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 2012

Natural Resource Data Series NPS/NCCN/NRDS—2016/1002

ON THIS PAGE
A dense layer of clouds shrouds lower elevation areas during a prolonged temperature inversion event. On this December day, Hurricane Ridge (in foreground) was 15°F warmer than sea level stations below the clouds.
Photograph by: Bill Baccus

ON THE COVER
Late season snowpack melts near the snout of the Black Glacier, Mt. Olympus. August 2012.
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.

This report is available in digital format from the North Coast and Cascades Network Inventory and Monitoring website (http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). 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 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 2012 water year, and is part of a set of climate summary reports from six 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. The report briefly discusses the implications of transitioning to a new climatological normal (1981 to 2010) from the old normal (1971 to 2000), which was referenced in previous reports. A summary is provided to describe any significant weather events during the water year and how these may have affected park resources.

Water Year 2012 continued a trend of wetter and cooler than normal weather conditions, which began in 2010. Summarized weather data indicated that this year had below normal annual temperatures and near normal annual precipitation. The snowpack built early, stagnated in mid-winter, then built to above normal conditions by late spring, persisting significantly longer than normal. The first part of summer remained cool and wet, while the later months of August and September were some of the driest on record.

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
- 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	National Weather Service Cooperative Observer Station
CRN	Climate Reference Network
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 Weather and 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 fall, winter, and spring seasons (Cayan et al. 1999) (Climate Impacts Group, 2014).

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.

Pacific Decadal Oscillation (PDO): a recently described pattern of climate variation similar to ENSO though on a timescale of decades and not seasons. In North America, warm phases of PDO are correlated with El Niño-like temperature and precipitation anomalies, while cool phases of PDO are correlated with La Niña-like climate patterns. PDO variability is strongly expressed in regional snow pack and stream flow anomalies, especially in western North America (Mantua 2010).

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, a 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.

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

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

Water Year: The Water Year (or Hydrologic Year) is most often defined as the period from October 1st to September 30 of the following year. It is called by the calendar year in which it ends. Thus, Water Year 2012 is the 12-month period beginning October 1, 2011 and ending September 30, 2012. The period is chosen so as to encompass a full cycle of precipitation accumulation.

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

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

Introduction

Climate is a dominant driver of the physical and ecologic processes of the North Coast and Cascades Inventory and Monitoring Network Parks (NCCN, Figure 1) (Davey et al. 2006). Trends in rainfall and temperature influence how 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 2012 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.

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 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.

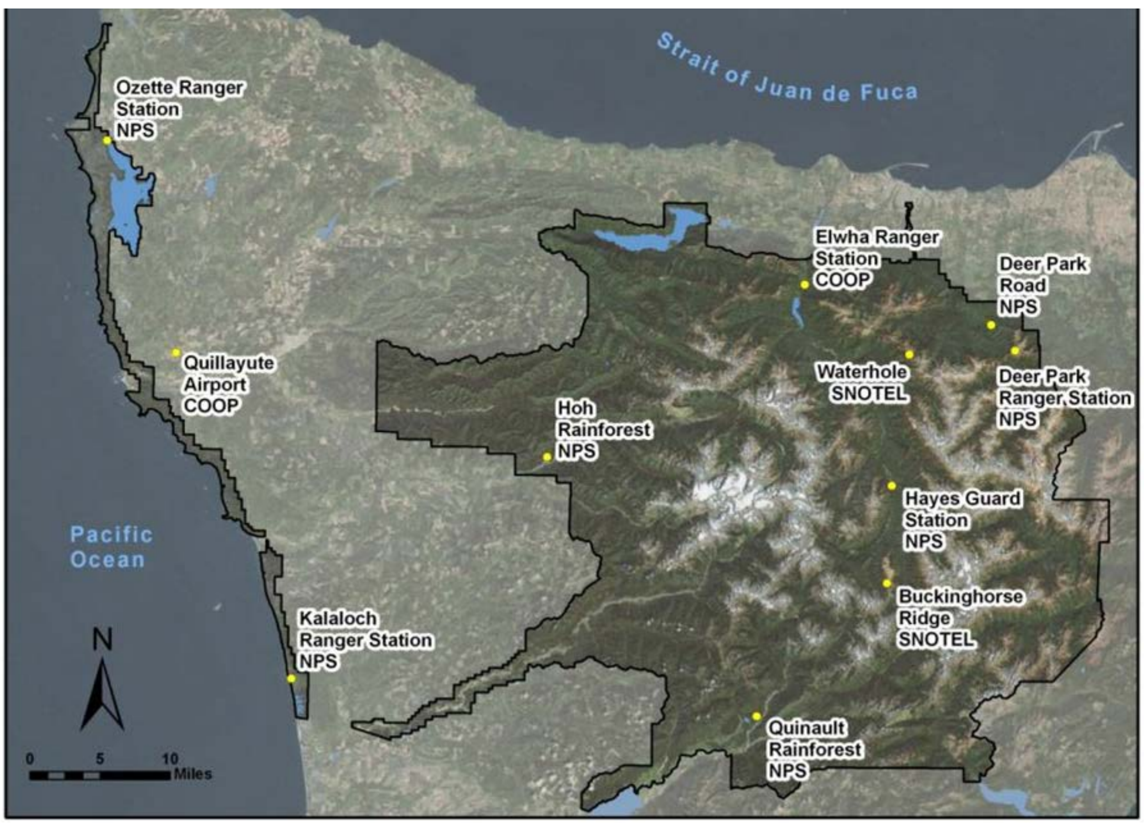

Figure 2. Location of weather stations referenced in this report.

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; X 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**	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 (National Climate Data Center 2014 and National Water and Climate

Center 2014, 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 2012 Data Quality

Recent upgrades to weather stations were effective in preventing the loss of data experienced in Water Year 2011. In that year, the snow depth sensor at the Buckinghorse SNOTEL station was over-topped when the snowpack reached 180 inches. In response to this, an additional length of pipe was installed that extended the height of the snow depth sensor. In Water Year 2012, the snowpack reached a new maximum of 211 inches, and the extension prevented snow burial of the sensor. At Ozette and the Quinault Rainforest sites, expanded memory on data loggers eliminated data gaps experienced in previous years when site visits were delayed.

NCCN weather stations continued to experience problems with the Vaisala HMP 45C temperature and relative humidity probes. In past years, we noted a downward drift of recorded air temperature values, seemingly when probes were exposed to prolonged periods of high humidity (e.g. coastal or understory locations) (Baccus et al. 2012). Without replicate instruments in place, this drift is difficult to detect, as data appear shifted only a few degrees below the suspected temperature (based on site visit measurements and data from nearby stations). Sensors that may have recorded below ambient temperatures during field deployment appear to record accurate measurements once drier conditions return. These sensors typically calibrate in the lab with no significant drift documented. As funds become available, we hope to replace these sensors with Campbell Scientific CS215 air temperature/Relative Humidity sensors or with CS108 temperature sensors.

Sensor failure may have occurred at the Hoh Rainforest in 2012. We compared 2012 temperature data from the Quinault and Hoh Rainforest sites to their period of record, and the departure of monthly temperatures at the Hoh were one or two degrees lower than the Quinault (Figure 3). The majority of weather stations within OLYM showed monthly temperature patterns similar to Quinault, making the Hoh pattern of temperature deviation questionable. The single exception came from the Elwha Ranger Station COOP where air temperature data (recorded with an entirely different sensor) exhibited a similar pattern of colder than normal months for most of the year (see Figure 7.) The air temperature data from the Hoh was flagged as uncertain with explanatory notes: even so, we present the data in this report as recorded.

