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Climatology of the Interior Columbia River Basin

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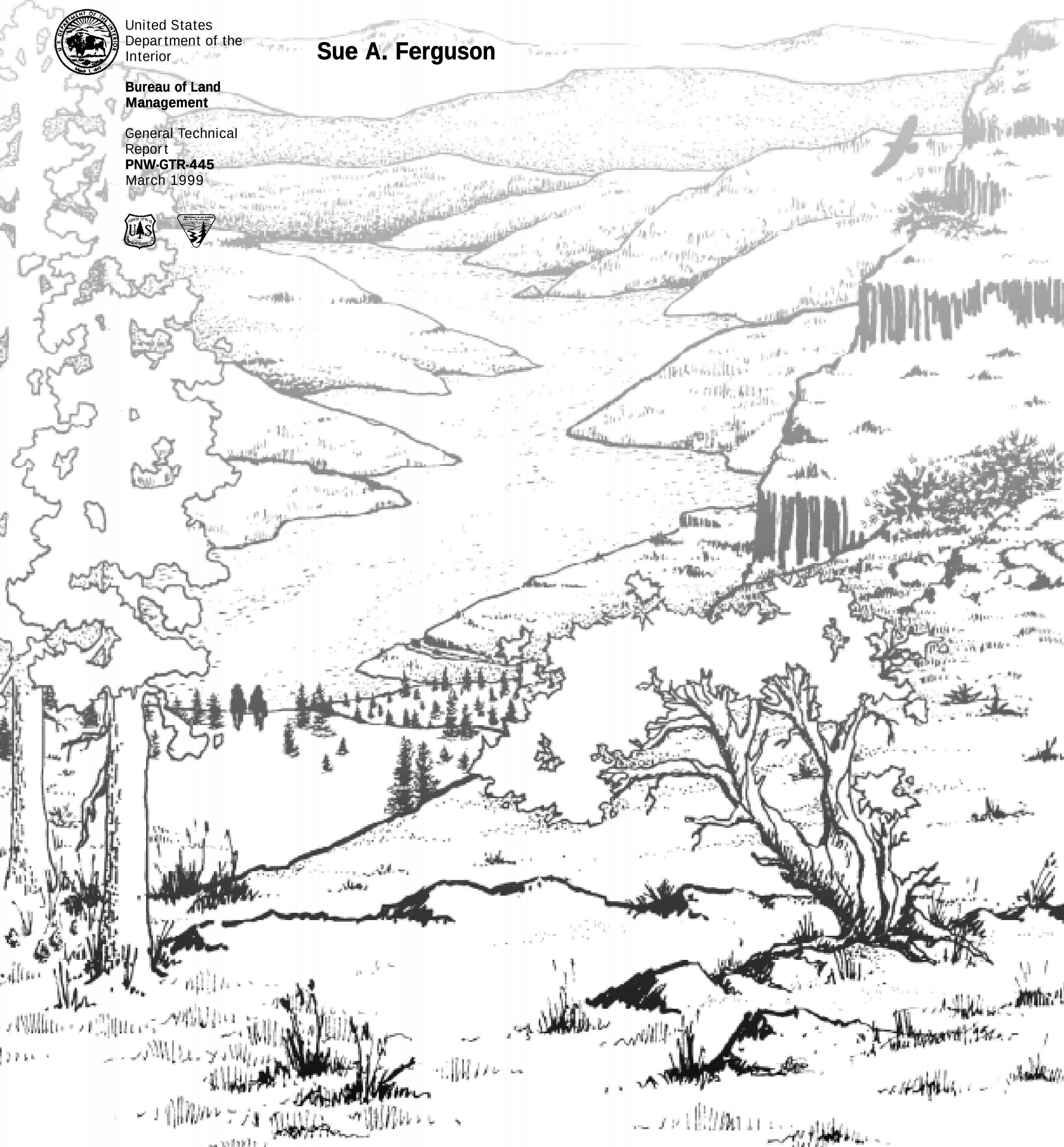

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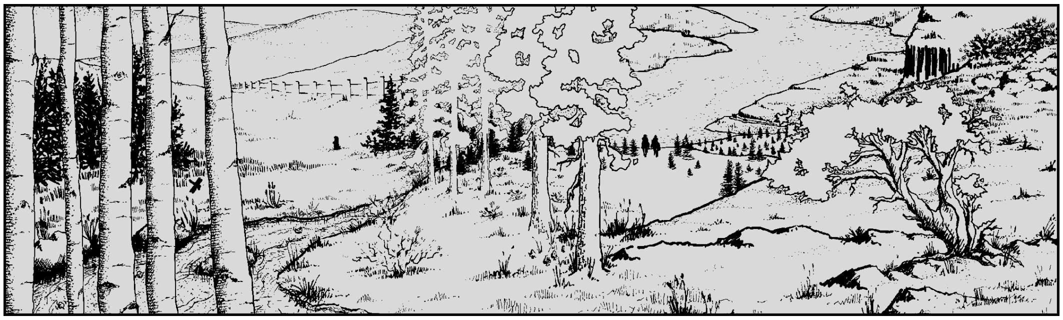

Climatology of the Interior Columbia River Basin

Sue A. Ferguson

Interior Columbia Basin Ecosystem
Management Project: Scientific Assessment

Thomas M. Quigley, Editor

United States Department of Agriculture
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Abstract

Ferguson, Sue A. 1999. Climatology of the interior Columbia River basin. Gen. Tech. Rep. PNW-GTR-445. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 31 p. (Quigley, Thomas M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

This work describes climate means and trends in each of three major ecological zones and 13 ecological reporting units in the interior Columbia River basin. Widely differing climates help define each major zone and reporting unit, the pattern of which is controlled by three competing air masses: marine, continental, and arctic. Paleoclimatic evidence and historical weather records show that the region has undergone significant fluctuations in temperature and precipitation as air masses alternate dominance over the basin. The major change in climate occurred near the time of western settlement with the end of the “Little Ice Age.” Since then there have been numerous annual cycles in climate that may be related to the Pacific Decadal Oscillation. During the last 50 years, winter precipitation has decreased slightly and summer precipitation has increased throughout most of the basin. At the same time, winter temperatures have increased and summer temperatures have slightly decreased. Some impacts of changes in climatic means and trends on ecological conditions in the basin are discussed.

Keywords: Climate, Columbia River basin, climatology, climate variability, temperature, precipitation, snowfall.

Preface

The Interior Columbia Basin Ecosystem Management Project was initiated by the Forest Service and the Bureau of Land Management to respond to several critical issues including, but not limited to, forest and rangeland health, anadromous fish concerns, terrestrial species viability concerns, and the recent decline in traditional commodity flows. The charter given to the project was to develop a scientifically sound, ecosystem-based strategy for managing the lands of the interior Columbia River basin administered by the Forest Service and the Bureau of Land Management. The Science Integration Team was organized to develop a framework for ecosystem management, an assessment of the socioeconomic and biophysical systems in the basin, and an evaluation of alternative management strategies. This paper is one in a series of papers developed as background material for the framework, assessment, or evaluation of alternatives. It provides more detail than was possible to disclose directly in the primary documents.

The Science Integration Team, although organized functionally, worked hard at integrating the approaches, analyses, and conclusions. It is the collective effort of team members that provides depth and understanding to the work of the project. The Science Integration Team leadership included deputy team leaders Russel Graham and Sylvia Arbelbide; landscape ecology–Wendel Hann, Paul Hessburg, and Mark Jensen; aquatic–Jim Sedell, Kris Lee, Danny Lee, Jack Williams, and Lynn Decker; economic–Richard Haynes, Amy Horne, and Nick Reyna; social science–Jim Burchfield, Steve McCool, and Jon Bumstead; terrestrial–Bruce Marcot, Kurt Nelson, John Lehmkuhl, Richard Holthausen, and Randy Hickenbottom; spatial analysis–Becky Gravenmier, John Steffenson, and Andy Wilson.

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Introduction

The Columbia River basin in the northwestern United States is in a transition-type climate zone. It is influenced by three distinct air masses: (1) moist, marine air from the west that moderates seasonal temperatures; (2) continental air from the east and south, which is dry and cold in winter and hot with convective precipitation and lightning in summer; and (3) dry, arctic air from the north that brings cold air to the basin in winter and helps to cool the basin in summer.

The timing and extent of competing air masses is controlled mainly by synoptic weather patterns and local terrain features that vary across the basin. Prolonged periods of drought occur when storms off the Pacific Ocean are deflected around the region, thereby preventing the intrusion of moist, marine air. At such times, dry, continental conditions prevail. Damaging frosts and freezing conditions commonly occur when arctic air invades the basin either in autumn before winter hardening or after budbreak in spring. Cold damage also may occur in winter if a warm, marine intrusion is followed by a sweep of arctic air. In addition, the unique interplay between air mass types results in dramatic changes during transitions. The most unique of these is rain-on-snow flooding that occurs when warm, wet marine air displaces cold, arctic conditions in winter. Lightning and gusty winds also occur during transitions between continental and marine air masses, mainly in spring and summer.

This paper summarizes the background of climatological studies in the basin and then describes analyses of available data for a detailed description of regional climate patterns. Emphasis is on aspects of climate that influence ecological processes because the major impetus for this work came from the Interior Columbia Basin Ecosystem Management Project (ICBEMP).

Previous Climate Studies

Every decade new normals (30-year averages) from thousands of weather observation stations throughout the United States are computed as part of an international effort led by the World Meteorological Organization. These normals are summarized in several documents available from the U.S. Department of Commerce, National Climatic Data Center (NCDC), in Asheville, North Carolina. The summaries list normals, means, and extremes for National Weather Service first-order and cooperative observation stations that have long-term weather records. Also, they include a narrative describing important features of distinct climate zones and summaries of climate divisions within each state. In addition to these official summaries, others have summarized various aspects of weather and climate in the Columbia River basin and the Western United States (for example, Pacific Northwest River Basins Commission 1968, 1969a, 1969b; Phillips 1962; Rumney 1968).

