AIR QUALITY CLIMATE IN THE COLUMBIA RIVER BASIN

PREPARED BY:

SUE FERGUSON
FORESTRY SCIENCES LABORATORY
SEATTLE, WASHINGTON

1996

INTERIOR COLUMBIA BASIN
ECOSYSTEM MANAGEMENT PROJECT

Preface

The following report was prepared by University scientists through cooperative agreement, project science staff, or contractors as part of the ongoing efforts of the Interior Columbia Basin Ecosystem Management Project, co-managed by the U.S. Forest Service and the Bureau of Land Management. It was prepared for the express purpose of compiling information, reviewing available literature, researching topics related to ecosystems within the Interior Columbia Basin, or exploring relationships among biophysical and economic/social resources.

This report has been reviewed by agency scientists as part of the ongoing ecosystem project. The report may be cited within the primary products produced by the project or it may have served its purposes by furthering our understanding of complex resource issues within the Basin. This report may become the basis for scientific journal articles or technical reports by the USDA Forest Service or USDI Bureau of Land Management. The attached report has not been through all the steps appropriate to final publishing as either a scientific journal article or a technical report.

AIR QUALITY CLIMATE IN THE COLUMBIA RIVER BASIN

Sue Ferguson

Forestry Sciences Laboratory
4043 Roosevelt Way, NE
Seattle, Washington 98105-6497
206/553-7815 FAX: 553-7709

INTRODUCTION

Climate patterns in the Columbia River Basin are dominated by topographic features. Surrounding mountain ranges prevent frequent intrusion from

progressing air masses and create an isolated, sometimes stagnant, basin atmosphere. Gaps through the mountains, however, allow a striking pattern of mixing that is unique to the Basin. The following describe several components of climate that influence air quality.

MIXING HEIGHT

Mixing height may be considered as a level in the atmosphere above which vertical exchange of air is inhibited. Low mixing heights mean that the air is generally stagnant with very little vertical motion and pollutants usually are trapped near the ground surface. High mixing heights allow vertical mixing within a deep layer of the atmosphere and good dispersion of pollutants.

One way to determine mixing height is to consider a parcel of air near the ground, whose temperature equals the daily maximum surface temperature, that is lifted dry adiabatically until it reaches the temperature of the ambient air, which is measured from a radiosonde observation (RAOB). The level at which the lifted parcel's temperature equals the ambient air temperature is defined as the mixing height. Above the mixed layer, further lifting of the parcel would cause it to become cooler than ambient air temperatures.

The afternoon RAOBs were used to approximately coincide with the time of maximum daily surface temperature. Afternoon RAOBS occur near 0 Greenwich Mean Time (GMT), which coincides with 4 to 6 pm in the Columbia River Basin. Data include approximately 1000 RAOBs from the period between 1966 and 1989. Mixing heights were calculated by the Western Regional Climate Center (P.O. Box 60220, Reno, Nevada 89506-0220). The stations analyzed included: Quillayute, Washington (58 meters elevation), the only station on the Pacific coast; Salem, Oregon (61 meters) and Medford, Oregon (421 meters), between the

coast and Cascade mountain ranges; Spokane, Washington (722 meters) and Boisé, Idaho (871 meters), inside the Basin; and Winnemucca, Nevada (1310 meters), just south of the Basin in northern Nevada.

During spring Winnemucca begins to "mix out" first because the air is not constrained by Basin topography (Figure 2). During summer (Figure 3) Winnemucca experiences consistently high mixing heights because the summer sunshine efficiently warms the inland continent. Within the Basin, the mean summer mixing height is about 1800 meters at Spokane and Boise. The range of mixing heights, however, includes levels below 900 meters, especially at Boise where topographic constraints from the Snake River valley are even more dominant than the overall Basin topography. The coastal stations are influenced by frequent intrusions of marine clouds that increase atmospheric stability. This mostly is observed at Quillayute on the Washington coast.

To illustrate potential areal extent of stagnant air, constant height levels of 1000 meters and 1400 meters were plotted over the basin topography. The first plot (Appendix Q-26) shows where stagnant air may occur if the mixing height is constant at 1000 meters, near the lowest summer mixing heights. Stagnant air is confined to the central plateau of the Basin and the lower Snake River valley. If the mixing height is constant around 1400 meters (Appendix Q-27), there is relatively good dispersion in the central plateau of the Basin. High basins and some high valleys in Oregon and western Montana may trap air, however, and cause pockets of stagnation.

