Wind Climate Trends in the Pacific Northwest and the Implications to Renewable Energy Supply

John E. Wade and Kelly T. Redmond

Abstract: This paper examines the influence of wind climate variations on new Pacific Northwest renewable energy sources. Wind represents a potentially valuable supplemental source of energy in the region. Hydroelectric provides about 85% of the region's electrical energy. Wind climate variation was found to have significant impact on availability of both energy sources. Since 1976, weaker winds were noted both at the surface and at higher levels in the atmosphere. The weaker winds were associated with up to an estimated 19% less wind energy available at some sites and 15% reduction in streamflow (measured at The Dalles on the Columbia River). The recent period of weaker winds may be associated with a stronger North Pacific Low in the last decade. This would result in winter storms more often being deflected farther north, to Canada. Also, in the last dozen years, lower SOI values were common. Other investigators have found low SOI to be associated with drier conditions in the Pacific Northwest.

Introduction

An implicit assumption in energy planning is that future climate will be similar to past climate. This assumption is often incorrect, but utilities have found there is little risk in assuming a steady-state climate. Planners use 30-year means, standard deviations, and ranges about the means to determine possible future climate variations. Normally, climate changes encountered will be within the variations described by these 30-year statistics.

In the past, utilities on the West Coast have operated with large reserve capacity. This reserve capacity and the flexibility of purchasing additional power from Canada and through interties have made energy planning somewhat insensitive to climate variation outside climate "normals". However, the prospect of global climate change may increase the vulnerability of energy planning to climate change. Utilities systems, particularly in the southwestern United States, are operating with smaller reserve capacity. New capacity additions are experiencing delays, and some transmission systems are approaching their limits. The combination of western United States utilities operating closer to the margin and the possibility of climate changes outside those in the past 10,000 years suggest challenges ahead for energy planners.

Most discussion about the influence of climate change on energy planning is focused on the demand side. Warm climate increases air conditioning and irrigation energy demand and reduces winter heating demand. Cool climate increases winter heating and reduces summer cooling demand. In the western United States, and particularly in the northwest, climate also has an important impact on energy supply. About 85% of the northwest's electrical energy is supplied by hydroelectric power. Hydroelectric energy supply is climate-dependent, as are wind and solar, two supplemental energy sources.

This paper discusses the sensitivity of wind and hydroelectric energy supply to climate change.

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Background

The investigation began as an attempt to determine how representative the wind climate for 1976-1983 was of a 30-year period (see Wade *et al.* 1986). (Thirty years represents the lifetime of wind turbine generator blades.) The study used surface wind data at several locations on the Oregon Coast and upper air data at Medford and Salem, Oregon. Winds measured along the coast were about 16% weaker than the 35-year mean. A consistent trend of below-average winds, both at the surface and higher levels in the atmosphere, were found in western Oregon, confirming earlier results by Redmond (1985). These findings were important for wind energy, because a 16% reduction in wind speed means a 42% reduction in available energy, due to the cubic relationship between wind speed and energy. The reduction in amount of energy produced by a turbine will be less, because a wind turbine cannot use all the energy available in the wind.

Wind is an important supplemental source of energy, but still makes up less than 1,400 megawatts of available capacity, compared to more than 45,000 megawatts of hydroelectric capacity in the western United States. The snow that falls in the mountains is carried in by winter storms. Weaker winds aloft are associated with weaker and less frequent storms and less snowpack. Less snowpack results in less hydroelectric energy. Subsequent studies (Wade *et al.* 1987 and 1989) found this trend of weaker wind circulation over the entire Pacific Northwest.

Method

The approach used was to determine the extent to which the winds measured from 1976 to 1987 represent the long-term wind climate (*i.e.*, a 30-year period). The years 1976-1987 represent the period over which wind data have been collected for Bonneville Power Administration's regional wind energy assessment.

Surface and upper air data were examined for the entire Pacific Northwest. For surface data, only sites with a long-term wind history at one anemometer height were considered. Few records went back before the 1950s because anemometer heights have varied so much. (In the 1960s, many airports selected 20 feet as an ideal anemometer height.) Upper air wind variations were examined at the seven Pacific Northwest upper air observing locations. Upper wind levels examined were for 850 mb (about 5,000 feet above mean sea level, or *msl*), 700 mb (near 10,000 feet msl), and 500 mb (about 35,000 feet msl). Upper air data have been collected via balloon soundings twice a day for the last 40 years.