An interesting analysis of temperature shows two major frontal zones in the Columbia River basin (Mitchell 1976). A Pacific air mass boundary, which dominates during summer, extends diagonally across the basin from northwest California to northwestern Montana. Relatively moist, marine air exists north of the boundary, and drier, continental air is common south of the boundary. Mitchell notes that the Pacific boundary coincides with the eastward extension of coastal vegetation found in northern Idaho and northwestern Montana. During summer the polar jet stream is usually too far north to bring many storms into the basin, except north of the boundary. The thermal trough and intermittent marine pushes continue to play a role, but the westerlies are much weaker than in winter. Strong convection in southeastern Idaho and western Montana continue through the summer but lack moisture because the prevailing northwesterly flow aloft is relatively dry. Only when the southwestern monsoon extends northward does the basin experience any appreciable summer precipitation.

Mitchell (1976) describes a westerlies-anticyclone boundary, which dominates during the winter, stretching east-west along the Oregon-Nevada border and across northern Utah. It marks the boundary between a region of prevailing westerly winds in the north and southerly winds in the south, which is caused by circulation around a persistent center of high pressure (anticyclone) over southern Nevada. This frontal zone also coincides with the northern or southern extent of several tree species.

In the transition period between winter and summer, a thermal trough migrates north from California. When combined with a marine push, convective precipitation and thunderstorms are possible, especially in Oregon and southern Idaho. In Washington, northern Idaho, and northern Montana, Pacific storms remain influential during spring. In all seasons, marine air flows through the Columbia Gorge into the Snake River valley and other valleys adjacent to and oriented toward the oncoming Pacific air mass.

Bryson and Hare (1974) note that precipitation variability in the Western United States is caused by numerous small-scale climatic controls (primarily the result of complex topography) embedded within large-scale climatic controls. Mock (1996) was able to determine the hierarchy of climatic controls that operate at different spatial scales by analyzing month-to-month precipitation patterns. He found that while large-scale climatic controls (such as the polar jet stream, Pacific subtropical high, and subtropical ridge) play important roles in precipitation variability, small-scale climatic controls (such as complex topography, thermal troughs, confined mixing heights, and convective systems) can dominate. In particular, winter precipitation is dominated by orographic lifting of strong westerlies associated with the mean position of the polar jet stream over Oregon and Washington.

Data

As in most climate studies, the type and availability of data can be limiting factors. Although the amount of weather data may seem quite large, it usually is not sufficient to adequately describe climate patterns in regions of complex terrain. This is because terrain strongly influences the atmosphere, and measurements in one location often do not represent measurements in another location if surrounding terrain changes between the stations. Value can be found in existing data records, however, and various sources are described below.

Observational Data

Recorded weather observations began in the Western United States in the mid 1800s. Because population was relatively sparse at the time, only eight stations within the interior Columbia River basin are identified as having consistent, quality controlled weather records approaching 100 years: Spokane Weather Station Office (WSO), Washington; Dufur, Oregon; Fortine, Kalispell WSO, and Haugan, Montana; and Priest River Experiment Station, Caldwell, and Saint Ignatius, Idaho. Daily summaries of precipitation and temperature from these stations have been adjusted for station relocations, changes in instrument heights and types, changes in observing times, and increases in urbanization as part of the Historical Climatology Network (HCN; Hughes and others 1992, Karl and others 1990).

The HCN data are a subset of the National Weather Service, Cooperative Observer Network (COOP; National Climatic Data Center 1991). Data from COOP stations provide the highest spatial resolution of daily temperature and precipitation measurements. Because many observers in the COOP network are volunteers, however, consistency and quality can be problematic. These data have undergone some quality control, but thorough review to locate those sites with reliable records for each period of interest is lacking.

High-quality measurements of multiple parameters are available from the National Weather Service first-order stations that are operated by trained observers. Hourly temperature, dew point, relative humidity, wind, precipitation, and radiation data from these sites are available through the Solar and Meteorological Surface Observation Network (SAMSON) data set developed by the National Renewable Energy Laboratory (1992). In addition, the hourly data are summarized each day and added to the COOP database.

The HCN and SAMSON observation sites usually are located near population centers or airports away from the wild land areas of forests and mountains. The COOP sites have more diverse locations, but most are near homes or businesses that commonly exist in valleys or away from wild land areas.

Significant additions to high-elevation data occurred in the mid-1930s and again in late 1970s and mid-1980s. The U.S. Department of Agriculture, Soil Conservation Service (now Natural Resources Conservation Service), added many observations in the mid-1930s (at the height of a nationwide drought) to measure snow depth and snow water equivalent along a transect of several elevations (snow course) in the headwaters of major river basins (USDA Soil Conservation Service 1988). Snow course measurements are acquired about every month during winter and spring. In the late 1970s, an automatic system, snowpack telemetry (SNOTEL), was added. The SNOTEL sites transmit temperature, accumulated seasonal precipitation, and total snow water equivalent about once each day (Barton 1977). In the late 1970s, remote automated weather systems (RAWS) also were installed by the USDA Forest Service and Bureau of Land Management (Redmond 1991; U.S. Department of Interior, Bureau of Land Management 1995). Most of the network was complete by 1985. These stations are designed to support fire weather forecasting and thus operate mainly during summer and are located in forest clearings on hill slopes and ridges. Those that operate year-round usually are not outfitted with de-icing equipment, so much of the winter data from RAWS sites are of poor quality. The RAWS stations transmit hourly information on air temperature, precipitation, fuel temperature, relative humidity, and wind. There are about 200 RAWS, 200 SNOTEL, and 200 snow course sites in the interior Columbia River basin.

A northwest cooperative agricultural weather network (AgriMet) is maintained by the Bureau of Reclamation in Boise, Idaho, as part of the Pacific Northwest Hydrometeorological Network for river and reservoir management.[1] Historical data since 1983 include daily summaries of soil moisture, soil and air temperatures, crop water use, and evapotranspiration.

A consistent network of radiosonde observations (RAOBs) began in the mid-1930s (U.S. Department of Commerce 1964) with electronic files available since 1948. The RAOB sensors measure wind, temperature, dew point, and height at mandatory atmospheric pressure levels (surface, 850 hectoPascals [hPa], 700 hPa, 500 hPa, etc.) and other significant levels twice a day, at 0000 Greenwich Mean Time (GMT) and 1200 GMT.

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[1] Bureau of Reclamation, 1150 N. Curtis Road, Boise, ID 83706.

Only two stations within the basin regularly report upper air data: Spokane, Washington, and Boise, Idaho.

A summary of surface and upper air climatic data, which are in accessible electronic formats, is shown in table 1. Other local and regional meteorological observations exist within the region; for example, the Hanford meteorological station, which includes a 125-meter (410-ft) tower, has been recording observations on a plateau in southwestern Washington since 1945 (e.g., Stone and others 1983). The Columbia River Operational Hydromet System (CROHMS) organizes data from the Bureau of Reclamation, U.S. Geological Survey, Natural Resources and Conservation Service, USDA Forest Service, National Weather Service, and British Columbia Hydro and Power Authority.[2] State highway departments began installing automated weather systems in the early 1990s. Also, regional avalanche centers and ski areas maintain automated weather stations (for example, Ferguson and others 1990). Other meteorological data, such as the forest fire lookout observations, remain in paper form but are no less valuable.

Simulated Data

Over 600 mountain weather and snowpack observations in the interior Columbia River basin would seem like enough to describe mountain climate. These stations, however, are spaced too far apart (50 to 150 kilometers [30-90 mi]) to represent small-scale climate caused by complex topography in the region. Horizontal resolution of at least 10 kilometers (6 mi) is needed to resolve many of the mesoscale features influencing climate in the Pacific Northwest (Doran and Skyllingstad 1992). In addition, the limited amount and quality of data from each station make complete analysis rather cumbersome. It is because of these network limitations that model-generated data play an increasing role in climate analyses of the mountainous west. Three sets of model-generated data have been completed for the U.S. portion of the Columbia River basin: (1) historical means of monthly and annual precipitation at 2.5-minute (about 5 kilometers [3 mi]) latitude-longitude spatial resolution from the PRISM model (Daly and others 1994); (2) average daily temperature and precipitation for three characteristic years (1982, 1988, and 1989) at 2-kilometers (1.2 mi) resolution from the MTCLIM-3D model (Thornton and Running 1996); and (3) monthly mean winds at 5-minute latitude-longitude resolution from the WINFLO[3] model. Output from these models was used to help describe major climatic features of each ecological zone, as discussed in the following sections.

Regional Climate Patterns

To help assess ecological conditions in the Columbia River basin, ICBEMP required a description of climatic means and trends in each of 3 major ecological zones and 13 ecological reporting units (ERUs). The major zones are (1) east side (“Eastern”) Cascades, (2) Northern Rockies, and (3) Central Columbia and Snake River Plateaus (fig. 1). The ERUs, which exist in each zone, do not exactly match National Weather Service climate division boundaries for which 30-year averages are calculated. Therefore, new summaries were calculated from available COOP and HCN data within each ERU (tables 2-14).

To increase representation of variability caused by terrain in the climate, all records with data for more than 10 years were used. This means that the ERU summaries may not match NCDC calculated normals (30-year averages) for the same area. Whenever possible, ERU summary data were compared with climate division summary data to ensure that magnitudes and trends of ERU calculations were within reason. Because the spatial density of stations increases over time, ERU summary data may be slightly biased toward the most recent 10 years.

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[2] Contact individual agencies for historical records.

[3] Ferguson, S.A.; Rorig, M.L.; Hayes, P.S.; Ruthford, J. Surface wind patterns in the Pacific Northwest. Manuscript in preparation.