RAIN DAYS PER MONTH

Airborne pollutants may fall out of the atmosphere by attaching to precipitating particles. Liquid precipitation (rain) is more efficient at scavenging gas and particles than solid precipitation (snow, hail, etc.).

Therefore, a simple analysis of rain days per month was conducted to help determine the frequency of wet deposition onto plants and into soils and snowcover.

To determine rain days in wild-land regions data from all National Weather Service (NWS) cooperative observation station sites above 900 meters elevation were selected. Days of rain were defined as those days with measured precipitation and mean temperatures greater than 5°C. When near-surface air temperatures are above 5°C, 100 percent of observed precipitation is rain (Ferguson, 1994; Ferguson and Breyfogle 1994). Because mean temperature was used, there may be some periods during the day when temperatures are lower and snowfall may occur, but these should be rare. This definition omits days with cold rain, mixed periods of rain and snow, and purely snow.

Rain days per month were calculated for January during three characteristic climate years, 1982, 1988, and 1989. In all years, there were few days of mid-winter rain at elevations above 900 meters. Although significant precipitation occurred during winter 1982, most fell as snow and rain was confined to lower elevations in eastern Oregon and western Idaho (Appendix Q-28). Only a small amount of precipitation occurred in January 1988 (Appendix Q-29) so a similar pattern of rain days occurred with some rain at higher elevations in central Idaho and western Montana. The "normal" year of 1989 (Appendix Q-30) again showed few mid-winter rain days, mostly at lower elevations.

The number of rain days per month become greater than snow days per month as seasonal temperatures increase. Slightly fewer stations observed rain during April in 1982 (Appendix Q-31) than other years because snowfall continued through spring that year. In 1988 there were a number of stations throughout the Basin that experienced 50 percent to 75 percent days with spring rain

(Appendix Q-32). In 1989, most stations experienced at least 25 percent days with rain, which is typical of spring (Appendix Q-33).

Summer precipitation in the Basin is dominated by atmospheric convection. During wet years, like 1982 (Appendix Q-34) a large number of stations experience more than 50 percent days with rain, especially in places where summertime convection dominates precipitation. In 1988 (Appendix Q-35) no station measured significant precipitation as dryness pervaded the Basin. During a normal year (Appendix Q-36) typical summer patterns of precipitation prevailed with most rain days occurring in places where convection is common like eastern Idaho and western Montana.

During autumn, convection remains important in precipitation distribution. In addition, the significance of frontal and orographic precipitation begin to increase but snow also may occur. In 1982 (Appendix Q-37) most of the mountain sites show over 25 percent of the days with rain. Cool than normal seasonal temperatures also may have caused days with snow. In 1988 (Appendix Q-38) few stations measured more than a few days with rain. Most of those occurred in Idaho and western Montana where convection probably remained important. During a typical year (Appendix Q-39) most stations observe about 25 percent of days with rain.

UPPER LEVEL WINDS

Winds in the upper atmosphere may carry buoyant pollutants long distances. Land managers have shown concern about the possibility of pollutants from the Basin reaching the Grand Canyon. This may occur if upper level winds over the Basin are strong northerly.

The distribution of wind speed and direction was calculated by the Western

Regional Climate Center (P.O. Box 60220, Reno, Nevada 89506-0220). Winds at the 700 millibar (mb) level are shown because that level usually is above the influence of terrain surrounding the Basin (about 3000 meters) and most likely to carry pollutants out of the Basin.

At Spokane, the mean winter 700 mb wind direction is westerly with a normal variation between SSW-W-NNW (Figure 5). Nine per cent of the winds have a northerly component with speeds greater than 11 m/s. Spring winds are highly variable with mean directions between SW and WSW. Twelve percent of the winds have a northerly component but all are less than 9 m/s and most are less than 2 m/s. A similar wind distribution occurs during summer (Figure 6) with a little more preference to SW and WSW directions. In autumn, prevailing winds begin to shift back to westerly. Four per cent of autumn winds have northerly components greater than 11 m/s.