The problems encountered while attempting to verify the accuracy of these air temperature sensors in a field environment highlight the need for a more stable temperature sensor and/or replicate sensors to enable better evaluation of the accuracy of our measurements.

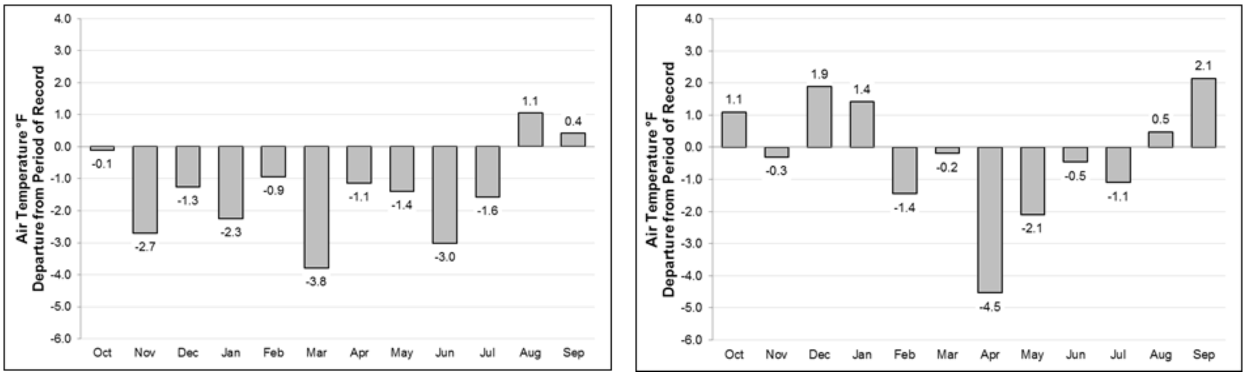

Figure 3. Comparison of average monthly temperature (°F) for the Hoh Rainforest (left) and the Quinault Rainforest (right) in Water Year 2012 against monthly averages for the period of record (1999-2011).

Power limitations continue to 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: October to May, Hayes River: November to March).

April 1st snow surveys were not conducted at the Deer Park and Hurricane Snow Courses this year. A major snow event and employee illness during the short sampling period stymied attempts to complete all three surveys.

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, 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. Available upon request are hourly, daily, or monthly weather data from each station noted in Tables 1 and 2.

Updated Climate Normals

Climate normals refer to the calculated long-term values of meteorological parameters at a specific location. Normals are typically based on the most recent 30-year average of temperature and precipitation data and serve as a baseline against which to compare current weather conditions with a longer term record.

In July of 2011, the National Climatic Data Center (NCDC) released new normals, based on 1981-2010 climate data. These new values were incorporated into National Weather Service climate products as of August 1, 2011, and replace the previous 30-year normal based on 1971 to 2000 data. Arguez et al. (2012) present an overview of the computation of the 1981-2010 climate normals. The NRCS released new normals for SWE in late 2012 (NRCS 2013). To provide consistency with these agencies, we used these new (1981-2010) normals in this report.

NCCN climate reports compare monthly temperature, precipitation, and SWE data from several weather stations against the climate normals. These data are displayed as a departure value from these normals. Newly calculated normals will often vary from the previous normals, due in part to long-term climate anomalies such as the Pacific Decadal Oscillation (PDO). The PDO exerts a notable influence on local climate patterns and expresses itself as oscillating warm and cool phases which are typically 15 to 25 years in length (Mantua et al. 1997). In cases where a large proportion of a 30 year normal is dominated by a single phase of the PDO, that phase (warm/dry vs. cool/wet) can influence the average values calculated for that period (i.e. the 30 year normal).

An extended cool and wet period in the early to mid1970’s influenced the 1971-2000 normal, while a prolonged warm and dry phase in the 1980’s and 1990’s (with only a few short cool phases at the end of the last decade) affected the 1981-2010 normal (see Figure 4). Thus, the 1981 to 2010 period includes a larger portion of warm and dry years than the previous normal, resulting in climate normals with a small increase in temperature, a slight decrease in precipitation, and a moderate decrease in snowpack.

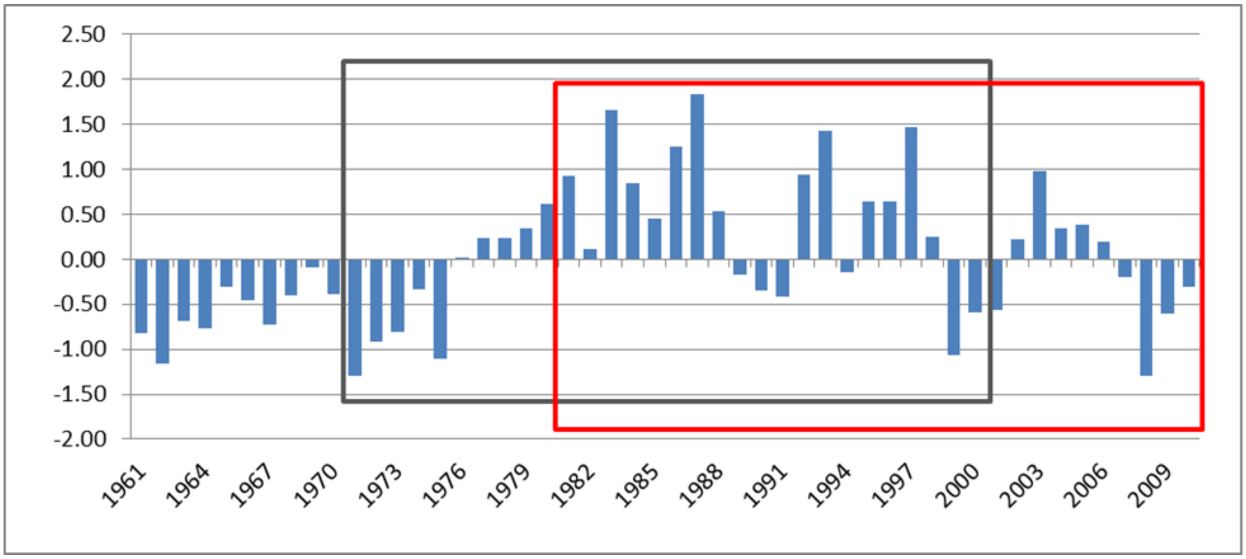

Figure 4. The relationship of the 1971-2000 (gray box) and 1981-2010 (red box) Climate Normals to standardized values of the Pacific Decadal Oscillation (PDO) index. Positive values indicate warm/dry phases of the PDO. Negative values indicate cool/wet phases.

When new temperature normals (1981- 2010) were compared to previous normals (1971-2000) at two long term OLYM weather stations, we observed several slight shifts. Annual temperature shifts were more significant at the Elwha Ranger Station (+1.0°F) than at our coastal site at Quillayute Airport (+0.2°F). At the Elwha, fall and summer months stood out as having the greatest increase in temperature. Although the combined winter months did not show the same increase as the fall months, it is noteworthy that for both the OLYM stations, the greatest change in monthly temperature was January with +1.0 and +1.8°F at the Quillayute and Elwha respectively (Table 3).