Table 1—Summary of climate data sets

Dataset name	Beginning year	Basin sites	Time step	Duration	Measurement
HCN	1895	8	daily	annual	T,[a] ppt[b]
Coop	varies >1895	>300	daily	annual	T, ppt
SNOTEL	1978	45	daily	annual	T, ppt, SWE[c]
Snow course	1930	50	monthly	winter	H,[d] SWE
RAWS	1985	~200	hourly	summer	T, Tf,[e] RH,[f] ppt, W[g]
SAMSON	1961	10	hourly	annual	T, Td,[h] RH, W, P,[i] Q[j]
RAOBS	1948	2	2 per day	annual	T, Td, W, P (multiple heights)

[a] Dry-bulb temperature

[b] Precipitation

[c] Snow water equivalent

[d] Snow depth

[e] Fuel temperature

[f] Relative humidity

[g] Wind

[h] Dew point temperature

[i] Atmospheric pressure

[j] Solar radiation

Despite the increased spatial density of weather observing stations, these data still do not represent the variability of climate in highly complex terrain. To quantify this concern, 30-second digital elevation model (DEM) data were analyzed for each ERU (fig. 2). Only ERUs with reasonably accessible terrain (for example, those dominated by rolling hills and plateaus as in ERUs 3, 4, 5, and 10 in fig. 2) have average weather station elevations in the midrange of terrain elevations. Inaccessible mountain terrain in all other ERUs cause most weather stations to be sited at elevations well below the mean terrain elevation. This can make it difficult to describe climate influences on vegetation within the basin because of the elevational extent of many species (Daubenmire and Daubenmire 1968, Fowells 1965, Franklin and Dyrness 1988, Johnson and Simon 1987, Shantz and Zon 1924, Volland 1976) is well above the average elevation of weather observing stations.

The elevational distribution of weather observations would improve by including data from snow course, SNOTEL, and RAWS stations. Unfortunately, the different reporting formats, inadequate metadata, insufficient station identification, lack of maintenance, and difficulty in obtaining records covering a long period from these observing networks prevented their use in ERU summary calculations. Data from these stations were used, however, to help verify model results and improve qualitative descriptions. Elevation-regression models such as PRISM (Daly and others 1994) and MTCLIM-3D (Thornton and Running 1996) improve representation of high-elevation climate by interpreting available observations through “topographically intelligent” techniques. Both methods are relatively consistent, differing only in local detail.

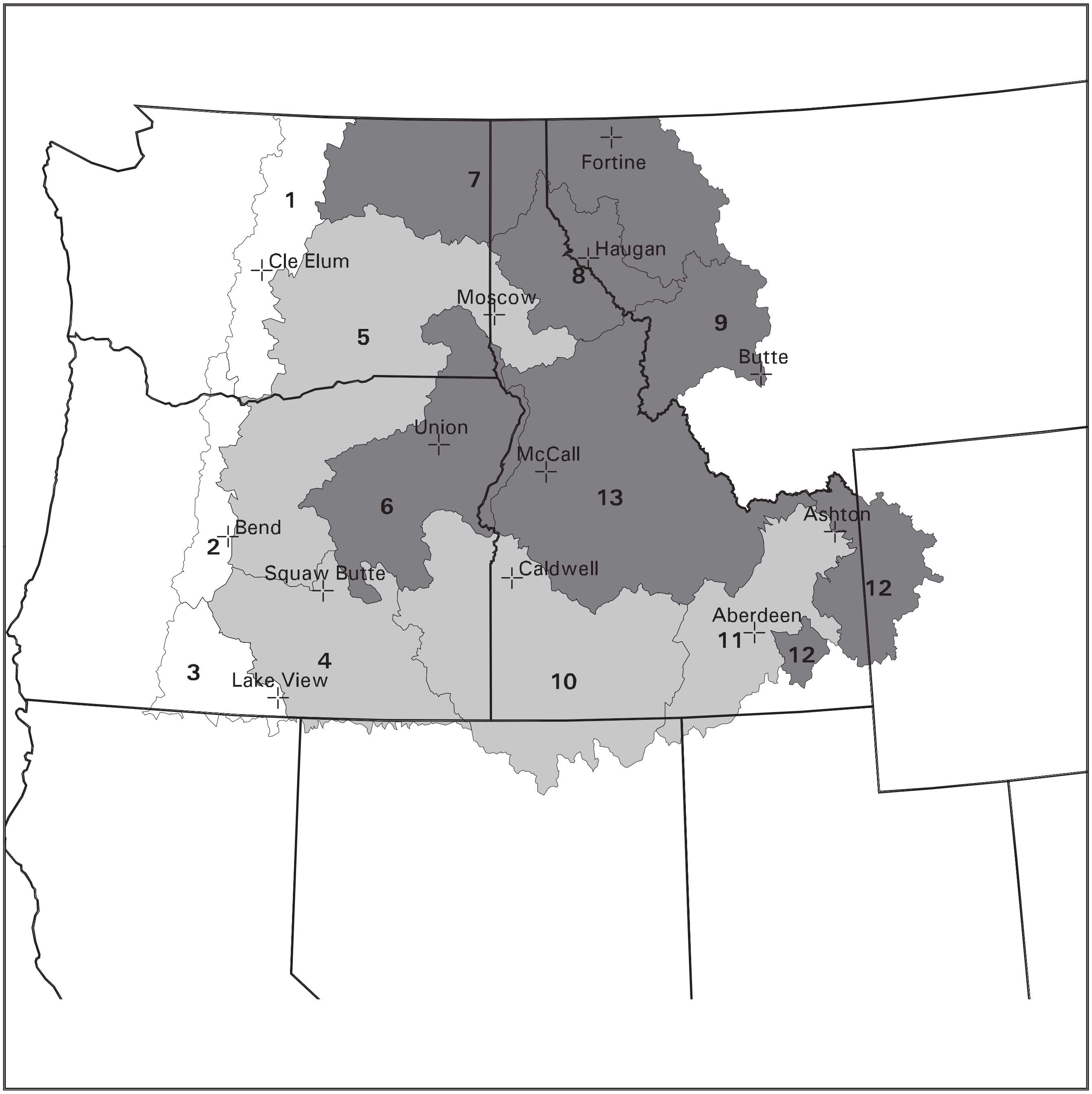

Figure 1—The interior Columbia River basin. Each ERU is numbered. The Eastern Cascades zone (ERUs 1-3) has no shading, the Northern Rockies zone (ERUs 6-9 and 12-13) is dark shaded, and the Central Columbia and Snake River Plateaus zone (ERUs 4, 5, 10, and 11) is lightly shaded. Stations selected to represent climate trends in each ERU are labeled.

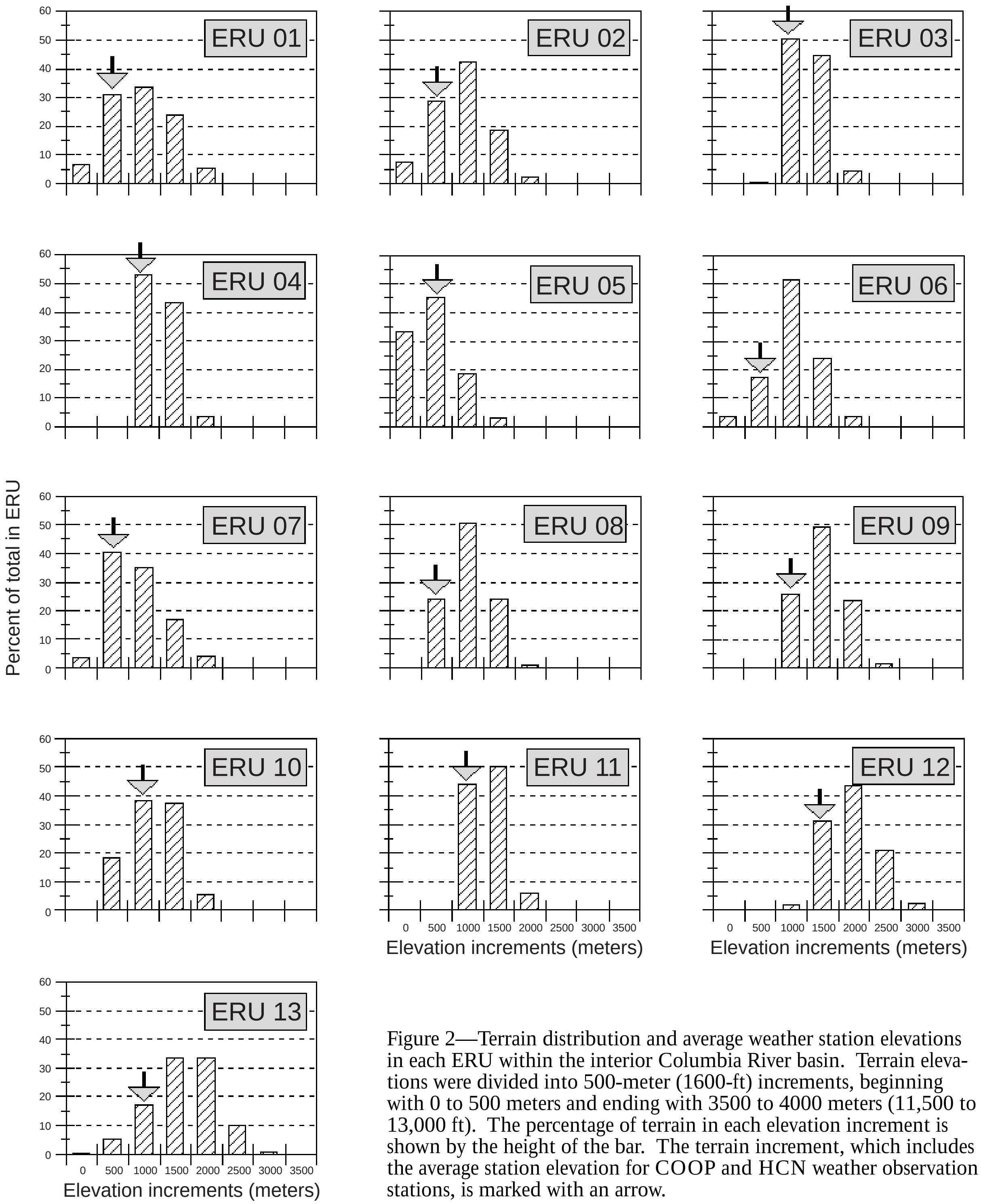

Figure 2—Terrain distribution and average weather station elevations in each ERU within the interior Columbia River basin. Terrain elevations were divided into 500-meter (1600-ft) increments, beginning with 0 to 500 meters and ending with 3500 to 4000 meters (11,500 to 13,000 ft). The percentage of terrain in each elevation increment is shown by the height of the bar. The terrain increment, which includes the average station elevation for COOP and HCN weather observation stations, is marked with an arrow.

