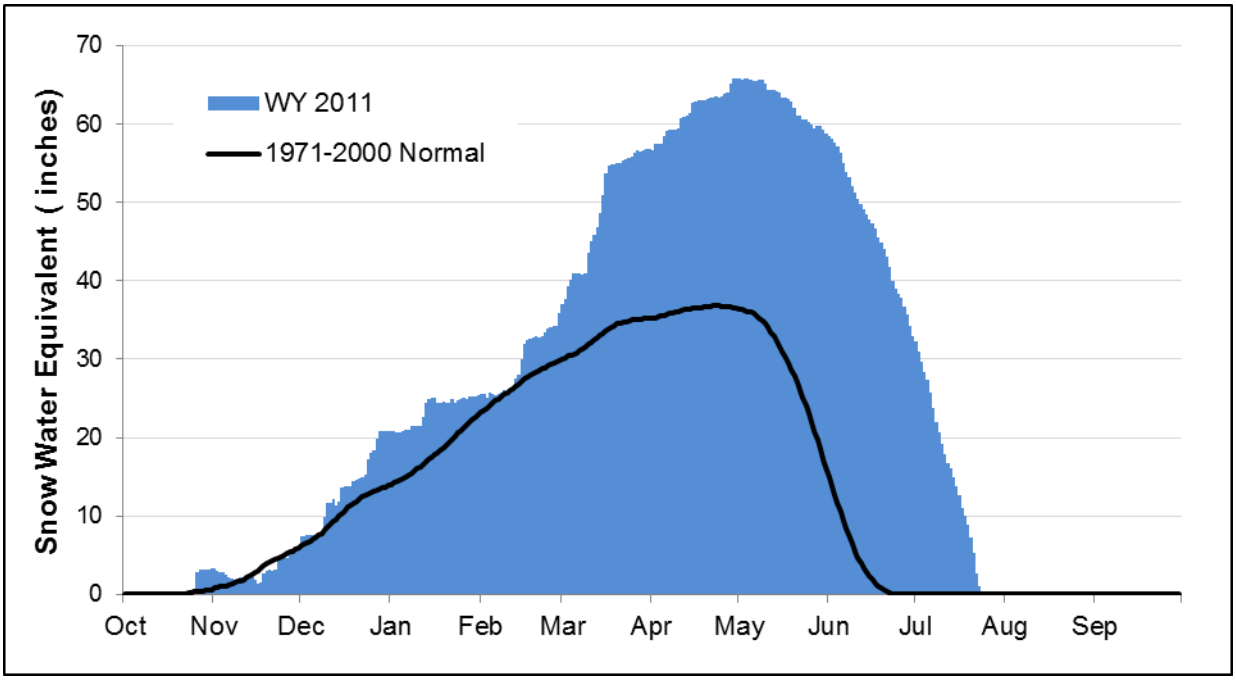

Figure I-7. Daily snow water equivalent (inches) at the Waterhole SNOTEL, Water Year 2011. The graph illustrates the unusually late accumulation of snow from March to mid-May.