A statistical model was developed to reconstruct the wind record at three wind energy survey sites with continuous data since 1976. Winds at these sites were correlated to nearby surface or upper air wind measurements at locations with 30 years' of data to reconstruct a wind record. Normalized departures from the mean for 1976-1987 for the wind energy survey site were correlated to normalized departures at the predictor long-term reference site.

To estimate the implication of long-term variations in wind speed to energy output, three types of wind turbines were used to compare projected output for 1976-1987 to projected output before 1976. The average percent difference in annual energy output for the three turbines was used to assess energy implications of wind climate variations over time.

Long-Term Trends in Wind Speed in the Pacific Northwest

Five long-term National Weather Service surface wind sites in the Pacific Northwest were examined for annual wind speed variation at surface anemometer height (Table 1). Sites were chosen because anemometer height at each of them remained stable for a relatively long period. All sites show a recent small decrease in mean annual wind speed. Changes in local roughness may also account for some of the recent wind speed decreases evident in Table 1. While it is possible to adjust wind data for changes in height, it is more difficult to correct for changes in surface roughness and exposure.

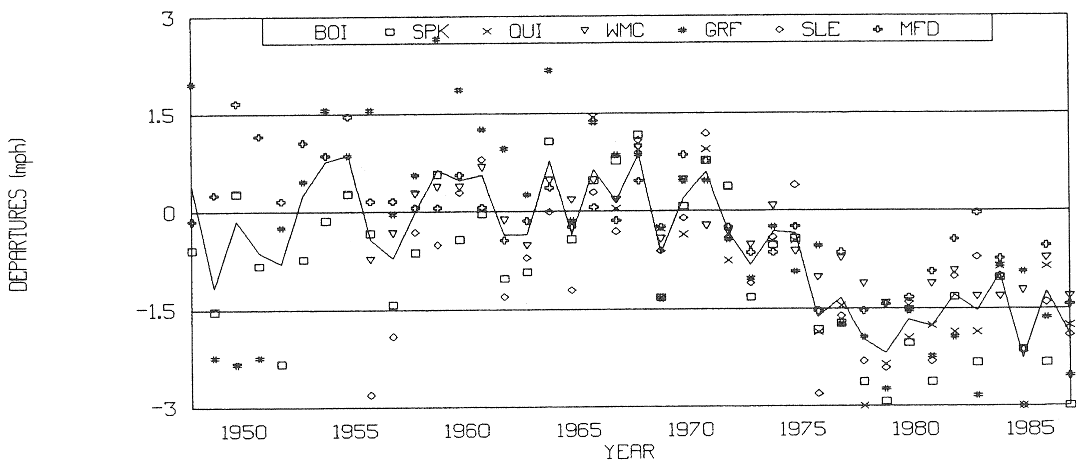
Table 1
MEAN ANNUAL SURFACE WIND SPEED,
STANDARD DEVIATION, AND PERCENT CHANGE SINCE 1976
(in miles per hour)

	Seattle-Tacoma WA	Pocatello ID	No. Bend OR	Salem OR	Medford OR
Period	1960-1987	1960-1987	1960-1987	1960-1987	1960-1987
Mean before 1976	8.5	10.0	8.5	7.2	4.9
Standard Deviation before 1976	0.9	0.6	0.4	0.4	0.3
Mean, 1976-1987	8.3	9.7	8.1	6.5	4.8
Standard Deviation, 1976-1987	0.2	0.3	0.3	0.4	0.2
Percent Change	–2.4	–3.0	–5.9	–9.2	–1.2

NOTE: Seattle-Tacoma: Moved 2,800 feet southwest of previous site from 1/1/60 to 12/2/69.
Pocatello: Began recording at 20 feet 8/6/60.
North Bend: 20 feet 1/60-12/87.
Salem: 20 feet since 2/59.
Medford: 20 feet since 5/59.

Winds aloft provide wind speed measurements over time at constant height and pressure levels. Figure 1 shows annual wind speeds for the seven National Weather Service upper air sites at the 850 millibar level. The figure shows distinctly weaker winds over the last 11 years than were measured previously. This was also evident at other pressure levels (700 and 500 mb).