Eastern Cascades

The Cascade Range blocks most marine air from entering the basin. The eastern slopes of the mountains (ERUs 1, 2, and 3) lie in a rain shadow from oncoming Pacific storms. During winter, however, when westerly winds are strongest, enough moisture spills over the crest to cause this region to remain wetter than other parts of the basin (fig. 3). This region also receives significant quantities of snowfall. Seasonal totals typically range from about 200 centimeters (78 in) in the south (ERU 03) to over 300 centimeters (120 in) in the north (ERU 01), with greater amounts at higher elevations (over 2000 centimeters [790 in] of snowfall has been recorded at Crater Lake, Oregon). During summer, when westerly winds are weak, the rain shadow effect of the Cascades is most apparent and this region becomes the driest in the basin (fig. 3).

Chinook winds can cause occasional warm, dry, and windy conditions that rapidly can melt snow or initiate blow-down. Strong winds also are common within mountain gaps as air flow is channeled from both east and west directions. The westerly gap winds, most common in summer, are strongest as they flow into the Eastern Cascade region. The principal mountain gap is the Columbia River Gorge, just east of Portland, Oregon. Tornadoes and funnel clouds have been observed near the outflow of the gorge's westerly winds. In addition, the persistence of its summer westerlies allow the gorge to be one of the Nation's principal wind surfing recreation areas. Strong southerly winds also are common, mainly during winter, on several east-west oriented ridges that protrude into the basin from the Cascade crest.

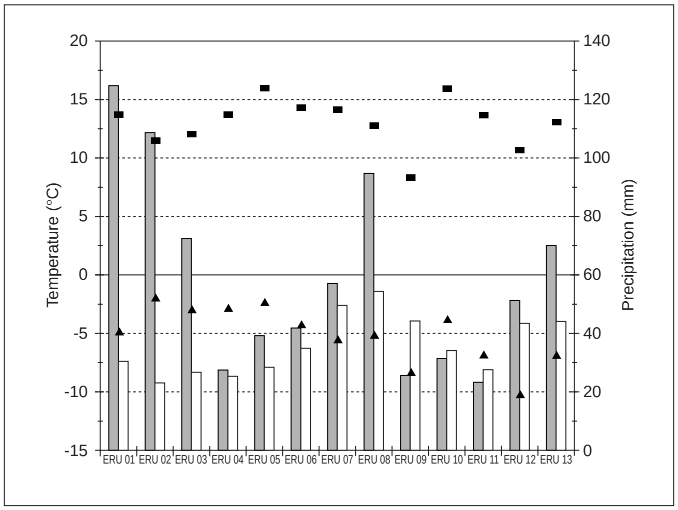

Figure 3—Seasonal values of temperature and precipitation for each ERU. The solid squares (■) mark July average temperatures and the solid triangles (▲) mark January average temperatures. The hatched bar shows January precipitation, and the hollow bar shows July precipitation.

Although this region often is under continental-type climate conditions (with cool, dry winters and hot, dry summers), marine air spilling over the mountain crests and through mountain gaps moderates both summer and winter temperatures and allows coastal vegetation species to coexist among interior species. In addition, arctic air often pools in the basin and is pulled against the Cascades, causing a persistent temperature inversion to about 1200 meters (4,000 ft), especially in winter, and elevational gradients in vegetation are diffused or inverted. Sharp contrasts in temperature occur when arctic air is displaced by marine air, and rain-on-snow flooding is common at all elevations.

Northern Rockies

The Canadian Rockies and other mountain ranges in British Columbia block most arctic air from entering the basin. The deep Okanogan, Columbia, and Pend Oreille valleys, however, can funnel the dry arctic air into the basin where it often stagnates, especially during winter when it is cold and dense.

The Rocky Mountains on the eastern border of the basin intercept continental air masses that rise over the imposing mountains, favoring thunderstorm development around the edge of the basin, especially in western Montana and southern Idaho. A thermal trough that migrates northward during spring and summer also can cause thunderstorms, mainly in eastern Oregon around the Blue Mountains (ERU 06). The convection causes an increase in precipitation during spring, with 24-hour accumulations often greater than 25 millimeters (1 in). Drier lightning is more common during summer and fall. Most of the convection and lightning occurs in the east and southeast units of this region (ERUs 9 and 12) nearest the Continental Divide.

Blow-down in this region is common. Strong down-burst winds associated with convective cells can cause blow-down, most commonly during spring. Blow-down also occurs in the elongated north-south valleys that channel strong southerly storm winds, mainly during winter. The high and contrasting topography also favors accelerated storm winds near ridgetops during winter and persistent slope winds during summer.

The northern Rockies are the coldest part of the basin with mean winter temperatures between -4.2 and -10.2 ˚C (-40 to -50 ˚F). Snowfall amounts range from about 200 to over 300 centimeters (78 to 120 in), with greater amounts at higher elevations. Note that although winter precipitation in the northern Rockies is less than along the east side of the Cascades, snowfall amounts are comparable. There are two reasons for this: (1) cold winter temperatures cause relatively low-density snow to fall in the northern Rockies, so snowfall amounts appear greater even though snow water equivalents may be less than along the east side of the Cascades; and (2) colder spring and fall temperatures in the northern Rockies allow more snowfall during those seasons than in the warmer Cascades.

Despite cold winter temperatures in the northern Rockies, occasional marine intrusions enter the northern part of the zone, mainly at lower elevations and in those places exposed to flow from the Columbia Gorge: northeastern Oregon, eastern Washington, the Idaho panhandle, and northwestern Montana. The increased exposure to maritime air masses allow a somewhat moister vegetation regime. Also, in summer the marine intrusions moderate summer high temperatures and add moisture to the convective cycle, thereby increasing the chance that lightning will be accompanied by precipitation. This helps to reduce the threat of wildfire somewhat in this northern section of the zone. In winter, marine intrusions can cause sudden warming and initiate rain-on-snow floods.

Central Columbia and Snake River Plateaus

This is the driest part of the basin (fig. 3) and supports various desert landscapes. The Columbia Plateau and Snake River Valley, however, are susceptible to marine intrusions that can relieve summer hot spells and winter cold spells. The accompanying moisture can put out summer wildfires or cause winter rain-on-snow floods. Although rain-on-snow floods are rare in this region, when they occur they are more destructive and of much greater magnitude than spring floods. Typical seasonal snowfall totals range from 40 to 80 centimeters (15 to 32 in).

The upper plateaus (ERUs 4, 10, and 11) experience a moderate spring cycle of convective precipitation, with lightning most common in ERU 11. The convection can be caused by the northward migration of a thermal low pressure center, especially in ERU 05, ERU 04, and the western part of ERU 10. Also, hot unstable air from the Great Salt Lake region can increase thunderstorm and lightning development over ERU 11 and eastern ERU 10.

The strongest sustained winds in this region occur during summer from the west at the eastern outflow of the Columbia Gorge (ERU 05) and during winter from the south and west along ridgetops. Because of the volcanic soils and significant agricultural tilling in this zone, the wind can cause significant soil erosion and degradation in visibility. Although climate in this region is marked by few extremes, long periods of stagnation occur during winter in the central Columbia basin (ERU 05), the Snake River Valley (ERU 10), and high, isolated basins (ERUs 4, 10, and 11). The stagnation events cause this region to be the most susceptible to air pollution concerns.

Trends in Regional Climate Patterns

For the years prior to about 1850, climatic trends in the interior Columbia River basin can be determined only by using proxy data such as that evident from tree rings, glacier fluctuations, and various sorts of geologic evidence. The tree-ring chronologies in the Pacific Northwest have helped to describe climate patterns from about the mid-1600s. Because tree-ring data must be adjusted for growth, some information about century-scale climate variability is damped out. Tree-ring data are being used, however, to help identify annual and decadal patterns in climate variability (for example, Briffa and others 1992). The data suggest periodic warm periods in 1630s, between 1640 to 1660, 1790s, and the 1920s, with temperatures about 0.5 ˚C (0.9 ˚F) greater than the 1881-1982 average. Alternating cold periods also are apparent in the chronologies, with the most significant from 1870 to 1900 (near the end of the "Little Ice Age," which occurred from about A.D. 1550 to 1850) having temperatures 0.2 to 0.5 ˚C (0.5 to 0.9 ˚F) less than the 1881-1982 average.

The historical extent of mountain glaciers can provide some information on climate, but data are complicated owing to fluctuations caused by differences in winter accumulation or summer melt, or both. Also, the dynamics of glacier movement complicate the time response to climate changes; therefore, climate patterns related to glacier fluctuations usually are described in decades or centuries. Most glaciers in the region significantly advanced during the "Little Ice Age." Since about 1850, the glaciers have been retreating (Ferguson 1992, Meier 1984), suggesting that the region has been experiencing warmer winters, cloudier summers, or both.

Geologic evidence includes lake levels, fossil pollen, and borehole measurements, which have shown major epochs in Northwest climate, such as a relatively cold and wet period between 12,000 and 9,000 years before present (B.P.), a warm and dry period between 9,000 and 6,000 years B.P., and a cool, moist period since 6,000 years B.P. (Whitlock 1992, 1993; Whitlock and Bartlein 1993). The spatial heterogeneity of these large-scale features is controlled primarily by topography (Davis and others 1986, Whitlock and Bartlein 1993).