Upper level winds at Boise have a slightly different distribution. This may be because the Snake River valley, which is oriented northwest to southeast may influence winds, even those well above the surrounding topography. Over Boise, winter winds prevail from the WNW and 15 percent have a strong (greater than 11 m/s) northerly component (Figure 7). Spring winds prevail from the W, WNW, to NW and 9 percent have strong northerly components. In summer winds over Boise prevail from the WSW and 14 percent of the winds have a northerly component, but all are less than 9 m/s (Figure 8). In autumn the westerly dominate. Seven per cent have a strong northerly component.

These results suggest that strong northerly winds are most common during winter when there is very little biomass burning. The northerly winds could scour away pollution trapped under the Basin's frequent winter inversion, however. Whether the scoured components can reach the Grand Canyon or deposit along the way is unknown. Strong northerly winds are possible during spring

and autumn burning seasons, but are rare. Summer northerly winds usually are too weak to transport material for long distances.

SURFACE WINDS

Winds near the earth's surface are most efficient at transporting non or neutrally-buoyant pollutants. They can carry smoke from biomass burning into nearby towns and cities. In addition, surface winds can carry pollutants from industrial sources into wild-land areas.

The characteristics of upper level wind can be determined from a few observations because above the influence of topography, atmospheric patterns usually change slowly over space and time. Near the ground surface, however, winds are strongly influenced by small undulations in topography. There are not enough observations of surface wind to show the true variation in wind. Therefore, simple mesoscale wind model was adapted to analyze the effect of surface wind on pollution transport.[1]

Surface wind during winter primarily is controlled by pressure gradient forces between a persistent region of high pressure over the continent and frequent low centers from approaching Pacific storms (Appendix Q-5). This pressure gradient causes strong easterly winds to persist through the Cascade mountain passes. It also causes much of the stagnant air, which is trapped under the frequent winter temperature inversion, to be pulled against the eastern Cascades.[2] The passing storms also cause winds to accelerate over the higher ridge tops, especially in the Rocky mountains. Converging winds are common,

---

[1] Ferguson, S.A.; Peterson, M.R.; Hayes, P.S. and Akram, T. [In preparation]. Surface wind patterns in the Pacific Northwest.

[2] Steenburgh, W.J; Mass, C.F; Ferguson, S.A. [In preparation]. Mesoscale structure of gap flows in the Pacific Northwest.

like in the lee of the Blue mountains and head of the Snake River. Stagnant winds also occur, usually below the persistent inversions (see the central Snake River valley and central Columbia plateau).

During summer (Appendix Q-7), surface winds are dominated by downslope flows caused by cooling air that drains into the valleys at night. An onshore flow also prevails, causing weak to moderate westerly winds through the Cascade passes. Areas of weak convergence or stagnation occur most frequently in valleys and basins where the downslope winds are trapped by surrounding topography.

DROUGHT

Drought stress causes plants to close stomata and become less susceptible to pollution. The frequency and spatial pattern of drought is discussed in Chapter 17C of this volume.

IMPLICATIONS OF GLOBAL CHANGE ON AIR QUALITY IN THE BASIN

Atmospheric concentrations of greenhouse gases are increasing. Major carbon constituents that contribute to the greenhouse effect are increasing at the following known rate: CO_2 - 0.4 percent or 1.5 parts per million (ppm) per year; CH_4 - 0.9 percent or 0.015 ppm per year; CFCs - 4.0 percent or 0.015 ppm (Intergovernmental Panel on Climate Change, IPCC, 1990 and 1992). A recent report by the Pacific Global Change Research Program (PacGCRP) summarized the effective sources and sinks of greenhouse gases and discussed possible implications for management (Bytnerowicz and others, in press). For example, major sources for CO_2 are listed as decomposition, respiration, biomass fires, volcanic emissions, fossil fuel burning, and changes in land use. It also was recognized, however, that more nitrogen can produce a cofertilization effect

in the terrestrial biomass, which would lead to sequestration of additional carbon. In addition, a discrepancy in the global nitrous oxide budget was attributed to emissions from forest soils and proper management practices could minimize these emissions. The PacGCRP report also explains that sources of atmospheric methane include cattle, wetlands, and termites. Like CO_2 and nitrous oxides, CH_4 emissions can change by altering management practices.

