National Park Service
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Natural Resource Stewardship and Science

North Coast and Cascades Network Climate Monitoring Report

Olympic National Park; Water Year 2016

Natural Resource Data Series NPS/NCCN/NRDS—2017/1139

ON THIS PAGE
Warm easterly winds on August 24th led to active fire behavior on four fires in Olympic National Park in 2016. The Hayes Fire, pictured here, eventually grew to 2417 acres. Photograph by: Bill Baccus

ON THE COVER
Debris from fallen trees litter and a reactivated branch of the East Fork Quinault River obscure a popular trail in the Olympic Wilderness. Four major atmospheric river rain events triggered debris flows and flooding in many areas of the park.
Photo Credit: Carter Urnes/Joe Zagrodnik

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William D. Baccus

National Park Service
North Coast and Cascades Network
Olympic National Park
600 E. Park Ave
Port Angeles, WA 98362

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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.

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

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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 provide essential information needed to support park operations and to monitor park resources.

This report summarizes climate data collected in Olympic National Park during the 2016 water year, and is part of a set of climate summary reports from national and historical 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 summarize the year's weather 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 coastal to high elevation sites in the mountainous core of the Olympics. Data were recorded using automated instruments operated by the National Park Service and collaborators, including the National Weather Service and the Natural Resources Conservation Service. For two stations with long term records, monthly average temperatures and monthly total precipitation are reported and compared to the 30-year normal (1981 to 2010). These two stations span a significant climate gradient, with the Quillayute Airport representing wet, west side conditions and the Elwha Ranger Station representing the drier, northern portions of the Park. Monthly snow depth and snow water equivalent (SWE) are reported and compared to the 30-year normal for two Snow Telemetry (SNOTEL) stations and three snow courses within the Park. A summary is provided to describe any significant weather events during the water year and how these may have affected park resources.

In Water Year 2016, the two weather stations with long term records were 2.5 and 2.0° F above normal. This continued a trend of warmer than normal temperatures extending back to the spring of 2014. Annual precipitation was slightly above normal, resulting from a profoundly wet winter season followed by two extremely dry periods, one in late spring, and one in late summer. The wet winter was the result of a steady series of warm and wet storm systems which led to widespread river flooding, landslides and damage to several park roads and trails. While the winter was warmer than normal, several months of near normal temperatures in the mountains, combined with this heavy precipitation to create a slightly above normal snowpack in the Olympic Mountains. A warm dry spring, however, led to the early melt of this snowpack. A second dry period in late summer, combined with warm temperatures to allow the spread of several major forest fires within the Park during the month of August.

Acknowledgments

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

- National Weather Service – National Weather Service Cooperative Observer Program
- Natural Resources Conservation Service - National Water and Climate Center, SNOTEL and Snow Survey Program
- Northwest Avalanche Center – High Elevation 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	National Weather Service Cooperative Observer Station
CRN	Climate Reference Network
ENSO	El Nino-Southern Oscillation
I&M	Inventory and Monitoring
NCCN	North Coast and Cascades Network
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWAC	Northwest Avalanche Center
NWS	National Weather Service
OLYM	Olympic National Park
PDO	Pacific Decadal Oscillation
PNW	Pacific Northwest
RAWS	Remote Automated Weather Stations
SNOTEL	Snowpack Telemetry
SWE	Snow Water Equivalent
WRCC	Western Regional Climate Center

Glossary

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

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

El Nino-Southern Oscillation (ENSO): A climate pattern based primarily on sea surface temperature and air surface pressure in the equatorial Pacific Ocean. ENSO is strongly associated with weather patterns of the Pacific Northwest and has three phases: a warm phase (El Niño) characterized by warmer and drier than normal conditions; a cold phase (La Niña) which typically results in cooler and wetter weather and a deep winter snow pack; and a neutral phase which exhibits no obvious weather patterns. The greatest variations are typically in winter and spring seasons (Cayan et al. 1999) (NWS Climate Prediction Center 2017).

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-Southern Oscillation.

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 gage, and air temperature sensor. Some enhanced sites also measure soil moisture and wind speed.

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

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

Water Year: The water year (or hydrologic year) is most often defined as the period from October 1st to September 30 of the following year. It is called by the calendar year in which it ends. Thus, Water Year 2016 is the 12-month period beginning October 1, 2015 and ending September 30, 2016. The period is chosen so as to encompass a full cycle of precipitation accumulation.

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

Introduction

Climate is a dominant driver of the physical and ecologic processes of the North Coast and Cascades Inventory and Monitoring Network Parks (NCCN, Figure 1) (Davey et al. 2006). Trends in rainfall and temperature influence how ecosystems and dependent organisms function. The quantity and timing of rainfall and snow can influence the productivity and health of forests (Nakawatase and Peterson 2006), the amount of water flowing in streams and rivers (Hamlet et al. 2007), and the increase or decrease in size and terminus position of mountain glaciers. Likewise, temperature can influence the quantity and timing of plant growth and stream runoff, or the extent and duration of winter snowpack and lake ice (Thompson et al. 2009). Through direct and indirect methods, climate affects the behavior and reproduction of terrestrial and aquatic animal species (Crozier et al 2008). Disturbance events such as forest fires, windstorms, and floods are strongly related to climate (Littell and Gwozdz 2011). These events can have a major impact on park landscapes and their associated ecosystems 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; to compare current and historic data to understand long-term trends; and to provide data to model future 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 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, 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 2016 water year, and is part of a set of climate summary reports from 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.

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

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

Methods

Station Locations

This report incorporates data collected from weather stations operated by the NPS, the NRCS (SNOTEL), and the National Weather Service (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.