Historical weather observations within the Columbia River basin began in the late 1800s around the time that the Little Ice Age ended. A large number of weather stations were added during the 1930s drought to help monitor mountain snowpack and agricultural water conditions. Therefore, many trends seen in available data could show slight cooling from that drought period. Drought returned in the 1950s and 1980s, but cooling comparable to the late 1800s has not occurred. There appear to be decadal trends in regional climate that could be related to the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) indices (Cayan and Peterson 1989, Mantua and others 1997, Redmond and Koch 1991, Ropelewski and Halpert 1986, Yarnal and Diaz 1986). These trends are most obvious in streamflow fluctuations, which aggregate precipitation and temperature signals over large areas of the catchment and drainage basins of the stream.

To analyze climatic trends in each ERU of the interior Columbia River basin, representative stations were selected that have weather records longer than 40 years and that lie near the midrange of station elevations for that unit. A simple 10-year moving average of monthly mean values was used to evaluate trends and to help smooth year-to-year variability. Historical trends in precipitation are apparent, but trends in temperature are not obvious.

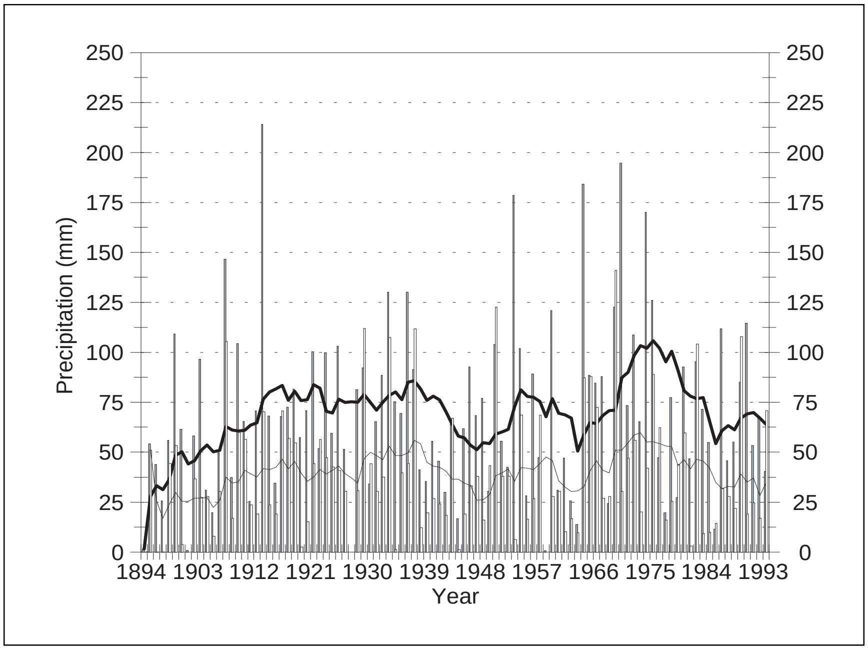

Figure 4—January precipitation and snowfall data from Moscow, Idaho, that represent winter climate trends in ERU 05. Shaded bars show monthly precipitation totals in millimeters. Hollow bars show monthly snowfall totals in centimeters. The thick line shows the moving 10-year averages of monthly precipitation, and the thin line shows the moving 10-year averages of snowfall.

A notable maximum in snowfall and winter precipitation occurred in all areas during the mid 1970s and is clearly seen in the precipitation traces at Moscow, Idaho (fig. 4). This coincides with a step-wise change in climate observed in other environmental variables during 1976 (Ebbesmeyer and others 1991). Several new ski areas were developed and existing areas expanded during that period. Previous maximums in winter precipitation occurred in the mid-1950s (when most alpine ski areas in the Western United States began), early 1940s, and mid-1930s, but these were not as pervasive throughout the basin as the mid-1970s maximum.

Winter precipitation since the mid-1970s has decreased by 30 to 80 percent in all areas to a level comparable to historical means, except in ERUs 3, 8, 9, and 10 where current winter precipitation trend is slightly lower than any in previous history; for example, at Lakeview, Oregon, shown in figure 5.

In contrast to winter trends, all areas showed an increasing trend (30 to 80 percent) in summer precipitation during the last 30 years, and figure 6 shows the summer trend at McCall, Idaho. Comparable highs in summer precipitation occurred around 1910. Since the mid-1980s, about half the basin (ERUs 3, 6, 10, 12, and 13) has shown a 20- to 70-percent decrease in summer precipitation but remains at 40 to 80 percent above the 1960s

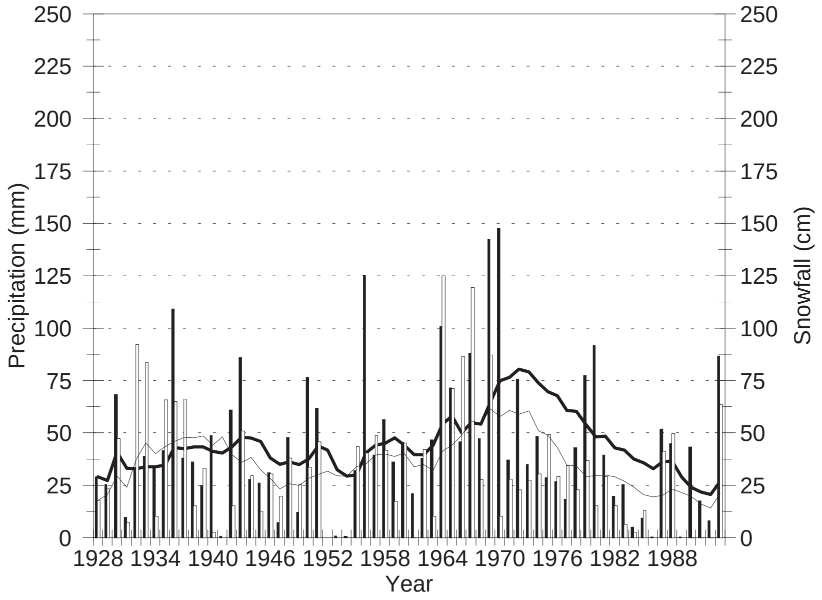

Figure 5—January precipitation and snowfall data from Lakeview, Oregon, that represent winter climate trends in ERU 03. See figure 4 for definitions of bars and lines.

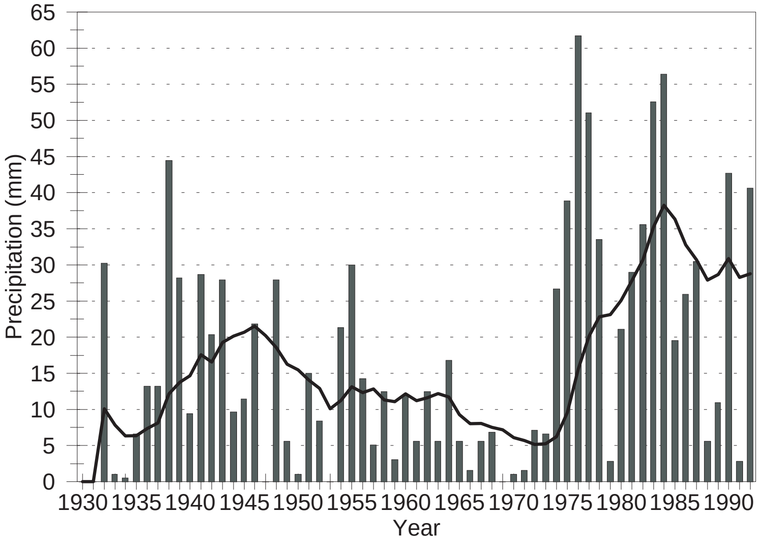

Figure 6—July precipitation data from McCall, Idaho, that represent summer climate trends in ERU 13. See figure 4 for definitions of bars and lines, except no snowfall.

levels. Periods of drought throughout the basin since 1988 appear to be related to the overall decrease in winter precipitation and beginning signs of decreasing summer precipitation.

Trends in annual precipitation over the last 100 years show significant variability around the basin (Karl and others 1996). The central basin (Washington, northeastern Oregon, and eastern Idaho) showed 5- to 10-percent increases. Elsewhere, annual precipitation decreased 5- to 10-percent, with ERU 03 showing a 20-percent decrease. It is difficult to compare the 100-year trends with those calculated from stations within each ERU that have records of only 50 to 70 years. Also, Mock (1996) illustrates the highly seasonal nature of precipitation in the Western United States. Therefore, changes in spring and autumn months that influence annual trends are not shown in the January and July records analyzed for each ERU.

Although there has been almost no change in measured winter temperatures for the east side of the Cascades, there has been a notable increase in the percentage of water in the winter precipitation; for example, since the early 1970s, snowfall at Bend, Oregon, has decreased at a more rapid rate than total precipitation (fig. 7). This could indicate somewhat higher snow levels with less snow accumulating at lower elevations. In the same region, a 1 to 2 ˚C (2 to 4 ˚F) decrease in the diurnal range of summer temperatures may suggest slightly increasing summer cloudiness (fig. 8). Other regions have less obvious changes, but the overall trends appear to be toward slightly cooler summers and slightly warmer winters.