Table 3. Comparison of 1971-2000 and 1981-2010 climate normal for temperature (°F).

		Quillayute Field COOP			Elwha Ranger Station COOP		
Season	**Month**	**1971-2000 Normal**	**1981-2010 Normal**	**Change**	**1971-2000 Normal**	**1981-2010 Normal**	**Change**
Fall	Oct	50.1	50.0	-0.1	48.1	48.9	0.8
	Nov	44.2	44.2	0.0	40.1	41.2	1.1
Winter	Dec	40.6	40.4	-0.2	36.1	36.5	0.4
	Jan	40.6	41.6	1.0	35.6	37.4	1.8
	Feb	42.2	42.1	-0.1	38.0	38.5	0.5
Spring	Mar	43.8	44.1	0.3	42.0	42.7	0.7
	Apr	46.7	46.1	-0.6	46.5	47.3	0.8
	May	51.2	51.3	0.1	51.9	52.8	0.9
Summer	Jun	54.9	55.3	0.4	56.3	57.6	1.3
	Jul	58.6	58.9	0.3	60.8	61.8	1.0
	Aug	59.3	59.6	0.3	61.9	63.0	1.1
Fall	Sep	56.5	56.6	0.1	57.0	58.0	1.0
Annual		49.1	49.3	0.2	47.9	48.9	1.0

Changes in precipitation were found by comparing previous and current normals, however the differences were slight. The new normal at Quillayute exhibited a -2.22 inch annual decrease, about a 2% change. The largest shift in precipitation at Quillayute was detected during winter months (Table 4), including reductions of 10% and 16% in January and February, respectively, and modest increases in October and November. Annual change in precipitation was even smaller at the Elwha; however significant monthly changes were observed in November and February, with a 10% increase and 21% decrease, respectively.

Table 4. Comparison of 1971-2000 and 1981-2010 climate normals for precipitation (inches).

		Quillayute Field COOP			Elwha Ranger Station COOP		
Season	**Month**	**1971-2000 Normal**	**1981-2010 Normal**	**Change**	**1971-2000 Normal**	**1981-2010 Normal**	**Change**
Fall	Oct	9.81	10.49	0.68	4.85	5.22	0.37
	Nov	14.82	15.52	0.70	9.41	10.38	0.97
Winter	Dec	14.5	12.99	-1.51	9.41	9.07	-0.34
	Jan	13.65	14.61	0.96	8.62	9.3	0.68
	Feb	12.35	10.35	-2.00	7.15	5.64	-1.51
Spring	Mar	10.98	10.83	-0.15	6.05	6.1	0.05
	Apr	7.44	7.85	0.41	3.25	3.21	-0.04
	May	5.51	5.11	-0.40	1.92	2.12	0.20
Summer	Jun	3.5	3.5	0.00	1.25	1.33	0.08
	Jul	2.34	1.98	-0.36	0.83	0.83	0.00
	Aug	2.67	2.49	-0.18	1.22	1.19	-0.03
Fall	Sep	4.15	3.82	-0.33	1.64	1.51	-0.13
Annual		101.72	99.5	-2.22	55.6	55.9	0.3

Climate normals for Snow Water Equivalent (SWE) decreased 7.0 to 21.5% at the OLYM stations when comparing the 1971-2000 normals to the 1981-2010 values (Table 5). The Hurricane Snow Course, which is the lowest elevation of the OLYM snow courses and occurs on a south facing slope, showed the most pronounced change whereas the Cox Valley Snow Course, at a highest elevation and within a sheltered, north-facing valley, showed less change. The substantial decreases observed between the climate normal periods will have pronounced implications for interpreting comparisons between annual change and a climate normal.

Table 5. Comparison of 1971-2000 and 1981-2010 climate normals for April 1st snow water equivalent (SWE) in inches.

Snow Course	**1971-2000 Normal**	**1981-2010 Normal**	**Change**
Cox Valley	38.7	36.0	-7.0%
Deer Park	18.8	16.7	-11.2%
Hurricane	19.1	15.0	-21.5%

Results

Temperature

Water Year 2012 was cooler than normal, with nearly 75% of monthly average temperatures at both Quillayute Airport and the Elwha Ranger Station showing negative deviations (Figures 5 and 6). The fall started cool, with October temperatures at or slightly below normal. Quillayute Airport had an

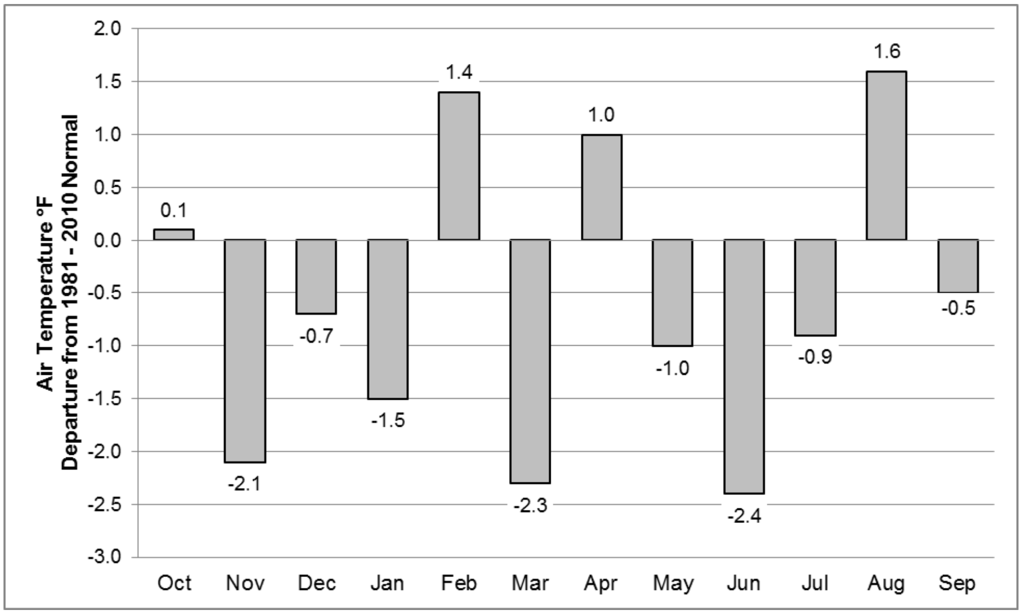

Figure 5. Comparison of average monthly temperature (°F) for Quillayute Airport in Water Year 2012 against monthly averages for the climatological normal 1981-2010.