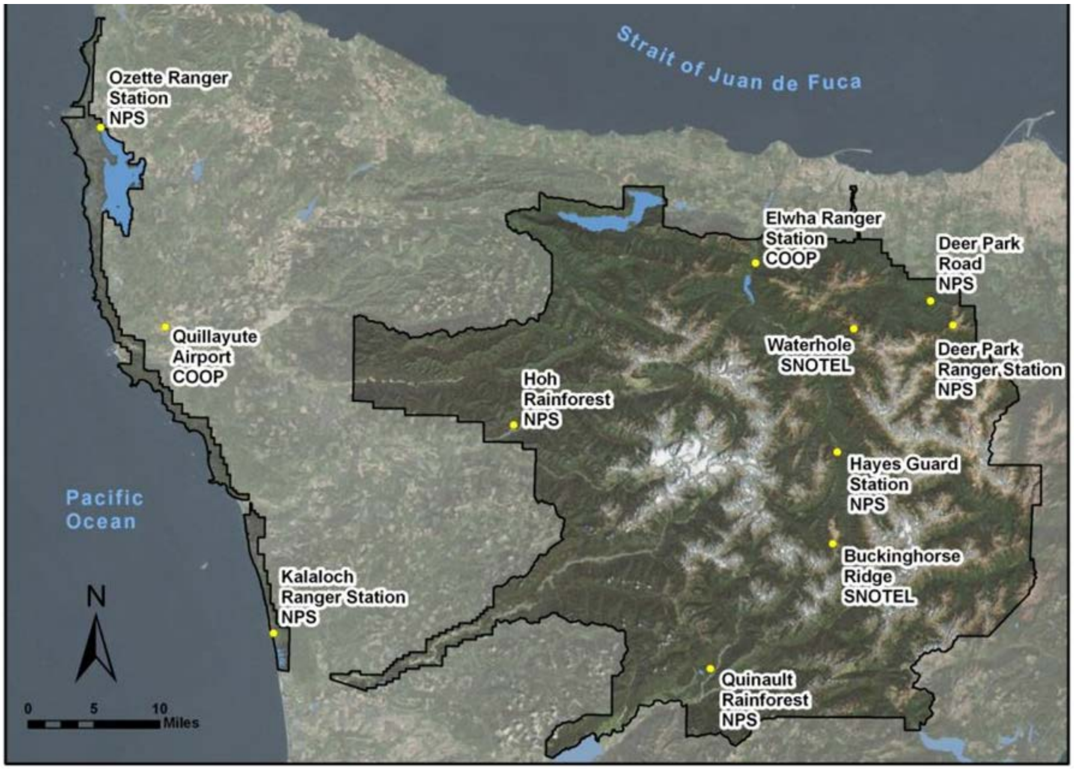

Figure 2. Location of weather stations referenced in this report.

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 available by request from Olympic National Park.

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

Station Name	Managing Agency – Station Type	Air 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**	–	–	–	✓	✓
Deer Park Ranger Station	NPS[2]	**X**	✓	**X**	**X**	–	–	–	–	–	–	–
Deer Park Road	NPS[2]	**X**	✓	**X**	–	–	–	–	✓	✓	✓	✓
Elwha Ranger Station	NWS COOP[3]	**X**	–	**X**	–	✓	–	–	–	–	–	–
Hayes River Guard Station	NPS[2]	**X**	✓	**X**	✓	–	–	–	–	–	✓	✓
Hoh Rainforest	NPS[2]	**X**	✓	**X**	–	–	–	–	✓	✓	✓	✓
Kalaloch Ranger Station	NPS[2]	**X**	✓	**X**	–	–	–	–	–	–	–	–
Ozette Ranger Station	NPS[2]	**X**	✓	**X**	–	–	–	✓	–	✓	–	–
Quillayute Airport	NWS COOP[3]	**X**	–	**X**	–	✓	–	–	–	–	–	–
Quinault Rainforest	NPS[2]	**X**	✓	**X**	–	–	–	–	✓	✓	✓	✓
Waterhole	SNOTEL[1]	**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 2017 and National Water and Climate Center 2016, 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 sequential 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 2016 Data Quality

At the Deer Park Ranger Station, a Campbell Scientific (CS705) snowfall adapter was added to the rain gauge in the fall of 2015. Despite installation, winter precipitation amounts from December to March compared poorly to a nearby site not typically affected by snow (Deer Park Road). In addition, during the months of April to June, low rainfall and evaporation of the glycol mix led to the malfunction of the gauge for those months. For these reasons, no precipitation amounts are presented for the months of December to June.

At the Elwha Ranger Station COOP, a remodel of the historic building required the removal of the NWS air temperature sensor from July 17, 2015 to April 2, 2016. This COOP station is collocated with an NPS automated weather station. For the purposes of this report, temperature data during this time period were derived from the NPS station.

At the Hayes Guard Station, air temperature data from the months of December through April are suspect, likely due to moisture problems with the Vaisala HMP45C temperature sensor. During these months, temperature was either clearly out of range (unusual negative values), or showed an obvious 1° to 4°F shift from the panel (reference) temperature measured at the data logger. Monthly temperature data for these months were estimated from the data logger panel temperature, using a correction value determined while both sensors operated properly. The corrected value was calculated by subtracting 0.6°F from the data logger panel temperature.

At the Ozette Ranger Station, failure of the weather station power system resulted in a loss of data from April 22 to May 20, 2016. A battery was replaced on May 20th during a site maintenance visit, and a new solar regulator was installed on February 14, 2017. For the purposes of estimating monthly and annual reporting, precipitation data from the Kalaloch Ranger Station were used in place of missing Ozette weather station values.

Data Reporting

Data in this report are based on the 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 typically extends from July through September. Because 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 migration 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.

In this report, we present 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, northeastern 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. Available upon request are hourly, daily, or monthly weather data from each station noted in Tables 1 and 2.

Results

Temperature

Water Year 2016 was 2.5 and 2.0° F above average at Quillayute Airport and Elwha Ranger Station respectively. Fall and winter months in Water Year 2016 continued an exceptional trend of warmer than normal conditions, extending back to the spring of 2014. Beginning in March of 2014, there were 20 consecutive months of above normal conditions at Quillayute Airport, with November 2015 being the first time monthly temperatures fell to below normal levels (Figure 3, below). This relatively cool month was then immediately followed by ten additional months of warmer than normal temperatures (Figures 3 and 4). Averaged over the three year period, temperatures at this coastal station were 2.6° F above normal.

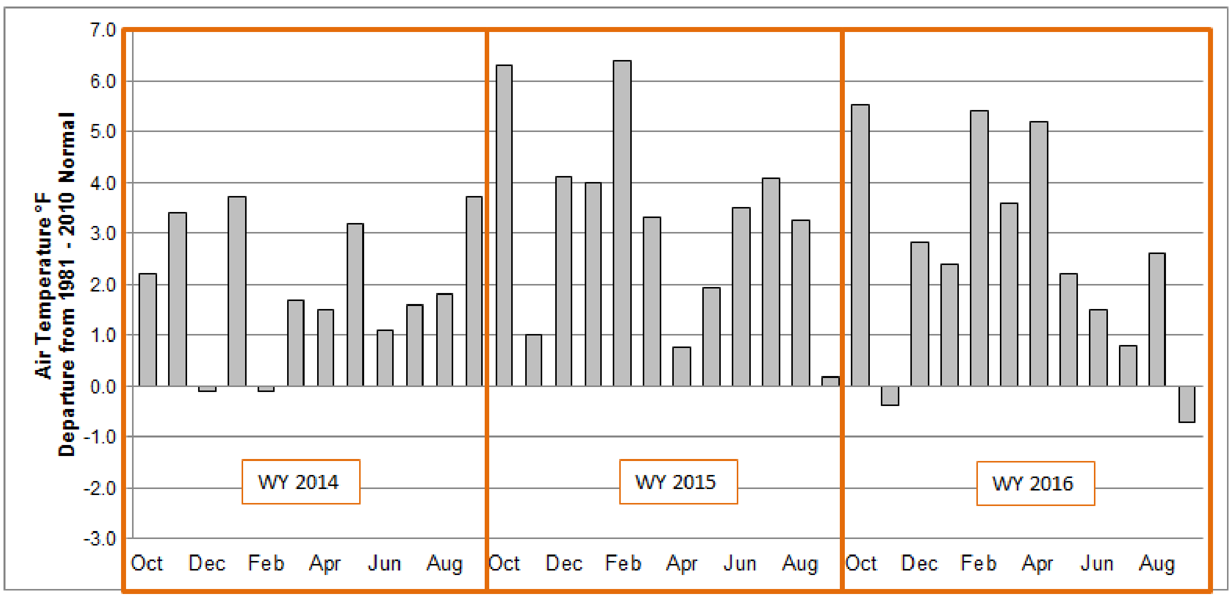

Figure 3. Comparison of average monthly temperature (°F) for Quillayute Airport from Water Year 2014 to 2016 against monthly averages for the climatological normal 1981-2010.