Mean temperature has increased 1 to 2˚C (2 to 4 ˚F) throughout the basin over the last 100 years (Karl and others 1990). Note again that many of the stations used to analyze ERU trends have records

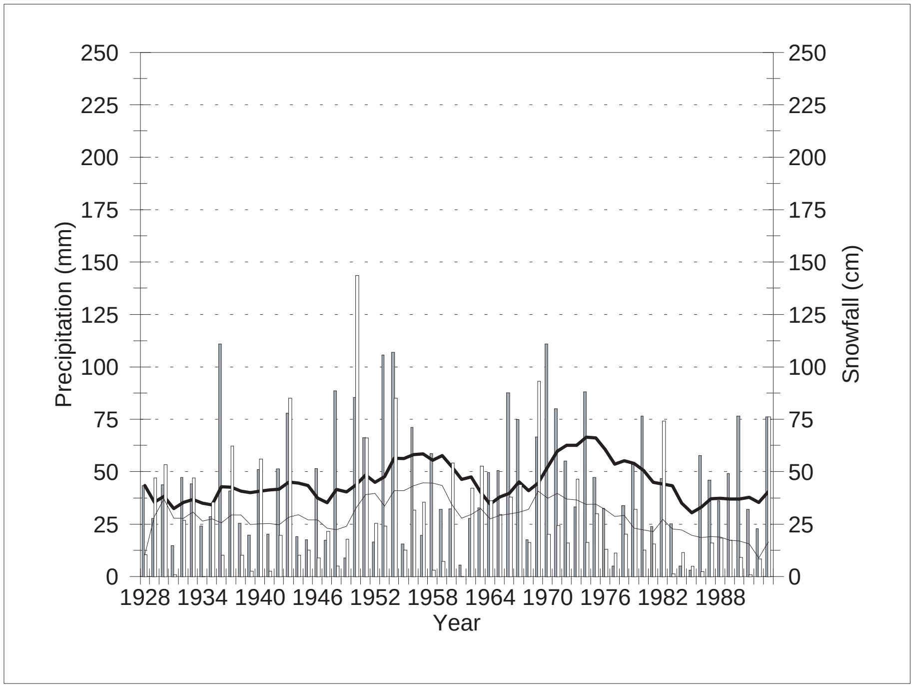

Figure 7—January precipitation and snowfall data from Bend, Oregon, that represent winter climate trends in ERU 02. See figure 4 for definitions of bars and lines.

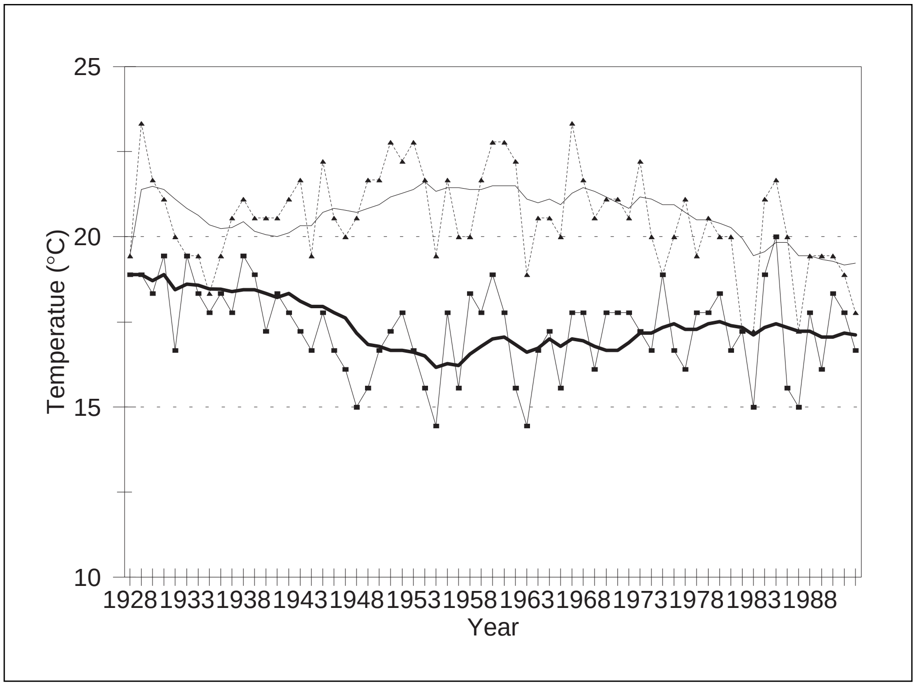

Figure 8—July temperature data from Bend, Oregon, that represent summer climate trends in ERU 02. Shown are monthly average temperatures (■), monthly average range between daily maximum and minimum temperatures (▲), with moving 10-year averages of each (thick and thin lines, respectively).

that began during the 1930s drought era. Therefore, their trends are smaller than the 100-year trends and are slightly negative.

The persistent drought throughout the basin in the 1930s may relate to warm winter temperatures and associated high snow levels. Many areas also experienced a decrease in summer precipitation during the 1930s, which added to severe drought conditions. Periods of significant drought in a few areas of the central basin and plateau regions during the 1950s appear to have been driven more by warmer than normal temperatures rather than by changes in precipitation.

Conclusions

Climate of the interior Columbia River basin can be characterized by three distinct air mass types that interact with each other in a region of complex topography. Most precipitation accumulates during winter (75 to 125 cm [30 to 50 in] in the Eastern Cascades, 25 to 95 cm [10 to 37 in] in the Northern Rockies, and 20 to 40 cm [8 to 16 in] in the Central Columbia and Snake River Plateaus). The mountain snowpack acts as a natural reservoir and supplies the basin with most of its usable water. Only the east and south ERUs of the basin have summer maximum precipitation, which is associated with significant thunderstorm activity. Summer precipitation throughout the basin ranges from about 20 to 50 cm (8 to 20 in). Trends in the last 50 to 100 years indicate a general decrease in winter precipitation and increase in summer precipitation.

Temperatures are generally mild in the basin because of periodic influxes of moderating Pacific moisture. Winter mean monthly temperatures range from -10 to -3 ˚C (-50 to 27 ˚F), and summer temperatures range from 10 to 15 ˚C (50 to 59 ˚F). Trends in the last 50 to 100 years indicate a slight increase in winter temperatures and slight decrease in summer temperatures.

Because most weather observation stations are located near towns that are in valleys or away from mountains, there is an elevational bias in the instrument data. More effective analysis of the Columbia River basin climate would include high-elevation data from snow course, SNOTEL, and RAWS sites. To do such analyses requires a significant amount of data processing to check and adjust for quality. In addition, outfitting RAWS sites with winter-durable sensors would improve their reliability as climatic indicators. Developing a unified database from all available data sources also would be a great asset. Exploring new methods of analyzing spatial and temporal variability would significantly improve our understanding of climate patterns in regions of complex topography, such as the Columbia River basin.

In addition to an elevational bias in this instrumental analysis, there also was a temporal bias because the number of weather observations has increased over time. Determining better ways of gathering and interpreting paleoclimatic data would significantly improve our understanding of climate variability and trends. Of particular interest is the “Little Ice Age,” when Northwest climate was significantly colder than now and when many tree species in Northwest forests were establishing. No weather measurements exist for this critical time period (approx. A.D. 1550 to 1850), and few proxy data are available. The climatological evidence in proxy data that do exist has not been fully realized. There are robust methods of climate analysis, however, that can re-create regional climate patterns from sparse proxy data and from correlations with long-period records in other parts of the world. These methods can be used to develop a detailed description of Northwest climate during a “presettlement” era when the impacts of climate variability and trend were not complicated by management practices.

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Appendix

Table 2a—Daily climate summary for ERU 01 (26 weather stations[a])

Month	Temperature Max.	 Min.	 Daily range	 Avg.	PPT [b]	Snowfall	Water content of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	-1.12	-8.61	7.49	-4.87	124.69	78.03	0.374
2	3.21	-5.92	9.14	-1.36	88.17	52.28	0.407
3	7.44	-3.55	10.98	1.95	69.87	36.15	0.483
4	12.44	-0.52	12.96	5.96	41.74	10.77	0.742
5	16.01	2.10	13.91	9.04	29.86	2.41	0.919
6	20.93	6.50	14.43	13.70	30.55	0.15	0.995
7	25.30	8.69	16.60	16.99	12.90	0.04	0.997
8	25.01	8.35	16.66	16.68	18.28	0.00	1.000
9	20.91	4.64	16.27	12.76	29.86	0.18	0.994
10	13.66	0.35	13.31	6.99	62.27	4.43	0.929
11	4.95	-3.18	8.12	0.87	114.12	36.14	0.683
12	0.43	-6.37	6.80	-2.97	135.49	77.14	0.431
Annual	12.43	0.21	12.22	6.31	63.15	24.81	0.746

[a] Station elevations: minimum = 195 meters, maximum = 1207, average = 603, range = 1012.

[b] PPT = precipitation.

Table 2b—Daily seasonal trends for ERU 01[a]

Season	Temperature trend Daily range	 Avg.	Precipitation trend All years	 Since 1960	 Since 1975	 Since 1985
	.... *°C*		.... *Percent*			
Winter	-0.5	0	0	--	-35	--
Summer	-2.5	0	+50	+50	--	+10

-- = negligible.

[a] Represented by data from Cle Elum, Washington (588 meters elevation and 64 years of record).

Table 3a—Daily climate summary for ERU 02 (18 weather stations[a])

	Temperature						Water content
Month	Max.	Min.	Daily range	Avg.	PPT	Snowfall	of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	2.42	-6.29	8.71	-1.95	108.68	62.77	0.422
2	5.30	-4.57	9.87	0.36	74.80	35.86	0.521
3	7.27	-3.71	10.98	1.76	61.68	26.40	0.572
4	11.10	-1.85	12.95	4.61	34.09	7.92	0.768
5	15.35	0.97	14.38	8.17	27.16	1.76	0.935
6	19.01	3.98	15.03	11.48	23.16	0.15	0.994
7	25.41	7.07	18.35	16.23	8.35	0.01	0.999
8	24.97	6.74	18.23	15.85	14.86	0.00	1.000
9	21.06	3.63	17.43	12.35	20.14	0.18	0.991
10	13.27	-0.57	13.84	6.35	44.24	2.54	0.943
11	6.98	-2.68	9.67	2.14	93.70	22.35	0.761
12	3.21	-5.06	8.27	-0.94	114.26	48.36	0.577
Annual	12.95	-0.20	13.14	6.37	52.09	17.36	0.790

[a] Station elevations: minimum = 30, maximum = 1475, average = 848, range = 1445.

Table 3b—Daily seasonal trends for ERU 02[a]

	Temperature trend		Precipitation trend			
Season	Daily range	Avg.	All years	Since 1960	Since 1975	Since 1985
	.... *°C*		.... *Percent*			
Winter	-0.5	0	0	--	-40	--
Summer	-1	-1	0	+75	--	+10

--- = negligible.

[a] Represented by data from Bend, Oregon (1116 meters elevation and 67 years of record).