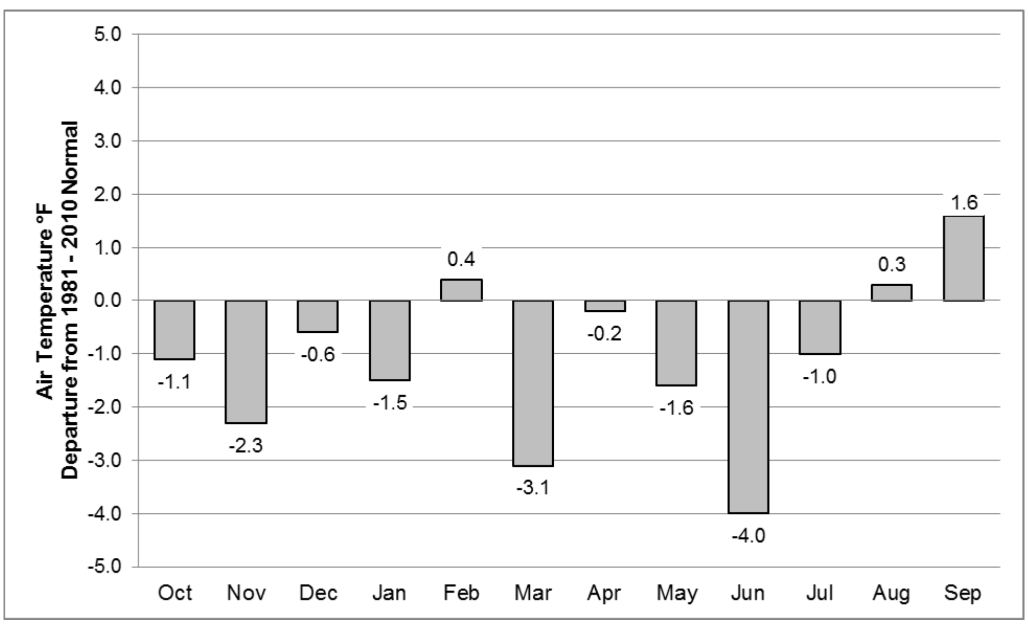

Figure 6. Comparison of average monthly temperature (°F) for Elwha Ranger Station in Water Year 2012 against monthly averages for the climatological normal 1981-2010.

average temperature of 42.1°F in November (Table 6), 2.1°F below normal (Figure 5). Conditions were similar at Elwha Ranger Station (Table 6 and Figure 6).

Winter months continued the trend from fall, with average monthly temperatures slightly cooler than normal at Quillayute Airport and the Elwha Ranger Stations (Figures 5 and 6). It is noteworthy that while cooler than normal conditions were recorded at these low elevation sites, the story was much different at high elevations. In December, a strong temperature inversion lasted several weeks and influenced monthly temperatures. This can be seen clearly when comparing monthly average temperatures at the Waterhole SNOTEL on Hurricane Ridge (4,961' elevation) with the low elevation stations at the Elwha Ranger Station (390'). In Figure 7, we compare air temperatures at these sites against the period of record, because a 30 year normal does not exist for any high elevation stations at OLYM. In December, the Waterhole SNOTEL was 3.5°F above average, while the Elwha Ranger Station, closer to sea level, had temperatures 1.3°F below average (Figure 7). This December inversion, and the warmer than average temperatures in February, made the winter season at high elevations above average, while at low elevations, the season was slightly below average.

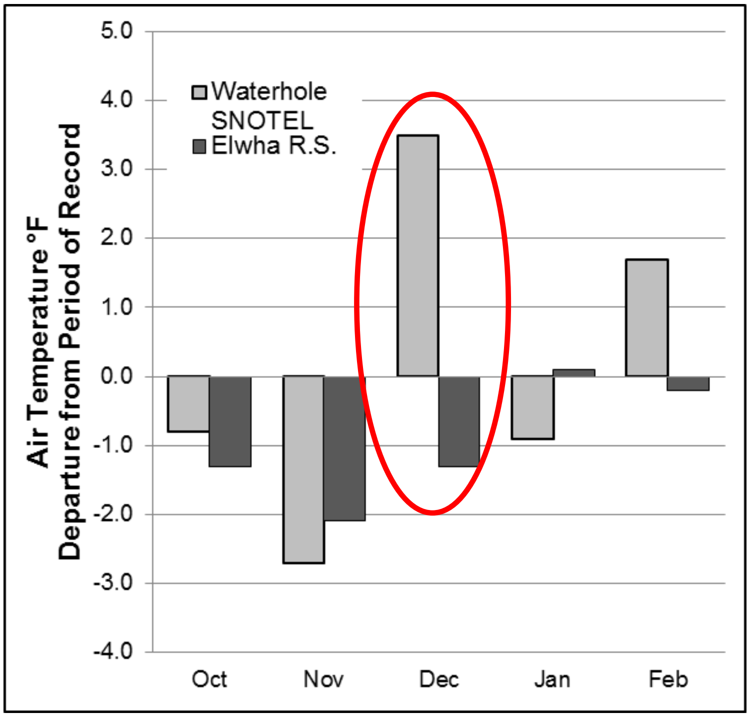

Figure 7. Comparison of average monthly temperature (°F) for Waterhole SNOTEL and the Elwha Ranger Station in Water Year 2012 against monthly averages for the period of record.

Spring months averaged 0.8 and 1.6°F below normal at Quillayute Airport and Elwha Ranger Station, respectively (Figures 5 and 6). March had the greatest deviation with 3.1°F below normal at the Elwha. Early summer continued quite cold, with June averaging 2.4 and 4.0°F below normal at Quillayute Airport and Elwha Ranger Station, respectively (Figures 5 and 6). Statewide, the average June temperatures ranked among the top ten coolest at several locations for the period of record (OWSC 2012a). The month of July remained slightly below normal; however, August averaged above normal.

Table 6. Average monthly air temperatures (°F) from weather stations within or adjacent to Olympic National Park in Water Year 2012.

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 2011	40.1	35.8	43.5	47.8	42.5	48.3	50.9	49.0	50.1	49.9	37.9
	November 2011	30.1	25.6	34.7	38.9	33.5	39.3	43.2	41.7	42.1	40.4	28.2
Winter	December 2011	34.2	29.4	35.5	35.9	31.0	36.8	40.9	39.3	39.7	38.6	31.1
	January 2012	29.8	25.4	33.6	35.9	31.2	37.0	41.0	39.9	40.1	38.4	27.6
	February 2012	31.6	27.6	35.6	38.9	32.3	38.7	42.7	43.1	43.5	36.7	29.5
Spring	March 2012	28.5	25.2	33.5	39.6	32.2	37.6	41.3	41.3	41.8	40.5	26.9
	April 2012	35.7	33.4	40.1	47.1	39.8	43.7	47.6	47.0	47.7	41.2	33.5
	May 2012	40.8	37.1	44.6	51.2	46.7	48.9	49.9	49.4	50.3	49.6	38.0
Summer	June 2012	42.9	40.1	46.1	53.6	51.0	52.4	53.8	52.7	52.9	56.4	40.7
	July 2012	54.3	52.4	56.9	60.8	58.7	58.0	56.7	56.4	58.0	60.3	51.5
	August 2012	56.7	53.8	60.6	63.3	59.3	60.4	57.9	59.2	61.2	61.4	52.9
Fall	September 2012	54.4	51.9	58.3	59.6	52.3	56.2	54.1	54.4	56.1	59.4	49.8
Water Year		39.9	36.5	43.6	47.7	42.5	46.4	48.3	47.8	48.6	47.7	37.3

Precipitation

Cumulative precipitation for Water Year 2012 was near average at most weather stations at OLYM. Quillayute Airport received 105.4 inches of annual precipitation, 106% of normal. Elwha Ranger Station received 48.7 inches, 87% of normal (Table 7).

Precipitation during fall months was slightly below normal (Quillayute 96% and Elwha Ranger Station 80%). Winter months remained below normal, mostly due to an unusually dry December, with precipitation totals 61% and 48% of normal at Quillayute Airport and Elwha Ranger Station, respectively (Figures 8 and 9). This ranked as the 5^{th} driest December on record at both Quillayute and Elwha, with records spanning back to 1966 and 1942, respectively.