This extended period of warmer than normal temperatures was caused by unusual conditions in the Eastern Pacific Ocean. Beginning in the winter of 2013/2014, a mass of water with sea surface temperatures averaging 4 to 5° F above normal, occurred off of the Olympic Coast (Bond et al. 2015). This water mass, often referred to as "the blob" by local press, persisted until the fall of 2015. During the winter months of 2016, the "blob" was dissipated by a strong El Nino, which, through different mechanisms, also typically brings warmer than normal conditions to the Pacific Northwest during winter and early spring months (Cavole et al. 2016, Jacox et al. 2016, NOAA 2016, NOAA 2017). The effects of both phenomena are reflected in the above normal temperatures recorded at the Quillayute Airport and Elwha Ranger Station from December 2015 to May 2016 (Figure 4).

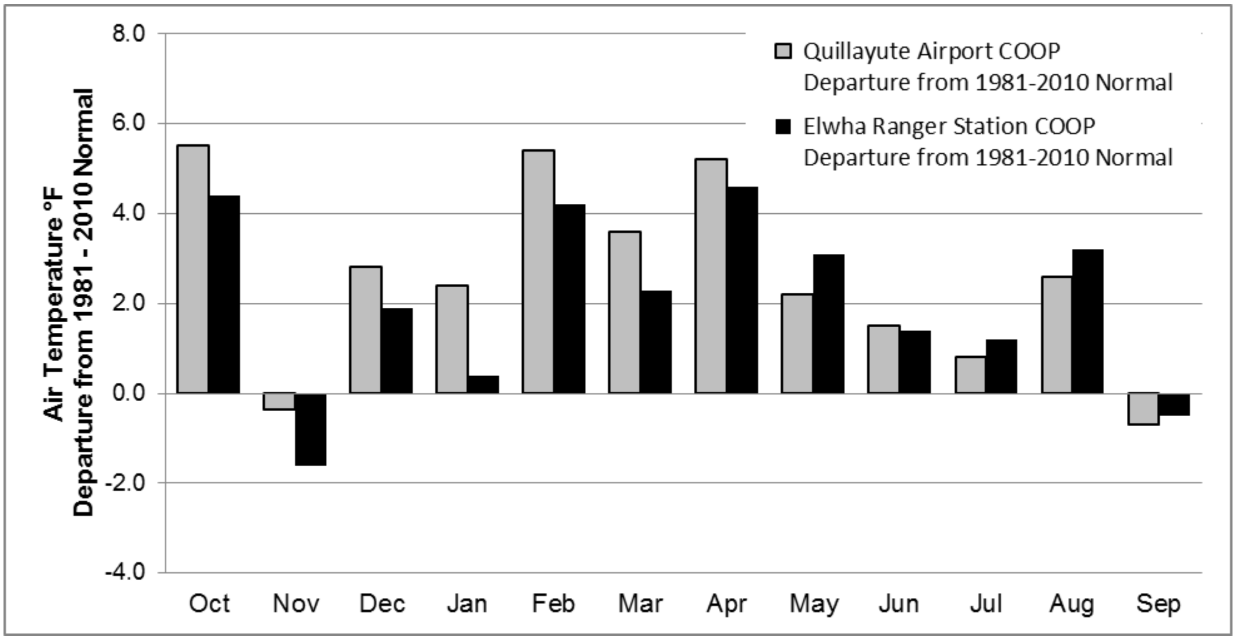

Figure 4. Comparison of average monthly temperature (°F) for Quillayute Airport and Elwha Ranger Station in Water Year 2016 against monthly averages for the climatological normal 1981-2010.

It is notable, that in contrast to the consistently above normal temperatures in coastal and low elevation interior sites, temperatures at high elevation sites of the Park were slightly cooler than average in late fall and early winter months (Figure 5). This allowed a robust snowpack to develop at higher elevation early in the winter season (see Snowpack).

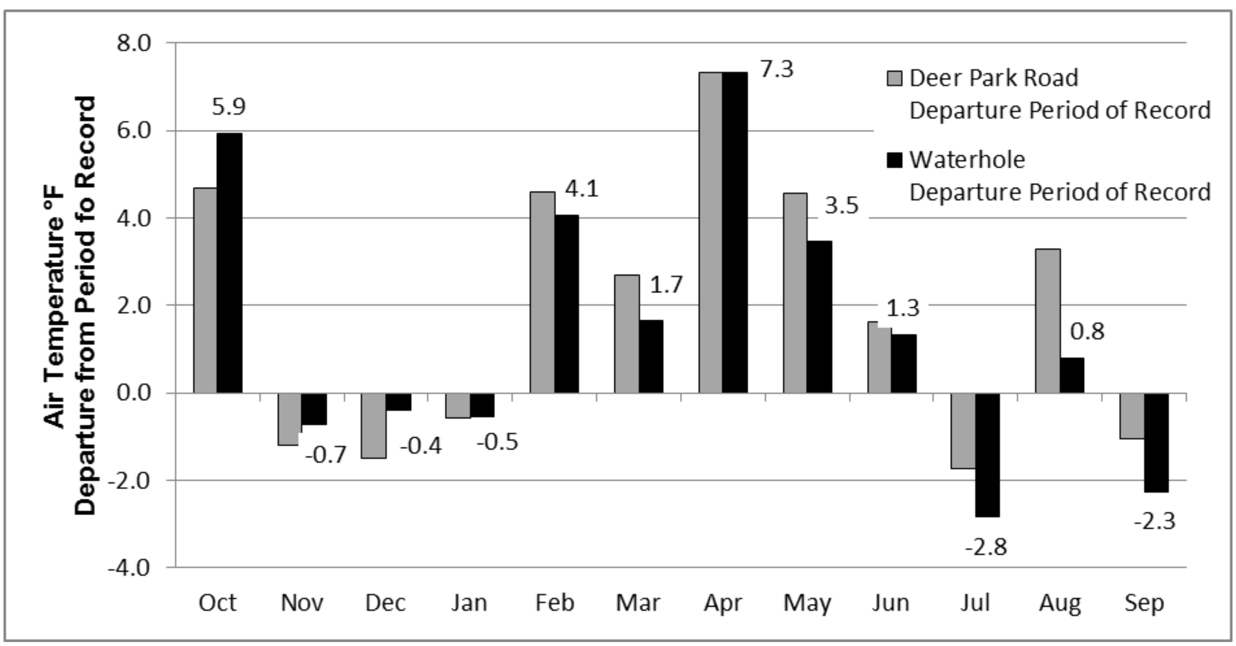

Figure 5. Comparison of average monthly temperature (°F) for Deer Park Road (Elevation 3115 ft.) and Waterhole SNOTEL (Elevation 4961 ft.) in Water Year 2016 against monthly averages for the period of record 2000-2016.