Table 4a—Daily climate summary for ERU 03 (12 weather stations[a])

Month	Temperature Max.	Min.	Daily range	Avg.	PPT	Snowfall	Water content of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	2.35	-8.24	10.60	-2.95	72.60	41.69	0.426
2	4.89	-6.39	11.28	-0.75	58.34	33.73	0.422
3	7.51	-4.81	12.32	1.34	55.82	34.20	0.387
4	11.78	-2.89	14.67	4.43	32.91	14.73	0.553
5	16.42	0.25	16.18	8.31	33.02	5.85	0.823
6	20.68	3.42	17.26	12.04	26.75	1.47	0.945
7	25.67	5.89	19.79	15.78	9.42	0.07	0.993
8	25.18	5.05	20.13	15.08	13.46	0.03	0.997
9	21.55	1.85	19.70	11.66	19.03	0.71	0.963
10	15.38	-1.52	16.90	6.92	41.68	6.39	0.847
11	7.35	-4.67	12.02	1.33	69.93	25.33	0.638
12	3.11	-7.30	10.41	-2.09	84.60	46.16	0.454
Annual	13.49	-1.61	15.10	5.92	43.13	17.53	0.704

[a] Station elevations: minimum = 1231, maximum = 1972, average = 1370, range = 741.

Table 4b—Daily seasonal trends for ERU 03[a]

Season	Temperature trend Daily range	Avg.	Precipitation trend All years	Since 1960	Since 1975	Since 1985
	.... *°C*		.... *Percent*			
Winter	-0.5	+1	10	--	-70	--
Summer	-3	0	+50	+50	--	-30

-- = negligible.

[a] Represented by data from Lakeview, Oregon (1457 meters elevation and 67 years of record).

Table 5a—Daily climate summary for ERU 04 (22 weather stations[a])

	Temperature						Water content
Month	Max.	Min.	Daily range	Avg.	PPT	Snowfall	of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	2.68	-8.32	11.00	-2.83	27.59	15.90	0.424
2	5.68	-5.96	11.64	-0.15	21.95	10.10	0.540
3	8.68	-4.31	12.99	2.17	25.30	9.35	0.630
4	13.12	-2.37	15.49	5.35	20.96	3.70	0.824
5	17.91	1.11	16.80	9.50	28.46	1.75	0.939
6	22.60	4.75	17.86	13.67	25.31	0.48	0.981
7	27.78	7.36	20.41	17.57	10.17	0.00	1.000
8	27.00	6.59	20.41	16.79	14.20	0.01	1.000
9	22.57	2.42	20.15	12.48	13.94	0.13	0.990
10	16.29	-1.48	17.77	7.37	20.20	1.53	0.924
11	7.81	-4.74	12.55	1.52	29.69	8.54	0.712
12	3.35	-7.80	11.15	-2.25	31.65	16.10	0.491
Annual	14.62	-1.06	15.68	6.77	22.45	5.63	0.788

[a] Station elevations: minimum = 1253, maximum = 1713, average = 1355, range = 460.

Table 5b—Daily seasonal trends for ERU 04[a]

	Temperature trend		Precipitation trend			
Season	Daily range	Avg.	All years	Since 1960	Since 1975	Since 1985
	.... *°C*		.... *Percent*			
Winter	0	+1	0	--	-30	--
Summer	-2	0	+10	+50	--	0

-- = negligible.

[a] Represented by data from Sqaw, Oregon (1420 meters elevation and 58 years of record).

Table 6a—Daily climate summary for ERU 05 (87 weather stations[a])

Month	Temperature				PPT	Snowfall	Water content of snow
	Max.	Min.	Daily range	Avg.			
	°C				*Mm*	*Cm*	*Percent*
1	1.75	-6.37	8.12	-2.32	39.13	19.46	0.503
2	5.63	-3.85	9.48	0.89	28.60	10.10	0.647
3	10.24	-1.61	11.85	4.31	30.20	6.14	0.797
4	14.91	0.98	13.93	7.94	25.78	2.17	0.916
5	19.72	4.54	15.19	12.12	28.60	0.47	0.984
6	23.89	8.00	15.89	15.94	28.40	0.03	0.999
7	28.61	10.39	18.22	19.49	10.33	0.00	1.000
8	27.96	9.95	18.01	18.95	13.04	0.00	1.000
9	23.22	6.14	17.08	14.67	16.37	0.05	0.997
10	15.80	1.47	14.34	8.63	24.47	0.78	0.968
11	7.17	-2.18	9.35	2.49	40.05	6.93	0.827
12	2.73	-4.94	7.68	-1.12	41.69	16.15	0.613
Annual	15.14	1.88	13.26	8.50	27.22	5.19	0.854

[a] Station elevations: minimum = 58, maximum = 1902, average = 566, range = 1844.

Table 6b—Daily seasonal trends for ERU 05[a]

Season	Temperature trend		Precipitation trend			
	Daily range	Avg.	All years	Since 1960	Since 1975	Since 1985
	°C		*Percent*			
Winter	-0.5	0	0	--	-35	--
Summer	+2	-1	+30	+60	--	-10

--= negligible.

[a] Represented by data from Moscow, Idaho (810 meters elevation and 95 years of record).

Table 7a—Daily climate summary for ERU 06 (34 weather stations[a])

Month	Temperature Max.	Min.	Daily range	Avg.	PPT	Snowfall	Water content of snow
	°C				*Mm*	*Cm*	*Percent*
1	0.66	-9.03	9.69	-4.20	41.76	10.90	0.337
2	5.05	-6.54	11.59	-1.11	31.39	6.13	0.504
3	9.07	-3.82	12.89	2.61	34.71	4.33	0.683
4	13.97	-1.11	15.07	6.42	30.61	1.39	0.884
5	18.62	2.34	16.29	10.46	39.47	0.27	0.983
6	22.93	5.63	17.31	14.27	35.04	0.02	0.998
7	28.31	7.81	20.50	18.04	14.23	0.00	1.000
8	27.78	7.10	20.68	17.43	18.47	0.00	1.000
9	22.97	3.08	19.89	13.02	19.21	0.11	0.986
10	16.19	-0.86	17.05	7.65	26.23	0.41	0.960
11	7.25	-4.23	11.48	1.50	39.57	4.08	0.738
12	1.80	-7.62	9.42	-2.93	44.38	9.21	0.473
Annual	14.55	-0.60	15.16	6.93	31.26	3.07	0.795

[a] Station elevations: minimum = 363, maximum = 1506, average = 959, range = 1143.

Table 7b—Daily seasonal trends for ERU 06[a]

Season	Temperature trend Daily range	Avg.	Precipitation trend All years	Since 1960	Since 1975	Since 1985
	°C		*Percent*			
Winter	+0.5	0	0	--	-30	--
Summer	-0.5	0	+50	+45	--	-15

--= negligible.

[a] Represented by data from Union, Oregon (844 meters elevation and 67 years of record).

Table 8a—Daily climate summary for ERU 07 (52 weather stations[a])

Month	Temperature Max.	 Min.	 Daily range	 Avg.	PPT	Snowfall	Water content of snow
	.... °C				Mm	Cm	Percent
1	-1.57	-9.48	7.91	-5.54	57.15	45.28	0.208
2	2.27	-7.18	9.45	-2.46	41.39	24.34	0.412
3	6.87	-4.58	11.44	1.13	38.36	14.39	0.625
4	12.78	-0.94	13.72	5.92	34.17	3.30	0.903
5	18.02	2.93	15.10	10.46	45.34	0.67	0.985
6	21.91	6.35	15.56	14.12	49.73	0.08	0.998
7	25.90	7.84	18.06	16.86	26.83	0.01	1.000
8	26.13	7.70	18.42	16.90	28.80	0.01	1.000
9	19.75	3.40	16.35	11.57	31.54	0.19	0.994
10	12.27	-0.66	12.93	5.80	36.31	2.27	0.937
11	3.83	-4.09	7.93	-0.13	58.77	18.14	0.691
12	-0.56	-7.58	7.02	-4.07	60.98	41.02	0.327
Annual	12.30	-0.52	12.82	5.88	42.45	12.48	0.757

[a] Station elevations: minimum = 250, maximum = 1795, average = 796, range = 1545.

Table 8b—Daily seasonal trends for ERU 07[a]

Season	Temperature trend Daily range	 Avg.	Precipitation trend All years	 Since 1960	 Since 1975	 Since 1985
	.... °C		.... Percent			
Winter	-2	+0.5	-25	--	-40	--
Summer	-2	+1	0	+30	--	na

--= negligible.

na = not available.

[a] Represented by data from Fortine, Montana (719 meters elevation and 95 years of record).

Table 9a—Daily climate summary for ERU 08 (29 weather stations[a])

Month	Temperature Max.	Min.	Daily range	Avg.	PPT	Snowfall	Water content of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	-1.36	-8.88	7.52	-5.13	94.84	54.51	0.425
2	2.06	-6.88	8.94	-2.41	67.44	32.48	0.518
3	5.42	-5.28	10.69	0.07	59.80	20.71	0.654
4	9.56	-2.82	12.38	3.38	45.81	4.09	0.911
5	15.44	0.87	14.58	8.15	51.54	0.98	0.981
6	20.61	4.90	15.70	12.74	54.33	0.05	0.999
7	24.19	5.78	18.41	14.98	23.20	0.00	1.000
8	24.91	6.15	18.76	15.53	29.54	0.00	1.000
9	20.56	2.77	17.79	11.04	39.60	0.28	0.993
10	11.02	-1.53	12.54	4.73	52.34	2.99	0.943
11	2.82	-4.76	7.58	-0.98	78.69	20.07	0.745
12	-0.67	-7.33	6.65	-4.00	100.53	52.82	0.475
Annual	11.21	-1.42	12.63	4.84	58.14	15.75	0.804

[a] Station elevations: minimum = 658, maximum = 1817, average = 882, range = 1159.

Table 9b-Daily seasonal trends for ERU 08[a]

Season	Temperature trend Daily range	Temperature trend Avg.	Precipitation trend All years	Since 1960	Since 1975	Since 1985
	.... *°C*		.... *Percent*			
Winter	-2	+2	-25	--	-50	--
Summer	-2	+0.5	+40	+40	--	na

-- = negligible.

na = not available.