Spring months exhibited a sudden shift to wetter than usual conditions, receiving 136% of normal precipitation at Quillayute Airport and 103% at the Elwha Ranger Station. March ended up being the wettest month of the year at most Park weather stations. Quillayute Airport received 21.0 inches, 194% of normal, while the Elwha was 175% of normal in March. The Buckinghorse Ridge SNOTEL recorded 30.4 inches in March, the highest monthly amount recorded at any site this water year. Early summer months continued wet, with June at 200% and 142% of normal at Quillayute and Elwha, respectively (Figures 8 and 9). July was near normal at 97% and 95% at Quillayute and Elwha, respectively. This wetter than normal period was followed by the unusually dry months of August and September, when Quillayute was 18% of normal and Elwha was 6% of normal. At both stations, this was the second driest combined August/September in the period of record.

Table 7. Total monthly precipitation (inches) from weather stations within or adjacent to Olympic National Park in Water Year 2012.

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 2011	12.2	2.6	2.5	3.6	6.6	9.1	8.5	7.5	10.4	13.0	4.4
	November 2011	21.4	4.8[a]	7.1	9.5	10.9	15.5	11.9	10.5	14.5	21.4	13.3
Winter	December 2011	8.7	2.6[a]	3.1	4.3	6.4[a]	6.8	6.6	6.7	7.9	10.3	4.9
	January 2012	23.8	4.1[a]	5.6	8.1	8.1[a]	16.2	14.1	11.4	15.6	21.0	14.6
	February 2012	13.4	1.7[a]	2.7	5.9	7.0[a]	12.0	12.1	9.7	11.4	13.0	6.9
Spring	March 2012	30.4	4.5[a]	5.2	10.7	11.9[a]	19.3	20.7	15.0	21.0	22.3	19.1
	April 2012	8.3	3.0	3.3	2.7	4.6	10.2	8.2	8.6	10.3	9.8	5.8
	May 2012	3.6	1.7	2.1	1.0	1.8	4.7	4.6	4.2	4.6	3.9	2.5
Summer	June 2012	3.8	2.6	3.0	1.9	2.6	4.9	6.9	7.5	7.0	4.6	3.1
	July 2012	1.0	1.2	1.3	0.8	0.9	2.0	2.3	1.6	1.9	1.4	1.1
	August 2012	0.4	0.4	0.3	0.1	0.1	0.3	0.5	0.3	0.5	0.5	0.1
Fall	September 2012	0.3	0.1	0.2	0.1	0.1	0.4	0.6	0.6	0.6	0.3	0.2
Water Year		127.3	29.3	36.3	48.7	60.9	101.6	96.8	83.4	105.4	121.4	76.0

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

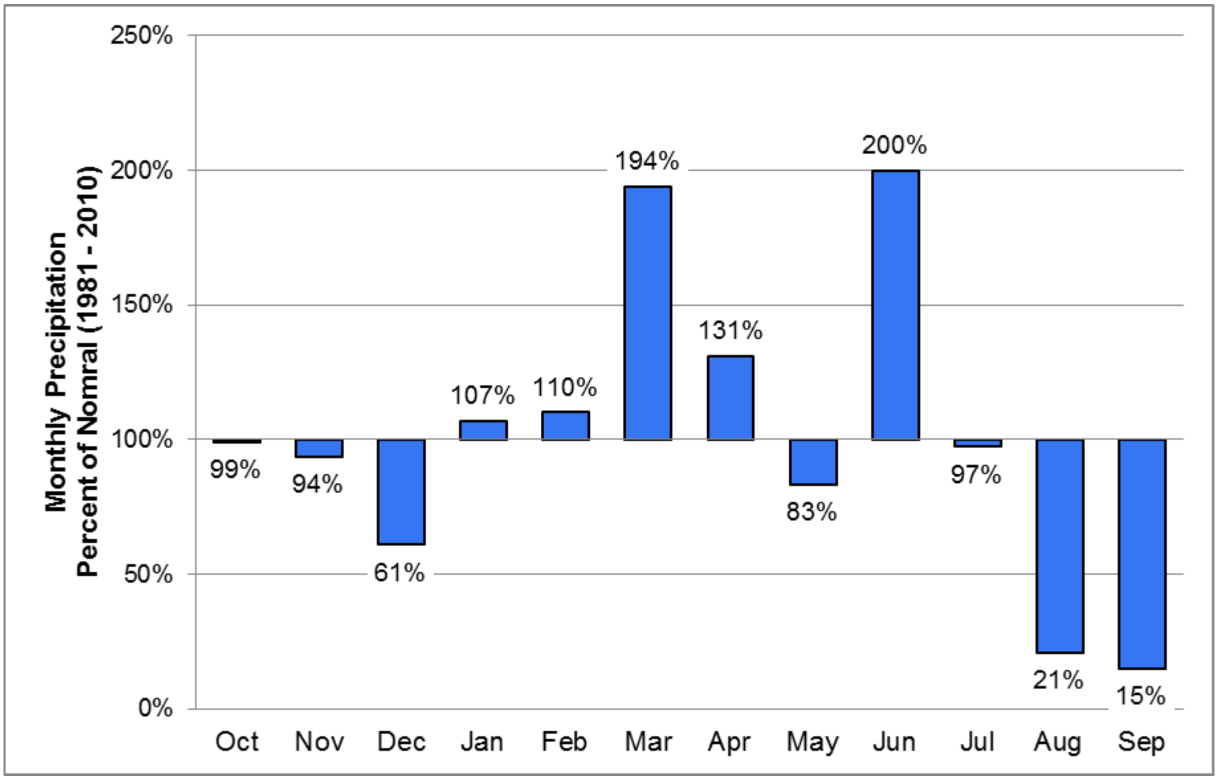

Figure 8. Comparison of monthly total precipitation (inches) as a percent of normal at Quillayute Airport in Water Year 2012 against the climatological normal 1981-2010.