Temperatures during spring months of March, April and May, were well above normal in Water Year 2016. In fact, statewide, 2016 was tied with 1992 as the second-warmest on record (OWSC 2016b). Quillayute Airport recorded its warmest spring since records began in 1966, averaging 3.7° F above normal for the 3 month period (Figure 4). The month of April had the greatest temperature deviation, with 5.2 and 4.6° F above normal at Quillayute Airport and Elwha Ranger Station, respectively.

Average temperatures during summer months were much closer to normal. Quillayute Airport, on the coast, remained above normal during all three months, however the Elwha Ranger Station recorded cooler than normal temperatures during the summer months of June and July (Figure 4). This was similarly reflected in several of our upper elevation sites (Figure 5, Table 3). August temperatures were well above normal at all sites and contributed to an active fire season in the Olympic Mountains (see Significant Weather Events and Patterns).

Table 3. Average monthly air temperatures (°F) from weather stations within or adjacent to Olympic National Park in Water Year 2016.

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 2015	47.5	44.7	50.9	53.3[a]	47.5	53.5	54.8	54.4	55.5	54.5	45.0
	November 2015	34.4	29.4	37.1	39.6[a]	34.7	39.9	43.3	42.6	43.8	40.0	31.2
Winter	December 2015	29.3	24.3	33.1	38.4[a]	33.5[b]	39.1	43.1	43.0	43.2	38.8	28.0
	January 2016	32.8	27.7	35.8	37.8[a]	31.0[b]	39.4	44.1	46.9	44.0	40.2	29.9
	February 2016	35.5	31.1	39.8	42.7[a]	36.8[b]	43.7	46.8	52.0	47.5	44.4	32.7
Spring	March 2016	33.5	29.2	38.8	45.0[a]	37.6[b]	44.3	46.7	49.1	47.7	44.5	31.0
	April 2016	43.4	39.6	47.3	51.9	45.9[b]	50.9	51.6	–	51.9	52.4	40.3
	May 2016	45.8	42.4	50.6	55.9	52.5	53.8	53.3	–	53.5	56.0	42.9
Summer	June 2016	48.6	45.1	52.8	57.1	55.1	56.6	55.9	56.5	56.8	58.6	46.4
	July 2016	52.0	48.7	56.8	61.5	59.8	59.8	58.7	59.4	59.7	62.1	49.6
	August 2016	56.1	53.4	62.5	66.2	60.7	62.0	57.9	60.3	62.2	63.7	52.9
Fall	September 2016	47.3	44.4	53.2	57.5	50.5	55.5	55.9	56.1	55.9	57.1	44.6
Water Year		42.2	38.3	46.6	50.6[a]	45.5[b]	49.9	51.0	–	51.8	51.0	39.5

[a] Temperature data substituted from a co-located NPS automated weather station.

[b] Monthly temperature data for these months was estimated from the data logger panel temperature, using a correction value determined while both sensors were operating properly.

Precipitation

Cumulative precipitation for Water Year 2016 was above average at most weather stations at OLYM. Quillayute Airport received 106.4 inches of annual precipitation, 107% of normal. Elwha Ranger Station received 68.0 inches, 122% of normal (Table 4, Figure 6). This relationship of lower percent of normal rainfall at coastal sites and higher at interior sites was documented across the network of OLYM weather stations. Annual totals at the Quinault Rainforest (inland) were 129% of average, while coastal sites including Kalaloch and Ozette Ranger Stations were 90% and 89% of average, respectively.

Precipitation during the fall was near normal (Quillayute 95% and Elwha Ranger Station 103%). Winter and early spring months, however, were extremely wet. A series of major Pacific storms pummeled the Olympic Mountains from mid-November through February, dropping significant amounts of rain. Winter months were 136% and 143% of normal at Quillayute Airport and Elwha Ranger Station, respectively (Figure 6). The early spring month of March continued this wet trend with precipitation amounts at 146% and 176% of normal (Quillayute Airport and Elwha Ranger Station, respectively (Figure 6). Extreme precipitation was most apparent in the southern Olympics. In the month of December, the Quinault received 40 inches of rain, 196% of average for that site. During this four month period, over nine feet (113 inches) of precipitation was recorded (Table 4).

In contrast, the late spring months of April and May were unusually dry, with most OLYM weather sites receiving only 20% to 50% percent of normal precipitation. Park wide, coastal sites tended to be drier than those in the Park interior. The Quillayute Airport and Elwha Ranger Station were 37% and 33% of normal during this two month period (Figure 6). This is the second year in a row that an unusually dry spring led to early drops in forest and soil moisture, a condition which may have contributed to active fires later in the summer (see Significant Weather Events and Patterns).

Early summer returned to wetter conditions, especially in the Northern sections of the Park. June precipitation was 101% of normal at Quillayute while Elwha was 152% of normal (Figures 6). This relationship was reflected at other nearby Park weather stations. The North interior sites of the Waterhole SNOTEL and Deer Park Road were 196% and 144% of average respectively. Meanwhile, southern and coastal sites reflected the closer to normal conditions documented at Quillayute, with the Quinault Rainforest recording 108% of average and Kalaloch Ranger Station, 111% of average. This situation reversed in July, with wetter conditions on the coast and drier conditions in the North interior. Quillayute Airport was 110% of normal, while the Elwha was 46% of normal (Figure 6). September was generally wetter than normal across all areas of the Park.

Table 4. Total monthly precipitation (inches) from weather stations within or adjacent to Olympic National Park in Water Year 2016.