Figure 1
ANNUAL VARIATION OF WIND SPEED AT THE
850-MILLIBAR LEVEL AT SEVEN PACIFIC NORTHWEST LOCATIONS
Winds are given as departures (in mph) from the mean before 1976.



To evaluate the association between wind climate variation and hydroelectric energy supply, the modified streamflow for January through July at The Dalles was compared to winter 850-millibar winds at Spokane, Washington. Normalized departures from the mean for the period 1949 to 1987 were plotted for both time series. The Dalles is the second to last dam on the Columbia River, and Spokane is the upper air site nearest the most important part of the Columbia River watershed.

At the 850-mb level, the decrease in wind speed over 1976-1987 was similar at all seven upper air sites (Table 2). Since many of the best potential wind energy development sites are at high elevations, results in Table 2 are of considerable interest. We would expect wind measurements at sites on well exposed ridgetops to be closely related to measurements in the free air at about 5,000 feet msl (1,500 meters). Winter showed the most evidence of recent weaker winds at sites. Summer had the least evidence of weaker winds aloft.

Table 2
PERCENT DEPARTURE CHANGE IN WIND SPEEDS FOR 1976-1987 FROM THE PREVIOUS RECORD AT THE 850-MILLIBAR LEVEL AT SEVEN UPPER AIR SITES IN THE PACIFIC NORTHWEST

	Percent Departure From:	
Site	All Years Before 1976	1966-1975 Mean
Quillayute, WA	–10%	–10%
Spokane, WA	–11%	–13%
Boise, ID	–11%	–11%
Great Falls, MT	–11%	– 9%
Salem, OR	– 9%	–11%
Medford, OR	–11%	– 9%
Winnemucca, NV	11%	–11%

Reconstructing Wind Energy Potential Before 1976

For the Cape Blanco wind energy site, we used wind data at North Bend Airport as a long-term reference. North Bend is also along the coast, but is about 50 miles north of Cape Blanco. The energy output for the most recent period at Cape Blanco was estimated to have decreased by 6%, which is similar to the wind speed deficit (Table 3). Much of the stronger wind during the reconstructed period at Cape Blanco would have been outside the operating range of the three representative wind turbines. Data used to reconstruct the Kennewick winds prior to 1976 were the 850-mb winds at Spokane. The Kennewick anemometer site is at elevation 2,200 feet. Data in Table 3 suggest wind speeds at Kennewick were stronger before 1976 by about 11% (±5%). Estimated average annual energy output of the three wind turbines would be 14% lower than what we estimate would have been available before 1976. At Pequop Summit, wind speeds were estimated to be 14% stronger before 1976 than after. An average of 19% more annual energy output would have been available with wind speeds estimated before 1976. The predictor information for Pequop Summit, at 7,500 feet, consisted of the Winnemucca 850 mb winds.

Table 3
COMPARISON OF WINDS ESTIMATED BEFORE 1976 TO THOSE MEASURED SINCE 1976

Wind Energy Site/ Reference Site	Velocity 1976-1987 (mph)	Velocity 1950-1976 (mph)	Percent Speed Difference	Percent Energy Difference
Cape Blanco	18.7	20.0	–6.5 ± 4.2	– 6
North Bend	7.9	8.7	–9.2	
Kennewick	15.4	17.3	–11 ± 4.9	–14
Spokane 850 mb	14.6	6.7	–13	
Pequop Summit	15.4	17.9	–14 ± 4.5	–19
Winnemucca 850 mb	9.4	10.6	–11	