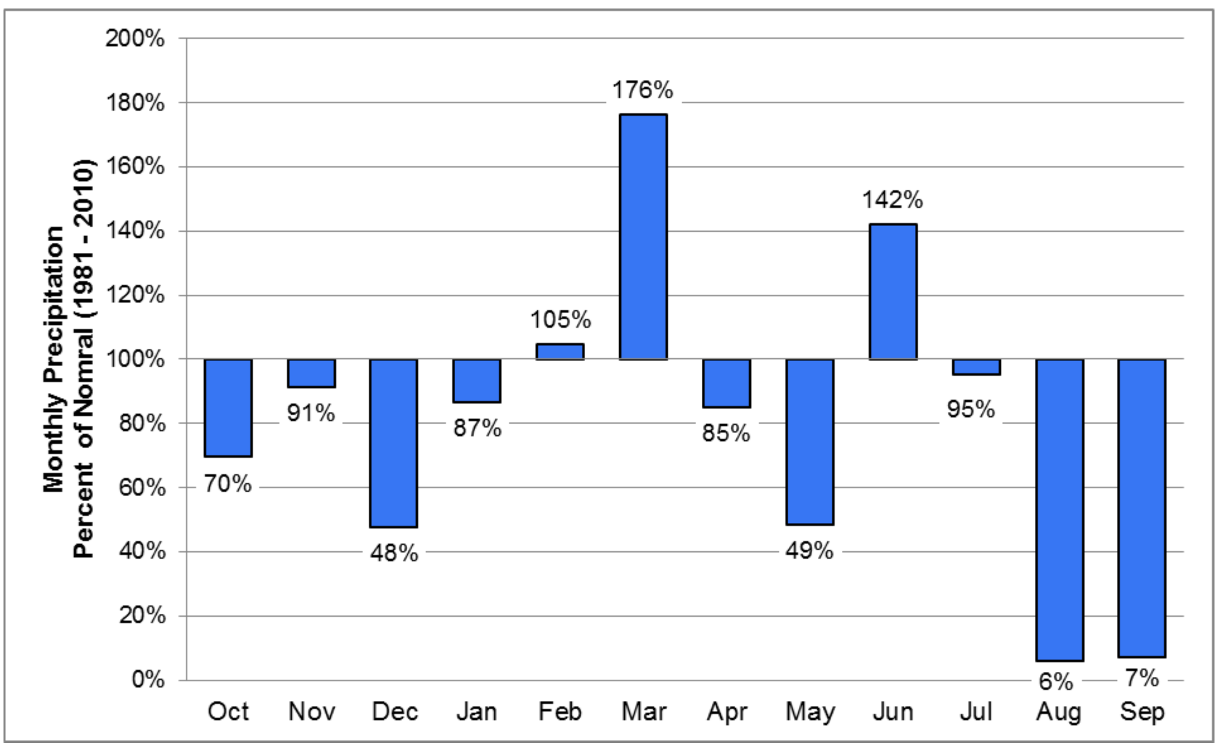

Figure 9. Comparison of monthly total precipitation (inches) as a percent of normal at the Elwha Ranger Station in Water Year 2012 against the climatological normal 1981-2010.

Snow

A series of late November storms contributed to an above normal snowpack by December 1st. Snow water equivalent (SWE) at Waterhole was 189% of normal as of December 1st (Figure 10). In December, unusually dry conditions limited the growth of the snowpack. In fact, SWE remained at ten inches with no growth in snowpack from November 25th to December 25th. By January 1st, SWE had dropped to 86% of normal. Overall, snowpack and SWE remained below or near normal from January to mid-February (Figure 11).

Mid-February marked a return to wetter conditions. Significant new snow at the end of February, and colder than normal temperatures and heavy snowfall in March, contributed to an above normal snowpack that lasted from March to early July (Figures 10, 11, and 12). Snowpack on April 1st was 213 inches at Buckinghorse SNOTEL and 155 inches at Waterhole (Table 8). The greatest snowpack deviation was measured at Deer Park, where the Snow Course was 206% of normal by May 1st (Figure 12). A colder and wetter than normal June slowed melting and contributed to a prolonged summer snowpack. The snow melted out at Waterhole on July 10, nineteen days later than normal (Figure 12).

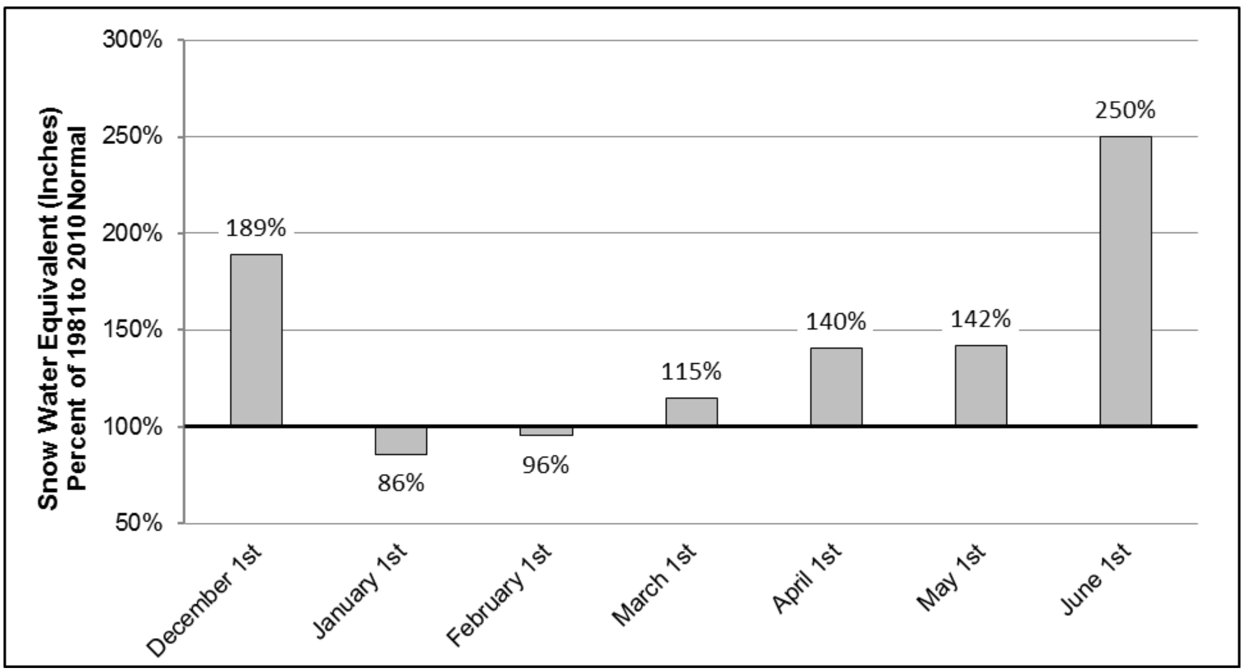

Figure 10. Comparison of snow water equivalent (inches) at the Waterhole SNOTEL in Water Year 2012 against the climatological normal 1981-2010.