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 2015	13.5	3.2	3.1	4.3	7.1	10.3	6.7	6.4	9.8	12.4	3.1
	November 2015	22.7	9.6	9.4	12.9	14.5	14.9	11.1	10.6	15.0	22.4	15.0
Winter	December 2015	38.8	–[a]	9.7	16.0	19.7	22.5	18.0	11.5	19.2	40.0	22.9
	January 2016	25.8	–[a]	6.4	8.9	14.6	17.4	13.1	12.9	15.7	28.5	13.5
	February 2016	18.1	–[a]	3.3	8.9	10.8	14.6	11.4	8.6	15.7	17.5	8.2
Spring	March 2016	26.2	–[a]	5.9	10.7	14.2	20.1	14.4	13.0	15.8	27.2	14.4
	April 2016	3.0	–[a]	1.8	1.4	2.2	3.9	2.2	1.2[c]	2.2	4.1	2.0
	May 2016	1.6	–[a]	1.0	0.5	0.9	2.4	1.9	1.9[d]	2.3	1.5	0.9
Summer	June 2016	1.8	–[a]	2.0	2.0	1.8	3.6	3.8	3.4	3.5	3.1	3.0
	July 2016	1.3	0.8	1.7	0.4[b]	1.0	1.4	2.3	2.2	2.2	2.1	1.1
	August 2016	0.9	1.7	0.4	0.4[b]	0.6	0.8	0.9	1.1	0.7	0.9	0.8
Fall	September 2016	4.0	1.7	1.2	1.7	1.9	4.6	3.3	4.7	4.2	4.9	1.7
Water Year		157.7	–	45.9	68.0[b]	89.3	116.3	89.0	77.4[e]	106.4	164.5	157.7

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

[b] To derive monthly totals, some missing daily data from COOP was substituted using nearby data from CoCoRaHS WA-CM-9.

[c] 9 days missing precipitation data estimated from Kalaloch Ranger Station.

[d] 19 days missing precipitation data estimated from Kalaloch Ranger Station.

[e] 28 days missing precipitation data estimated from Kalaloch Ranger Station for purpose of deriving annual total.

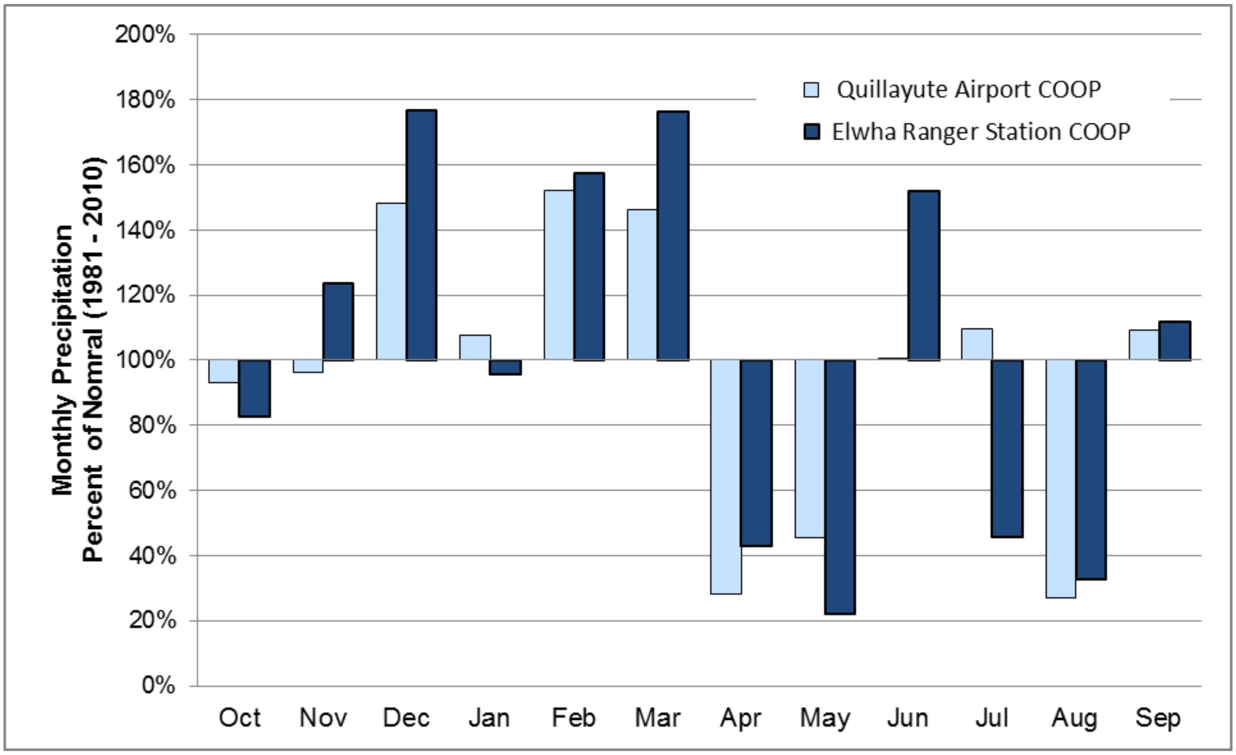

Figure 6. Comparison of monthly total precipitation (inches) as a percent of normal at Quillayute Airport and Elwha Ranger Station in Water Year 2016 against the climatological normal 1981-2010.

Snowpack

The slightly below average mountain temperatures during late fall and winter months combined with above average precipitation led to an above normal snowpack in the Olympics by early winter. On January 1st, snowpack at the Waterhole SNOTEL was 136% of normal, a sharp contrast to the lack of snow in Water Year 2015 (data on file at OLYM). Despite a return to much warmer than average conditions in the following months, above normal precipitation and a steady series of spring snow events, helped to nourish the snowpack and maintain it above normal through April 1st. At this point, a shift to extremely warm, dry and unusually sunny conditions occurred. At the Waterhole SNOTEL, the month of April was 7.3° F above average, while precipitation was 45% of average (Figure 5). These conditions led to the quick melt of the snowpack, especially on exposed mountain aspects subject to direct solar radiation. Because of this, snow course and SNOTEL measurements were inconsistent in April and May. Southern and sparsely treed areas exposed to direct sunlight exhibited rapid snow loss, while sun-sheltered areas in steep northern drainages maintained a more robust snowpack. This is illustrated at the Waterhole SNOTEL, a relatively sheltered site, where snow water equivalent went from 140% to 142% of normal over the month (Figure 7), while an exposed site, the Deer Park snow course, went from 88% to 13% during the month (Figure 8). Continued warm temperatures in May, hastened the melting even in sheltered locations. The Waterhole SNOTEL melted out on June 1st, 18 days earlier than average (Figure 9).