Another implication of increasing greenhouse gases is their possible effect on global climate. Although uncertainty remains in the rate and magnitude of expected change, a general warming trend due to increasing concentrations of greenhouse gases is almost certain. A climate change scenario that considered the regional effect of doubling the global atmospheric concentrations of carbon dioxide ($2xCO_2$) on regional climate is discussed in Chapter 17B of this volume. The following summarize possible effects on air pollution.

1) greatest warming over high-latitude continents: less intense Arctic influence and thus weaker temperature inversions during winter,

2) continents could warm more than oceans: higher summer mixing heights,

3) decreased snow cover: less intense winter stagnation and earlier seasonal discharge of pollutants held in the snowpack,

4) increased convection over continents: more wet deposition in spring and summer with less frequent drought in southeast portions of the Basin,

5) decreased soil moisture during summer: greater summer drought, especially in the central Basin,

6) fewer, but stronger, winter cyclones: less frequent but more significant

disruption of winter stagnation.

SUMMARY

The Columbia River Basin experiences similar air pollution patterns as typical basins. For example, temperature inversions, which can trap pollution in stagnant air near the ground, are common. The Basin's topography and influence from three distinct air mass types (marine, arctic, and continental), however, create unique patterns of climate that can influence the trajectories of polluting gases and particles. Winds through the mountain gaps can transport pollution into and out of the Basin, or scour away stagnant air that is trapped in the Basin. Also, rainfall is common enough to cause relatively efficient scavenging of air borne pollution during all seasons.

A few, relatively simple, analytical tools were used to show the general pattern of climate in the Basin that influences air pollution. More comprehensive analyses is possible with mesoscale meteorological models and atmospheric dispersion and deposition models. These tools could help to show greater details in the timing and extent of stagnation periods, distance and concentration of pollution gases and particles, and pollution distribution patterns under different climate and management scenarios.

LITERATURE CITATIONS

Bytnerowicz, A.; Fenn, M.; Ferguson, S.; [and others]. In press. State of Knowledge for the USDA Forest Service Pacific Global Change Program: Atmosphere/Biosphere Gas and Energy Exchange (ATBIOX).

Ferguson, S.A. 1994. Precipitation identification for hazard reduction. Olympia, Washington: Washington State Department of Transportation. Final

report WA-RD 316.2. 44 p.

Ferguson, S.A.; Breyfogle, S. 1994. Remote identification of precipitation type. In: Proceedings of the 1994 International Snow Science Workshop: October 31 to November 4, 1994, Snowbird, Utah. ISSW '94, P.O. Box 49, Snowbird, Utah 84092: 222-259.

Intergovernmental Panel on Climate Change. 1990. Climate change: the IPCC assessment. Houghton, J.T.; Jenkins, G.J.; Ephraums, J.J., eds. Cambridge University Press. Cambridge, England. 364 p.

Intergovernmental Panel on Climate Change. 1992. Climate change 1992: the supplemental report to the IPCC scientific assessment. Houghton, J.T.;Callander, B.A.;Varney, S.K., eds. Cambridge University Press. Cambridge, England. 200 p.

LIST OF FIGURES

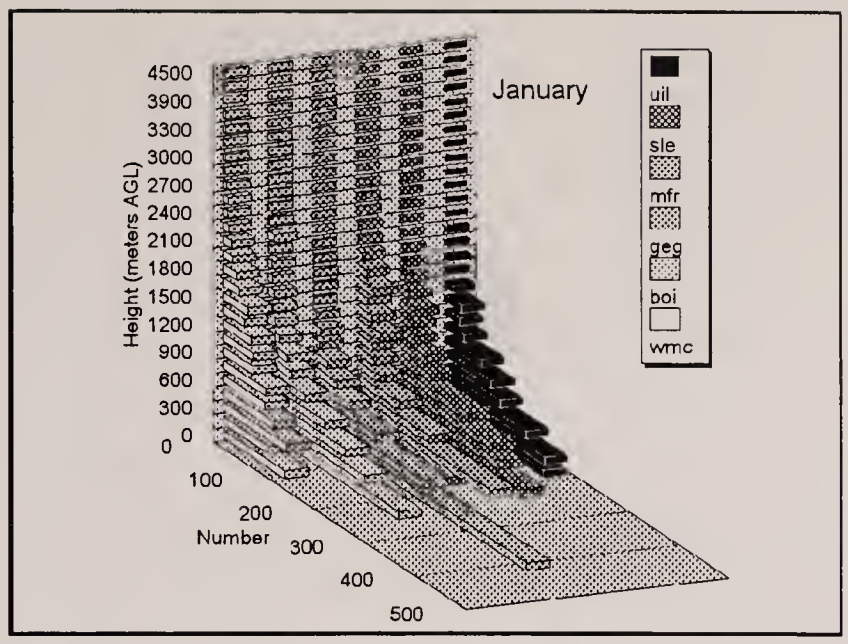
Figure 4. Distribution of mixing height in October. Same as in Figure 1.