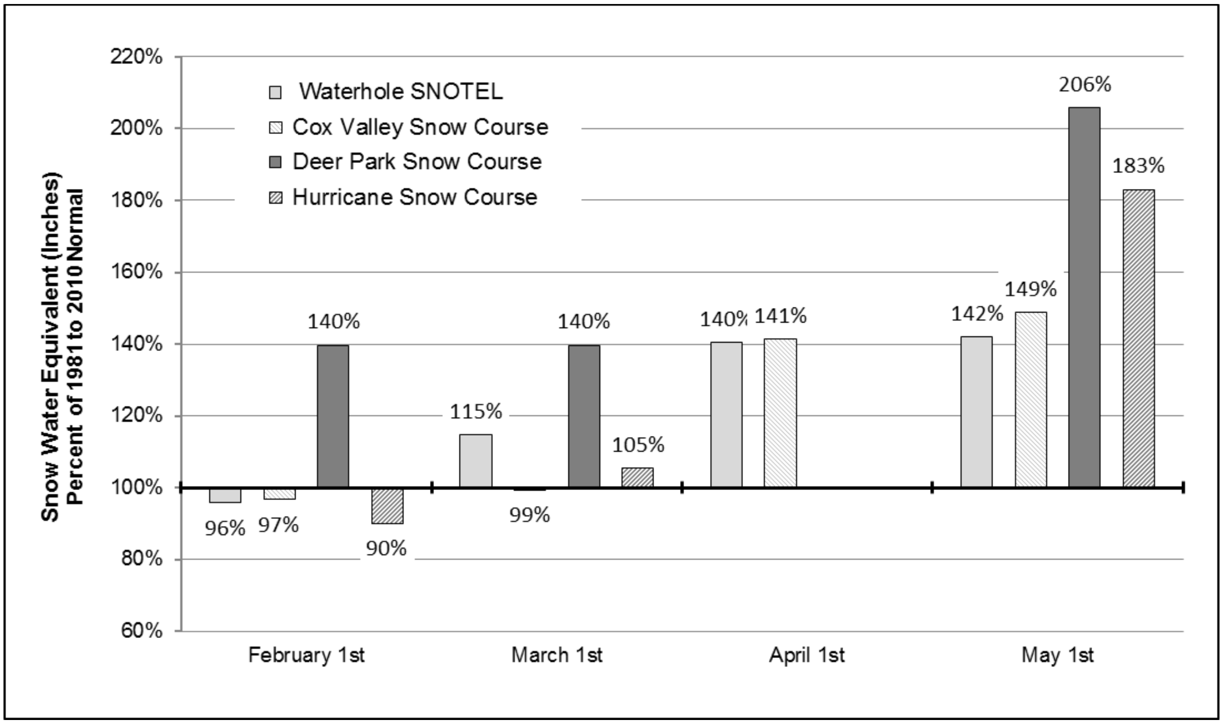

Figure 11. Comparison of snow water equivalent (inches) at long-term SNOTEL and snow courses within Olympic National Park in Water Year 2012 against the climatological normal 1981-2010.

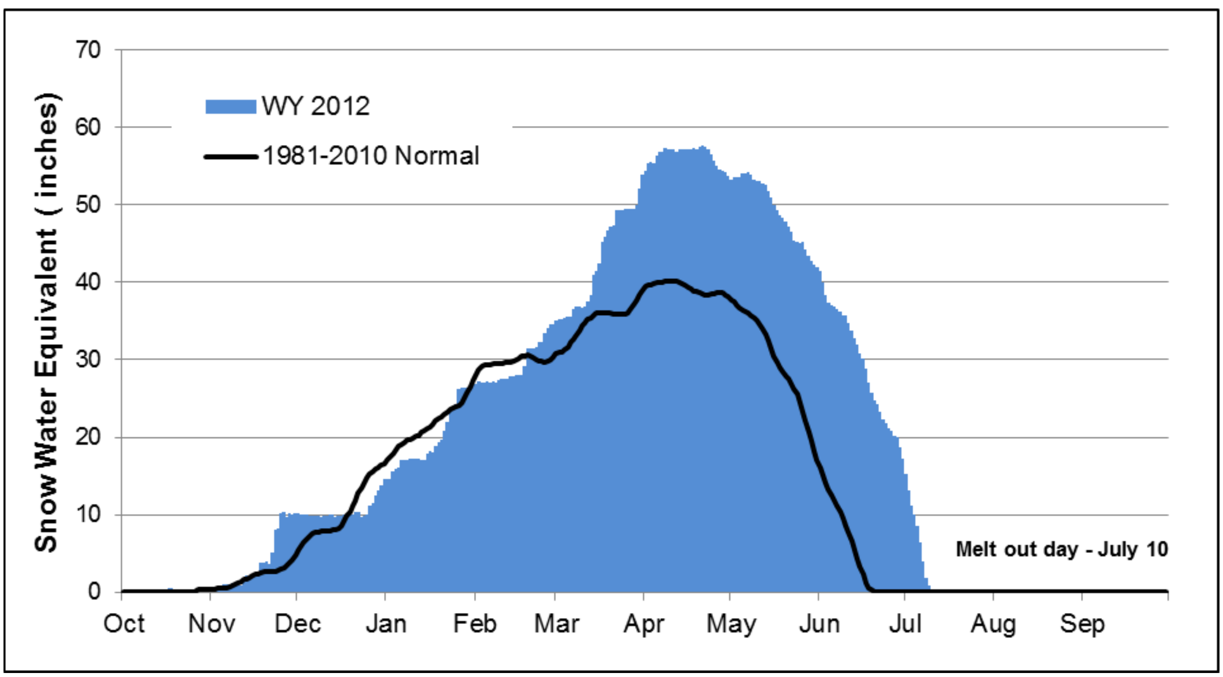

Figure 12. Daily Snow Water Equivalent (inches) at the Waterhole SNOTEL, in Water Year 2012.

Table 8. Snow depth (inches) measured on the first day of the month at SNOTEL and snow courses within Olympic National Park during Water Year 2012.

Month & Year	Buckinghorse Ridge SNOTEL	Waterhole SNOTEL	Cox Valley Snow Course[1]	Deer Park Snow Course[1]	Hurricane Snow Course[1]
November 1, 2011	0.0	0.0	----	----	----
December 1, 2011	32.0	25.0	----	----	----
January 1, 2012	53.0	42.0	----	----	----
February 1, 2012	105.0	72.0	68.9	46.2	41.7
March 1, 2012	140.0	100.0	83.0	57.3	55.5
April 1, 2012	213.0	155.0	153.8	----[2]	----[2]
May 1, 2012	158.0	116.0	110.0	57.1	53.1
June 1, 2012	112.0	74.0	----	----	----
July 1, 2012	59.0	18.0	----	----	----

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

[2] Snow course measurements were missed at these two locations due to winter storm events in conjunction with staff scheduling conflicts.

2012 Water Year in Review

Significant Weather Events and Patterns

Relatively dry and cool conditions in late October and early November abruptly changed on November 11th with the first in a series of significant winter storms. The largest occurred on November 21st, when a warm, moist air mass produced heavy rain, high winds, and snow accumulation at higher elevations. This storm produced the highest precipitation of the year at weather stations on western slopes and leeward areas. The Hoh Rainforest recorded 7.25 inches between the 21st and 24th. Peak winds on the 21st into the 22nd were noteworthy, with maximum gusts at Destruction Island Lighthouse (near Kalaloch) recorded at 76 miles per hour (NDBC 2014). A second, warmer air mass collided with the mountains on November 26th bringing higher temperatures and mountain rain.

In December, the Pacific Northwest experienced a major shift in weather patterns. A strong ridge of high pressure formed off the coast, resulting in unusually dry conditions and a significant temperature inversion. During this period, cold air, fog, and overcast conditions were the norm in lowland and coastal areas, while mountain locations were sunny and comparatively warm. The best example was on December 10th, when the Waterhole SNOTEL had an average temperature of 42°F, while the Elwha Ranger Station (390’ elevation) averaged a chilly 29°F (Figure 13). This persistent inversion lasted over three weeks, resulting in the fifth driest December on record at the Quillayute Airport. Change finally occurred on December 25th with a series of wet frontal systems once again producing more typical rain and snow.