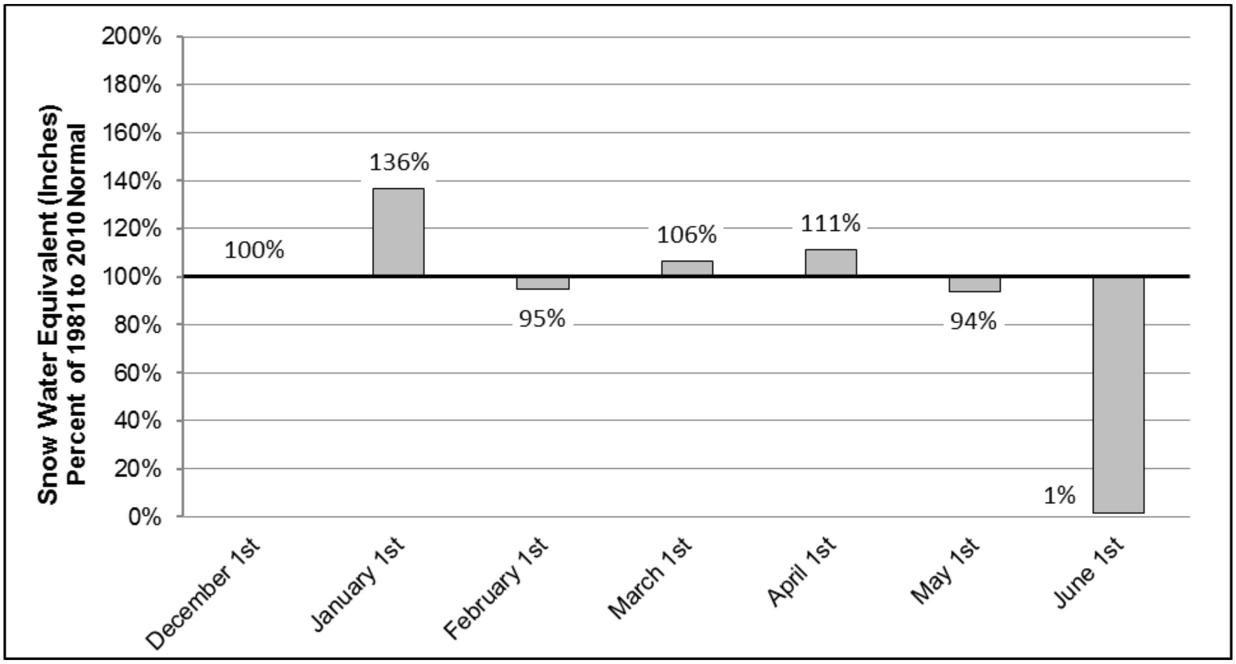

Figure 7. Comparison of snow water equivalent (inches) at the Waterhole SNOTEL in Water Year 2016 against the climatological normal 1981-2010.

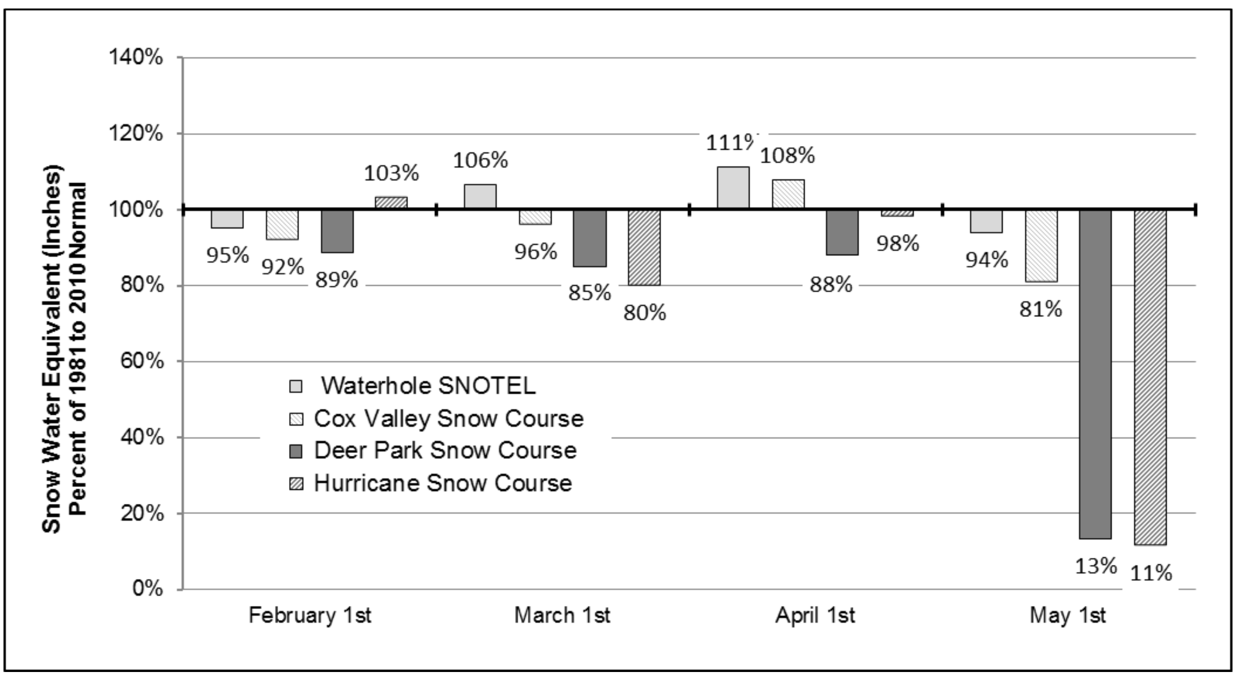

Figure 8. Comparison of snow water equivalent (inches) at long-term SNOTEL and snow courses within Olympic National Park in Water Year 2016 against the climatological normal 1981-2010.