[a] Represented by data from Haugan, Montana (890 meters elevation and 43 years of record).

Table 10a—Daily climate summary for ERU 09 (21 weather stations[a])

	Temperature						Water content
Month	Max.	Min.	Daily range	Avg.	PPT	Snowfall	of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	-3.55	-13.07	9.53	-8.31	25.65	27.61	-0.076
2	-0.66	-11.12	10.46	-5.90	17.49	17.95	-0.026
3	2.56	-8.66	11.22	-3.05	19.06	18.04	0.054
4	7.51	-5.16	12.67	1.16	22.41	7.63	0.659
5	11.86	-1.84	13.70	5.00	38.53	2.59	0.933
6	15.46	1.17	14.30	8.31	44.36	0.27	0.994
7	19.83	2.64	17.19	11.23	23.03	0.00	1.000
8	19.32	1.98	17.34	10.64	25.53	0.09	0.997
9	15.84	-0.57	16.41	7.61	26.41	1.48	0.944
10	10.03	-4.17	14.20	2.93	21.37	4.80	0.775
11	1.24	-8.62	9.85	-3.69	22.07	15.05	0.318
12	-2.85	-11.97	9.12	-7.43	23.74	24.86	-0.047
Annual	8.05	-4.95	13.00	1.54	25.80	10.03	0.544

[a] Station elevations: minimum = 1030, maximum = 1847, average = 1367, range = 617.

Table 10b—Daily seasonal trends for ERU 09[a]

	Temperature trend		Precipitation trend			
Season	Daily range	Avg.	All years	Since 1960	Since 1975	Since 1985
	.... *°C*		.... *Percent*			
Winter	0	0	-50	--	-45	--
Summer	0	0	0	+35	--	0

-- = negligible.

[a] Represented by data from Butte, Montana (1689 meters elevation and 95 years of record).

Table 11a—Daily climate summary for ERU 10 (62 weather stations[a])

Month	Temperature Max.	Min.	Daily range	Avg.	PPT	Snowfall	Water content of snow
	°C				*Mm*	*Cm*	*Percent*
1	1.23	-8.81	10.03	-3.81	31.41	17.21	0.452
2	4.94	-6.21	11.15	-0.66	24.89	12.97	0.479
3	9.47	-3.57	13.04	2.93	27.09	7.93	0.707
4	14.77	-0.39	15.16	7.19	24.17	3.95	0.836
5	19.80	3.62	16.18	11.69	28.94	1.50	0.948
6	24.52	7.34	17.19	15.91	34.18	0.27	0.992
7	29.81	10.47	19.34	20.13	8.01	0.00	1.000
8	28.93	9.45	19.49	19.18	10.64	0.04	0.997
9	23.58	4.76	18.82	14.17	14.52	0.49	0.966
10	6.94	0.06	16.89	8.49	19.32	2.05	0.894
11	7.84	-4.27	12.11	1.78	30.18	6.88	0.772
12	2.18	-7.85	10.03	-2.86	30.39	12.41	0.592
Annual	15.34	0.38	14.95	7.85	23.65	5.47	0.803

[a] Station elevations: minimum = 652, maximum = 2146, average = 1124, range = 1494.

Table 11b—Daily seasonal trends for ERU 10[a]

Season	Temperature trend Daily range	Avg.	Precipitation trend All years	Since 1960	Since 1975	Since 1985
	°C		*Percent*			
Winter	-1	-0.5	-25	--	-60	--
Summer	-2	+2	0	+50	--	-70

-- = negligible.

[a] Represented by data from Caldwell, Idaho (722 meters elevation and 90 years of record).

Table 12a—Daily climate summary for ERU 11 (22 weather stations[a])

	Temperature						Water content
Month	Max.	Min.	Daily range	Avg.	PPT	Snowfall	of snow
	°C				*Mm*	*Cm*	*Percent*
1	-1.88	-11.76	9.89	-6.83	23.31	20.46	0.122
2	1.42	-9.14	10.56	-3.89	19.92	14.04	0.295
3	5.96	-5.82	11.79	0.06	21.90	8.78	0.599
4	12.04	-2.08	14.12	4.95	22.32	3.66	0.836
5	17.06	2.00	15.06	9.50	32.48	1.09	0.966
6	21.74	5.54	16.19	13.64	27.44	0.02	0.999
7	26.71	8.60	18.11	17.65	13.44	0.00	1.000
8	25.96	7.51	18.45	16.74	14.67	0.00	1.000
9	20.74	3.01	17.73	11.88	16.60	0.15	0.991
10	14.24	-1.65	15.89	6.30	18.38	1.69	0.908
11	5.08	-6.19	11.27	-0.57	22.87	8.33	0.636
12	-0.46	-10.36	9.91	-5.42	23.08	18.37	0.204
Annual	12.38	-1.70	14.08	5.34	21.37	6.38	0.713

[a] Station elevations: minimum = 1268, maximum = 1798, average = 1409, range = 530.

Table 12b-Daily seasonal trends for ERU 11[a]

	Temperature trend		Precipitation trend			
Season	Daily range	Avg.	All years	Since 1960	Since 1975	Since 1985
	°C		*Percent*			
Winter	0	0	0	--	-75	--
Summer	-2	-1	0	+80	--	+10

-- = negligible.

[a] Represented by data from Aberdeen, Idaho (1344 meters elevation and 81 years of record).

Table 13a—Daily climate summary for ERU 12 (12 weather stations[a])

Month	Temperature Max.	Min.	Daily range	Avg.	PPT	Snowfall	Water content of snow
	.... *°C*				*Mm*	*Cm*	*Percent*
1	-3.83	-16.42	12.59	-10.21	51.22	71.29	-0.392
2	-0.67	-14.50	13.83	-7.65	42.33	51.59	-0.219
3	2.89	-11.35	14.24	-4.25	40.36	46.55	-0.153
4	8.32	-6.00	14.32	1.15	40.17	23.86	0.406
5	14.31	-1.48	15.79	6.39	53.49	7.43	0.861
6	19.56	1.77	17.79	10.66	43.39	0.53	0.988
7	24.18	4.07	20.11	14.10	29.99	0.00	1.000
8	23.41	3.23	20.18	13.34	32.79	0.02	0.999
9	18.44	-0.73	19.17	8.81	38.16	2.04	0.946
10	12.05	-5.10	17.15	3.46	34.08	10.10	0.704
11	2.40	-10.25	12.65	-3.94	48.79	45.20	0.074
12	-3.18	-15.60	12.42	-9.46	50.29	66.05	-0.313
Annual	9.82	-6.03	15.85	1.87	42.09	27.06	0.408

[a] Station elevations: minimum = 1603, maximum = 2487, average = 1959, range = 884.

Table 13b—Daily seasonal trends for ERU 12[a]

Season	Temperature trend Daily range	Avg.	Precipitation trend All years	Since 1960	Since 1975	Since 1985
	.... *°C*		.... *Percent*			
Winter	0	0	0	--	-50	--
Summer	-2	+1	+50	+80	--	-35

-- = negligible.

[a] Represented by data from Ashton, Idaho (1603 meters elevation and 47 years of record).

Table 14a—Daily climate summary for ERU 13 (51 weather stations[a])

	Temperature						Water content
Month	Max.	Min.	Daily range	Avg.	PPT	Snowfall	of snow
	°C				*Mm*	*Cm*	*Percent*
1	-1.17	-12.48	11.31	-6.87	70.07	44.12	0.370
2	2.51	-10.29	12.80	-3.90	42.09	28.03	0.334
3	6.53	-7.05	13.59	-0.27	40.85	20.79	0.491
4	11.98	-3.06	15.04	4.45	37.02	7.99	0.784
5	17.31	0.81	16.49	9.05	43.48	2.11	0.952
6	21.86	4.29	17.57	13.07	44.06	0.13	0.997
7	27.37	6.54	20.84	16.93	19.22	0.00	1.000
8	26.78	5.68	21.10	16.22	21.84	0.00	1.000
9	21.36	1.63	19.73	11.48	26.91	0.33	0.988
10	13.76	-2.85	16.61	5.45	30.35	2.87	0.906
11	4.94	-6.74	11.68	-0.92	48.71	20.53	0.578
12	-0.49	-11.31	10.82	-5.94	65.76	41.51	0.369
Annual	12.73	-2.90	15.63	4.90	40.86	14.03	0.731

[a] Station elevations: minimum = 485, maximum = 2225, average = 1371, range = 1740.

Table 14b—Daily seasonal trends for ERU 13[a]

	Temperature trend		Precipitation trend			
Season	Daily range	Avg.	All years	Since 1960	Since 1975	Since 1985
	°C		*Percent*			
Winter	-1	+2	0	--	-50	--
Summer	+2	-0.5	+50	+60	--	-20

-- = negligible.

[a] Represented by data from McCall, Idaho (1533 m elevation and 65 years of record).

Ferguson, Sue A. 1999. Climatology of the interior Columbia River basin. Gen. Tech. Rep. PNW-GTR-445. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 31 p. (Quigley, Thomas M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

This work describes climate means and trends in each of three major ecological zones and 13 ecological reporting units in the interior Columbia River basin. Widely differing climates help define each major zone and reporting unit, the pattern of which is controlled by three competing air masses: marine, continental, and arctic. Paleoclimatic evidence and historical weather records show that the region has undergone significant fluctuations in temperature and precipitation as air masses alternate dominance over the basin. The major change in climate occurred near the time of western settlement with the end of the "Little Ice Age." Since then there have been numerous annual cycles in climate that may be related to the Pacific Decadal Oscillation. During the last 50 years, winter precipitation has decreased slightly and summer precipitation has increased throughout most of the basin. At the same time, winter temperatures have increased and summer temperatures have slightly decreased. Some impacts of changes in climatic means and trends on ecological conditions in the basin are discussed.

Keywords: Climate, Columbia River basin, climatology, climate variability, temperature, precipitation, snowfall.

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