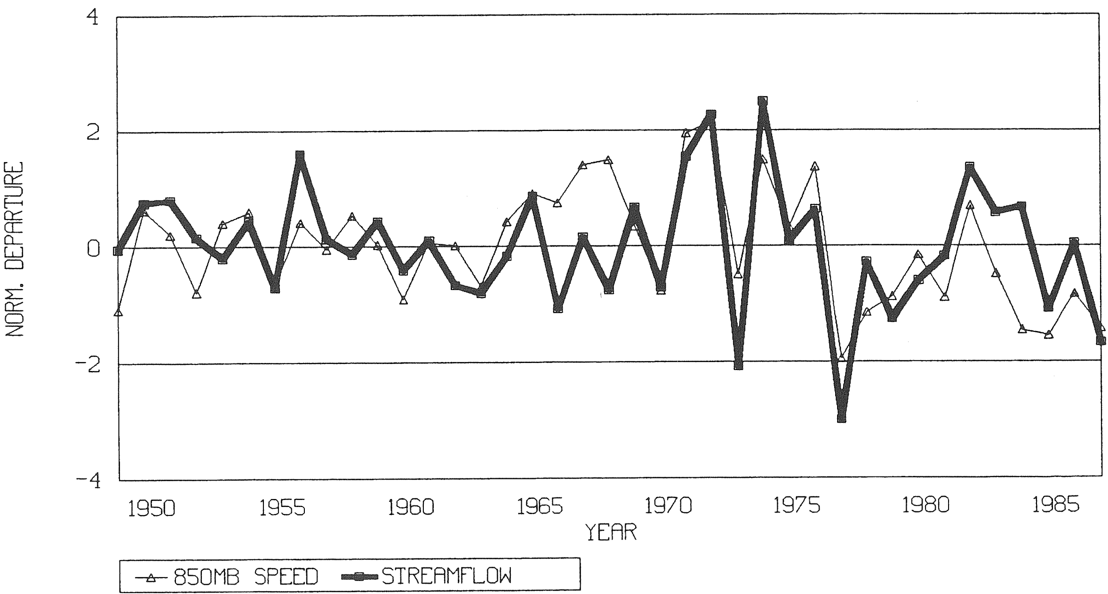
Relationship of Wind Climate to Hydroelectric Supply

Wind climate variations are associated with variations in another source of renewable energy — hydroelectricity. Although most precipitation in this region occurs from November through March, peak streamflow is during the spring and early summer, when snow melts in the mountains. The amount of January through July streamflow determines how much energy Bonneville Power Administration will have to supply Pacific Northwest customers. Flow exceeding 90 million acre-feet (about 90% of average) can be sold to other utilities in the western United States.

Figure 2 shows a comparison of the strength of winter winds at 850 mb to January-July streamflow at The Dalles. Weaker winter winds are associated with lower streamflow. These results support earlier work by Cayan and Peterson (1989) who found that effects of large-scale circulation anomalies can be detected in the variation of streamflow in the western United States. They found these circulation anomalies most evident in winter, when atmospheric circulation was most variable. When the North Pacific Low is strong, storms tend to be carried northward into British Columbia, so the Pacific Northwest is dry. When the low is weak, the jet stream carries ample moisture over the Pacific Northwest, resulting in high streamflow.

Redmond and Koch (1990) and Wade *et al.* (1989) noted that the Southern Oscillation index (used to identify El Niño events) is also related to streamflow and winter precipitation in the Pacific Northwest. High SOI values are related to high precipitation and higher streamflow. Since 1976, when weaker winds have prevailed in the Pacific Northwest, the SOI has been lower and the North Pacific Low has been stronger. At the same time, January- July streamflow for 1977 through 1987 has been about 15% lower than for the previous 11 years (1966-1976), when high SOI and weaker North Pacific Lows were more frequent.

Figure 2
ANOMALIES OF JANUARY-JULY STREAMFLOW AND 850-MILLIBAR WIND SPEED FOR DECEMBER-JANUARY AT SPOKANE



WINDS SPOKANE UPPER AIR
STREAMFLOW AT THE DALLES

Conclusions

- Winds measured in the Pacific Northwest from 1976 through 1987 were weaker than those measured before 1976 at many surface and all upper air locations.
- Estimates of wind energy availability based on the winds measured since 1976 will be conservative for most of the region. For the three wind energy sites with over a decade of wind data the estimated decrease in annual energy output for the past eleven years varied between 6 and 19%.
- The results of this investigation suggest that weaker winds aloft in the winter months in the Northwest are associated with reduced streamflow on the Columbia River during the January to July runoff period.
- The January to July streamflow for 1977 through 1987 has been about 15% lower than for the previous 11 years (1966-1976) when high SOI values and weaker North Pacific Lows were more frequent.
- Climate change that would result in a weakening of the prevailing westerly flow in the winter and spring months will influence the supply of hydroelectric energy in the Pacific Northwest.

Acknowledgments

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