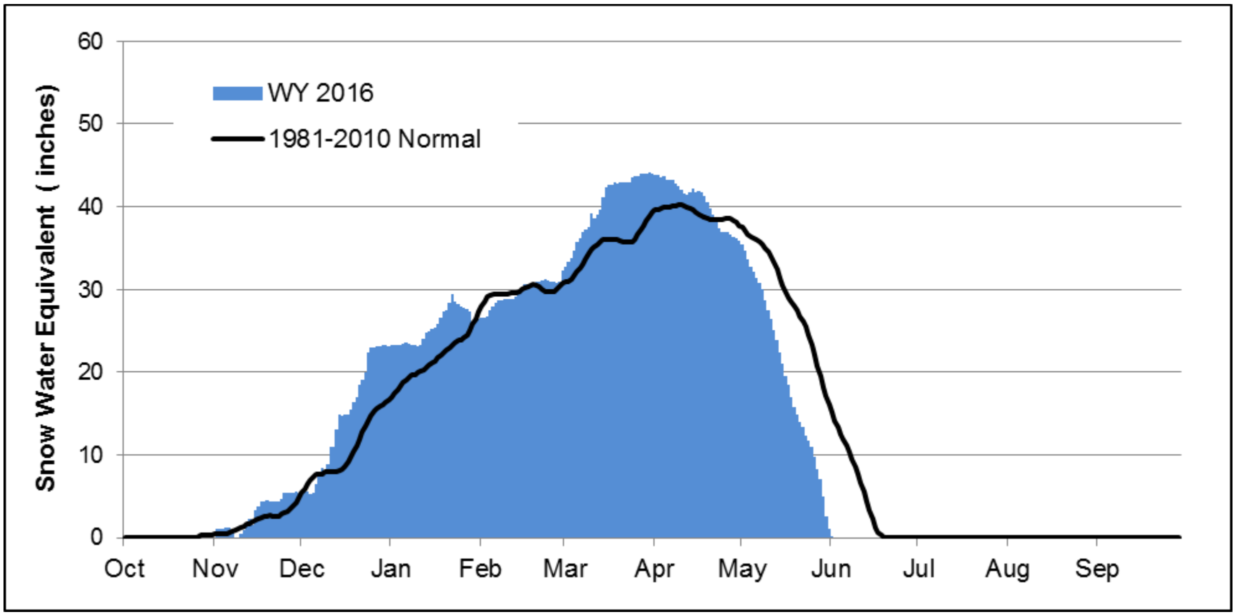

Figure 9. Daily Snow Water Equivalent (inches) at the Waterhole SNOTEL, in Water Year 2016.

2016 Water Year in Review

Significant Weather Events and Patterns

The Water Year started quite warm and wet with several significant rain events throughout October and into November. On November 13th, the first of the year's many atmospheric rivers slammed into the Olympic Mountains. This storm was followed several days later with high winds which toppled trees and heavy rains that triggered multiple landslides. Significant damage occurred in the Quinault, where large swaths of the East Fork Quinault trail were damaged (Figure 10). By the end of the six day event, over 16 inches of rain had been recorded. The same storm dropped over 8 inches of rain at the Elwha Ranger Station, leading to a major flood event on the Elwha River. This flood damaged and closed the Olympic Hot Springs Road, and buried the Elwha campground in sediment.

Figure 10. A large debris flow obscures the East Fork Quinault trail near Fire Creek. (Photograph: Carter Urnes/Joe Zagrodnik).

The November storms were followed by a stable and cold period which included record cold temperatures on the coast. A second major atmospheric river brought heavy rains to the Olympics between December 3rd and 10th, in a series of storms. The southern portions of the Park seemed to take the brunt of the event. Five day precipitation totals at the Quinault Rainforest peaked at 16 inches, and the 8 day storm total was over 25 inches of rain (Figure 11). River flooding from this event damaged the Graves Creek Road leading to its closure for the remainder of the winter. Wet warm systems continued to cross the Olympics, with major rain events on January 11th, 19th and 21st. The event on the 21st was the single wettest day of the year, dropping 2.5 inches of rain at Deer Park, and over 6 inches at the Quinault.

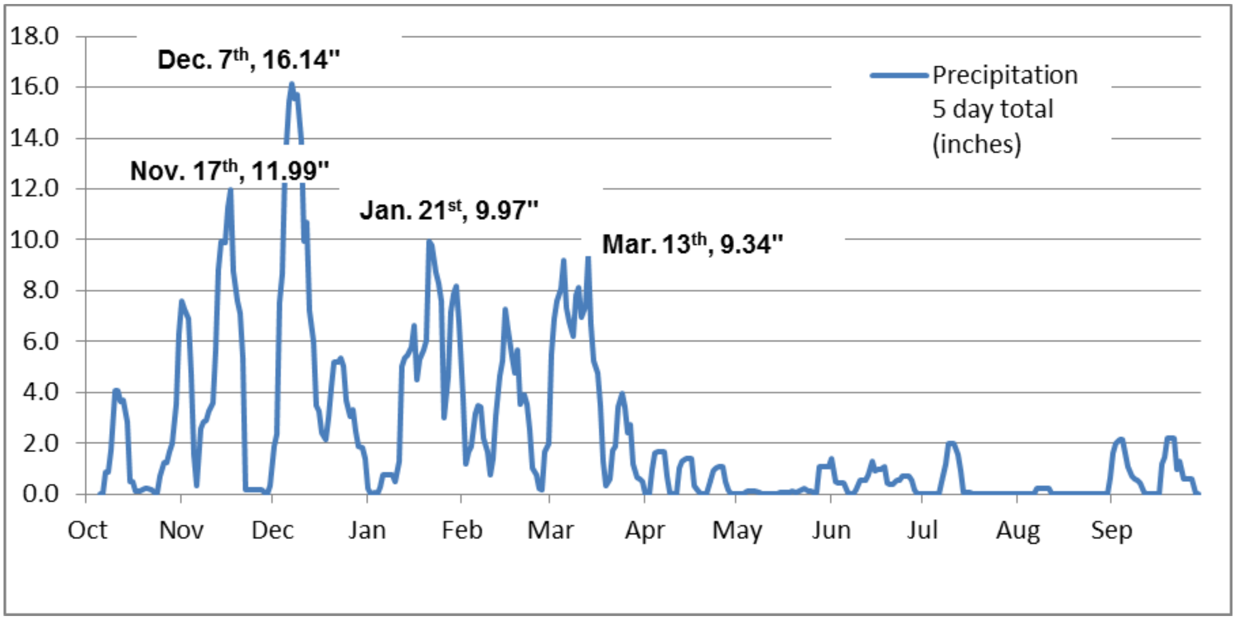

Figure 11. Five day running total of precipitation at the Quinault Rainforest weather station in Water Year 2016.

Warm weather occurred in the early part of February when a ridge of high pressure set in over the Pacific Northwest. On February 9th, the Quillayute Airport recorded a high temperature of 73° F, which tied an all-time high temperature record for the month of February (OWSC, 2016a). A second warm period occurred at the end of the month. Due in part to these events monthly average temperatures in February were warmer at most Park weather stations than the following month of March. March was also quite wet, receiving wave after wave of cool precipitation events. At the Quinault, there were only two days without rain in the first 27 days of the month, and the cooler temperatures helped to build a robust spring snowpack (Figure 9).

Conditions dried out remarkably in April and May. This period had many clear and warm days and the mountains experienced rapid melting of the snowpack, especially on exposed slopes. The month of June began on the warm side, and June 5th was the warmest days of the year at many of the Park weather stations. At the Elwha Ranger Station, the temperature reached 93° F. The remainder of June and the first part of July were notably cooler and wetter.

Conditions changed dramatically in the latter half of July and through the month of August. The Olympics experienced a prolonged period of dry weather, with only one rain event over a 48 day period between July 13th and August 31st. On July 21st, an unusually vigorous lightning storm passed over the Olympic Mountains with hundreds of documented strikes. Four of these lightning strikes ignited into wildfires which the Park allowed to burn for resource benefit. These fires grew slowly during the first part of August, but beginning on August 18th, high temperatures, and low humidity associated with off-shore flow caused the growth of the fires to accelerate rapidly. The Obstruction Point Road as well as the Dosewallips, Hayden Pass and upper Elwha River trails were closed due to active fire behavior. By the end of August, these four fires had burned over 3500 acres, the largest total acreage ever burned in the Park in a single year. Fire activity ebbed at the end of the month when on-shore flow and a rainy period subdued fire growth. September was comparatively cool and wet, with no significant weather events. The most notable aspect of September was that for many Park weather stations, it was the first month since November with below normal temperatures.