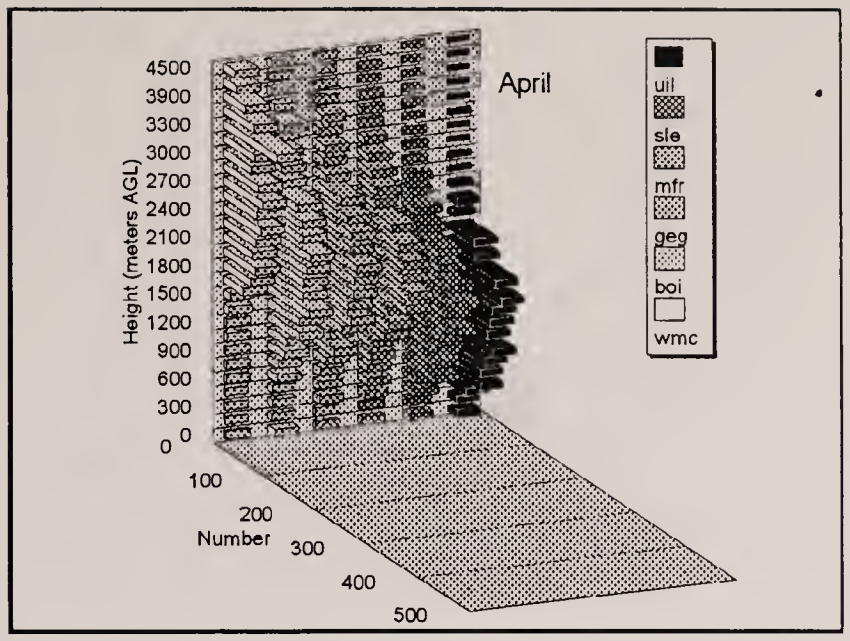
Figure 5. Distribution of winds at the 700 mb level over Spokane, Washington during January. Note that speed categories were calculated in miles per hour then converted to approximate values in meters per second.

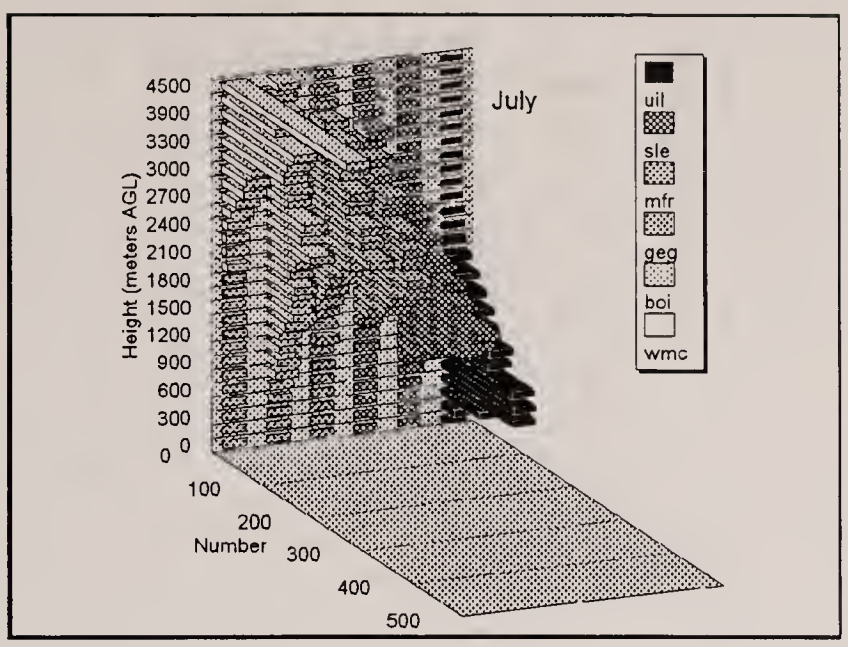
Figure 6. Distribution of winds at the 700 mb level over Spokane, Washington during July. Same as in Figure 5.