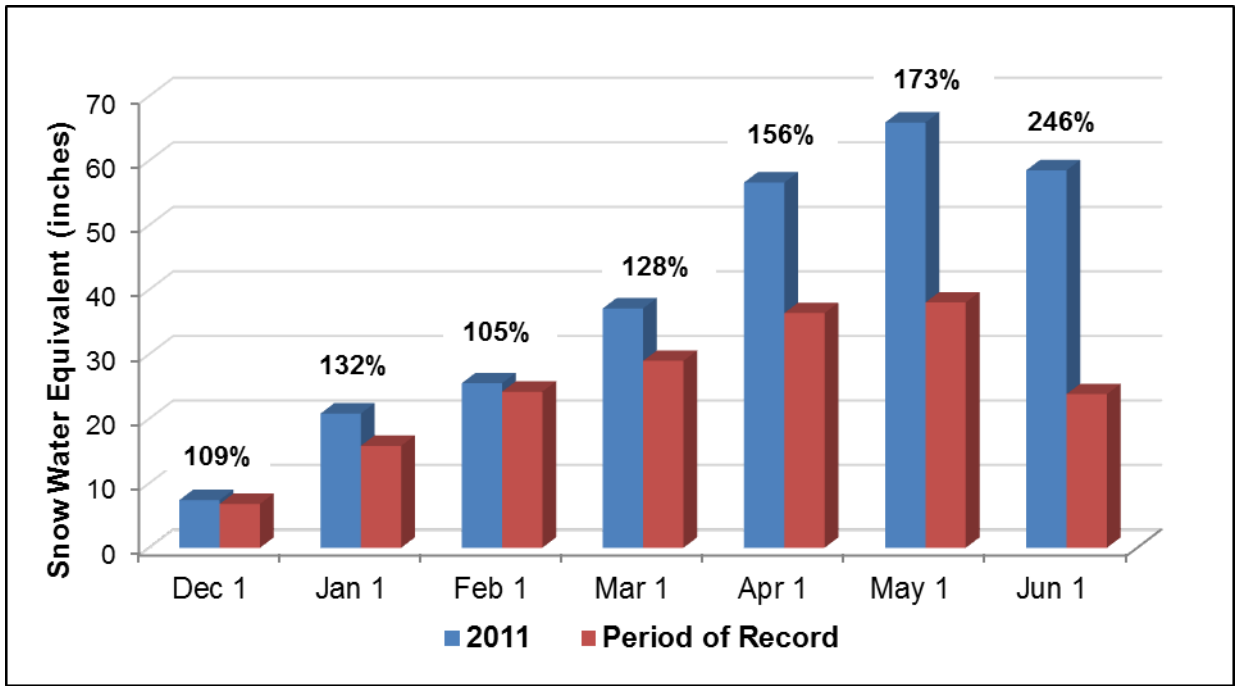

Figure I–8. First of the month snow water equivalent (inches) at the Waterhole SNOTEL in Water Year 2011, compared with the period of record (2000-2010).

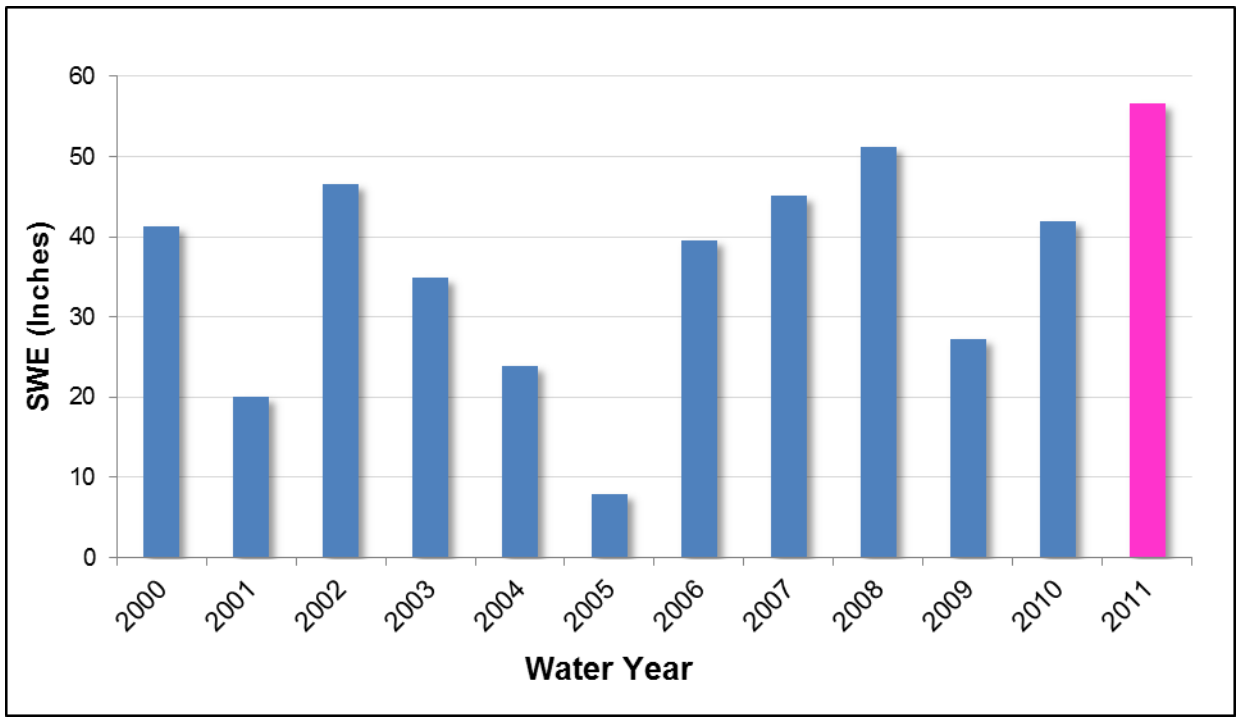

Figure I-9. April 1 snow water equivalent (inches) at the Waterhole SNOTEL for the period of record (2000 -2010). Highlighted column indicates Water Year 2011.