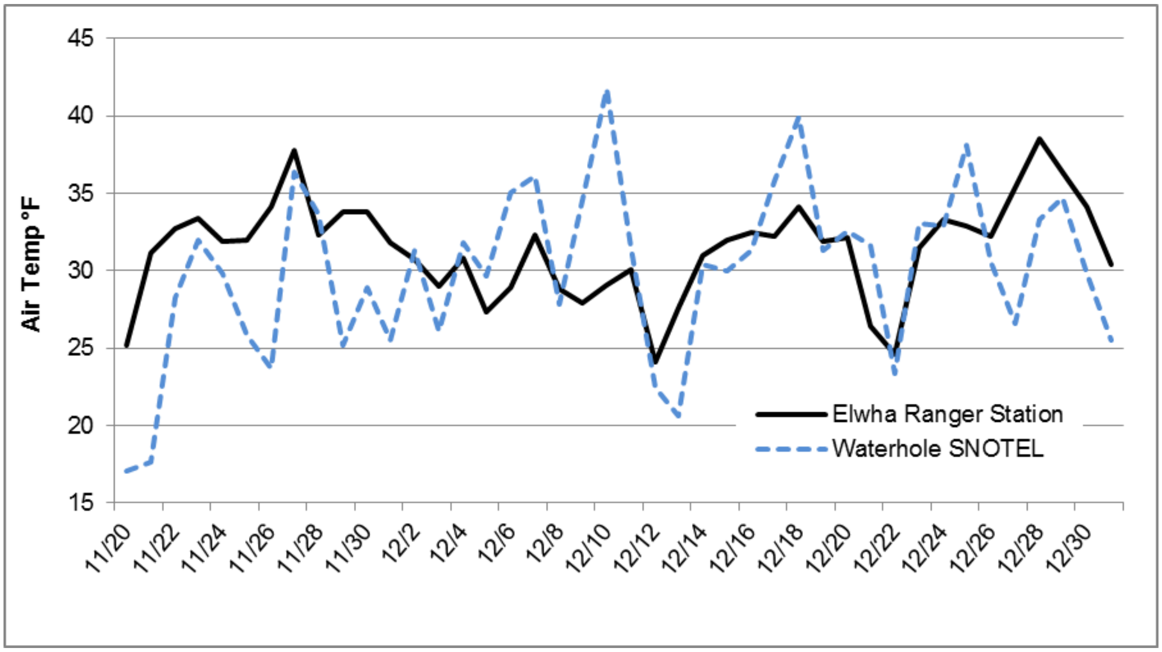

Figure 13. A comparison of daily air temperature at a low elevation weather station (Elwha R.S., 390') versus a high elevation site (Waterhole SNOTEL, 4,961'), exhibits the dramatic temperature inversion which occured during much of December 2011.

January and February were more typical with a consistent wet and cool weather pattern. A warm storm front on January 20th contributed several days of heavy rain, caused minor flooding, and created the top wind gusts of the year on the Olympic Coast, with gusts of 86 miles per hour recorded at Destruction Island Lighthouse (NDBC 2014). March was far from typical, with precipitation well above average and a monthly average temperature colder than the previous winter month of February. A major storm occurred from March 12th to 14th, drenching coastal areas (Kalaloch, Quillayute, and Ozette received the highest daily rainfall of the year) and loading the mountains with snow. In a one week period, the snowpack increased by nearly 30%. Heavy rainfall again occurred at the end of the month, with a daily precipitation record set at Quillayute Airport (1.80 inches) on March 29th. This final storm ensured that this month was the third wettest March on record at the Quillayute Airport. Cool and wet conditions continued through the months of April and May. The month of June was quite cold, which slowed the release of mountain snowpack at higher elevations. Coastal areas were extremely wet, and Quillayute Airport reported the wettest June on record.

The summer month of July was slightly cooler than normal but otherwise not unusual. Extreme thunderstorm activity, which brought downpours and fires to many mountainous areas of the Pacific Northwest, largely bypassed the Olympics. An unusually long, warm and dry period began in August and did not end until mid-October. Record dry conditions were experienced throughout Washington State (OWSC 2012b). The Elwha Ranger Station recorded 36 consecutive days without precipitation. The total precipitation amounts for the combined months of August and September within the Park ranged from 0.20 inches in the Elwha Drainage (both Elwha and Hayes River Ranger Stations), to 1.09 inches at the Quillayute Airport, where it was the second driest August/September on record.

Parkwide Annual Precipitation Summary

The southwestern slopes of the Olympic Mountains receive among the highest precipitation totals in the United States. In Water Year 2012, precipitation at the Park's coastal weather stations ranged from 83.4 to 96.8 inches. Stations on the western slopes of the Olympics received over 100 inches, with the highest amount, 127.3 inches, occurring at the Buckinghorse SNOTEL (Figure 14). 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 36.3 inches of precipitation (Figure 14).

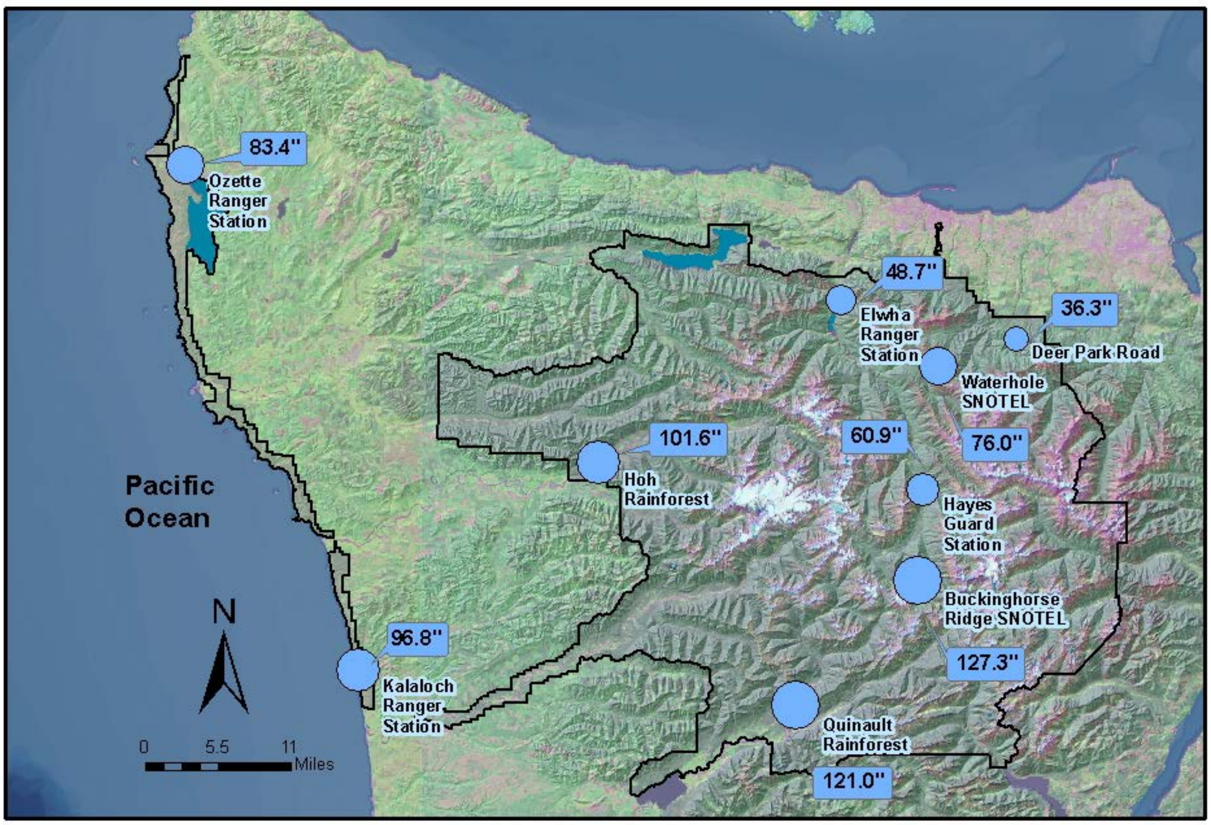

Figure 14. Total precipitation measured at weather stations located within Olympic National Park during Water Year 2012. Blue circles are proportional to the total amount of precipitation measured at each site.

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