Parkwide Annual Precipitation Summary

The slopes of the Olympic Mountains receive among the highest precipitation totals in the United States. In Water Year 2016, a steady swath of storms doused the southwestern slopes of the Olympics. The highest totals were at the Quinault Rainforest where 164.5 inches (nearly 14 feet) of rain fell. The second highest was also in the southwest corner, at the Buckinghorse SNOTEL, where 157.7 inches of precipitation (mostly snow) was recorded. The Park's coastal weather stations ranged from 89.0 to 77.4 inches. 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. Deer Park was the driest site, receiving only 45.9 inches of precipitation (Figure 12).

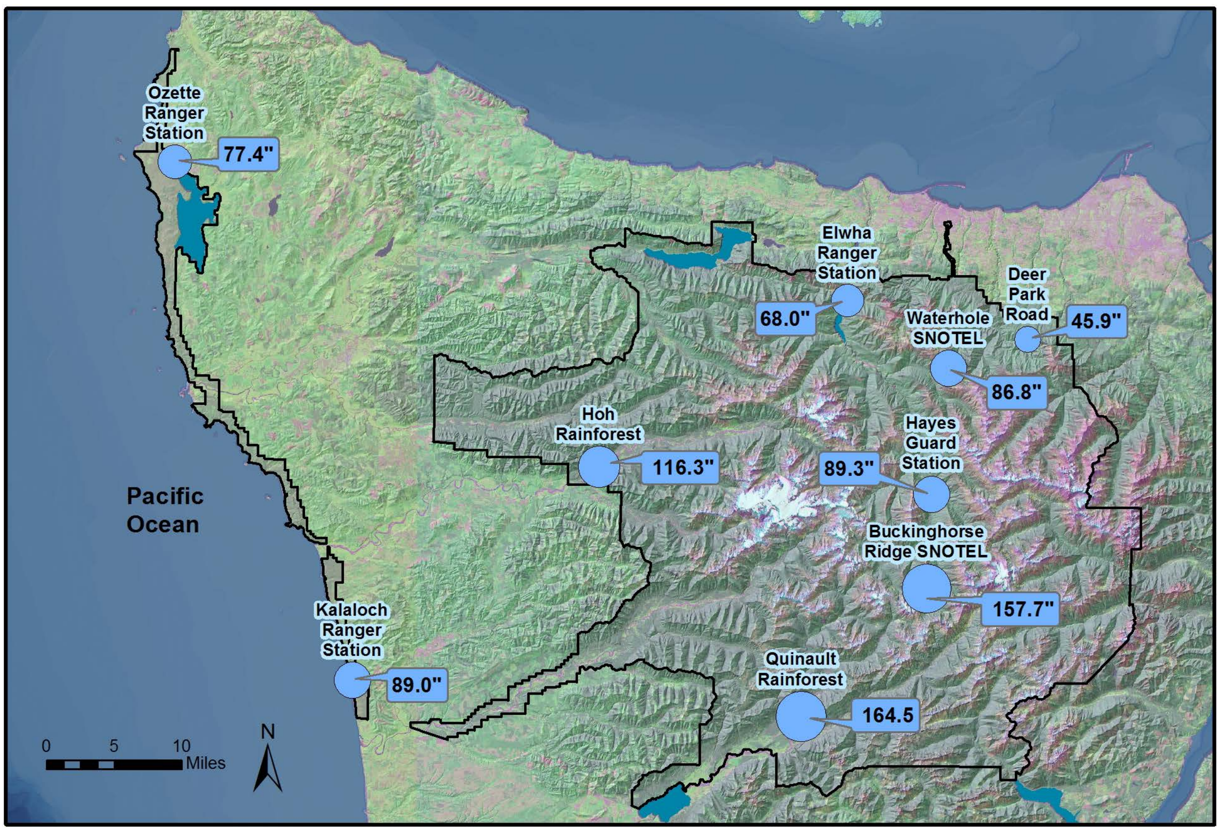

Figure 12. Total precipitation measured at weather stations located within Olympic National Park during Water Year 2016. Blue circles are proportional to the total amount of precipitation measured at each site.

Literature Cited

Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters 42:3414–3420. doi: 10.1002/2015GL063306.

Cavole, L.M., A.M. Demko, R.E. Diner, A. Giddings, I. Koester, C.M.L.S. Pagniello, M.-L. Paulsen, A. Ramirez-Valdez, S.M. Schwenck, N.K. Yen, M.E. Zill, and P.J.S. Franks. 2016. Biological impacts of the 2013–2015 warm-water anomaly in the Northeast Pacific: Winners, losers, and the future. Oceanography 29(2):273–285, https://doi.org/10.5670/oceanog.2016.32.

Cayan, D. R., K. Redmond, and L. Riddle. 1999. ENSO and hydrologic extremes in the Western United States. Journal of Climate 12:2881–2893.

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_nccn inventory_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.

Jacox, M. G., E. L. Hazen, K. D. Zaba, D. L. Rudnick, C. A. Edwards, A. M. Moore and S. J. Bograd. 2016. Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events. Geophysical Research Letters 43(13):7072–7080. doi:10.1002/2016GL069716.

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.

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. 2016. SNOTEL and Snow Course data report generator. Available online: https://wcc.sc.egov.usda.gov/reportGenerator/ (accessed 2 December 2016).

NOAA – Climate.gov. 2016. The Oceanic Nino Index. Available online: https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-nino-index (accessed 12 April, 2017).

NOAA - National Centers for Environmental Information. 2017. El Niño 2015/16: A historical perspective. Available online: https://www.ncdc.noaa.gov/monitoring-references/dyk/elnino-2015-2016 (accessed 12 April, 2017).

NWS Climate Prediction Center 2017. El Niño and La Nina – Related Winter Features over North America. Available online: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/nawinter.shtml (accessed 5 June 2017).

Office of the Washington State Climatologist (OWSC). 2016a. Newsletter, March 8, 2016. Available from: http://www.climate.washington.edu/newsletter/2016Mar.pdf (accessed 14 April 2017).

Office of the Washington State Climatologist (OWSC). 2016b. Newsletter, June 14, 2016. Available from: http://www.climate.washington.edu/newsletter/2016Jun.pdf (accessed 12 April 2017).

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

Western Regional Climate Center. 2017. NOAA Cooperative Climatological Data Summaries. Available online: http://www.wrcc.dri.edu/climatedata/climsum/ (accessed 19 January 2017).

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Natural Resource Stewardship and Science

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

www.nature.nps.gov