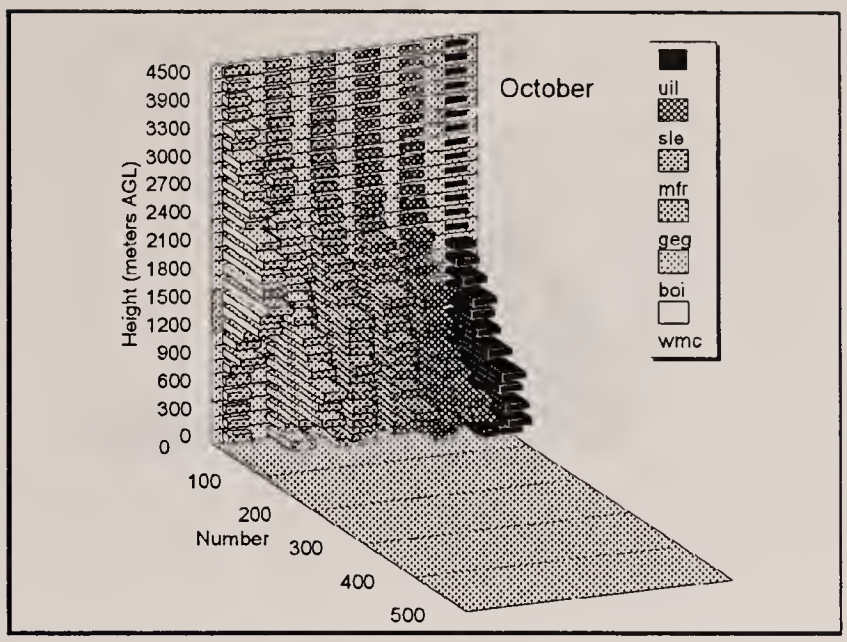
Figure 7. Distribution of winds at the 700 mb level over Boise, Idaho during January. Same as in Figure 5.

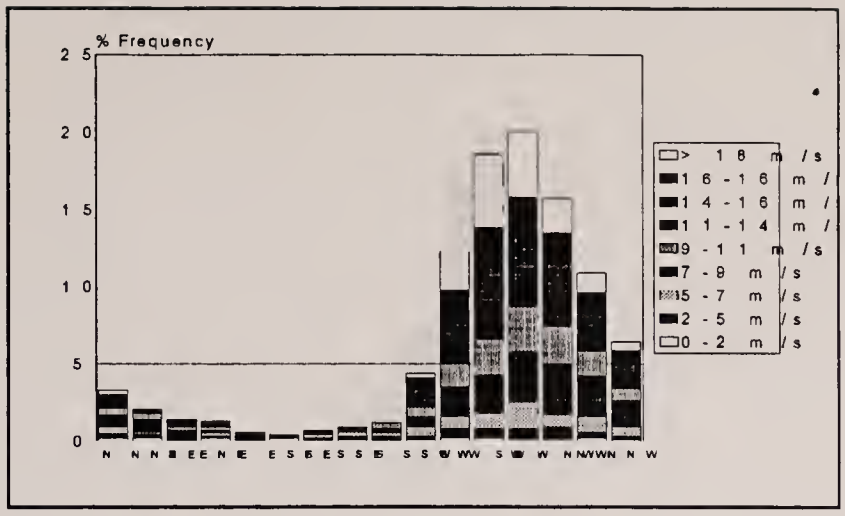
Figure 8. Distribution of winds at the 700 mb level over Boise, Idaho during July. Same as in Figure 5.

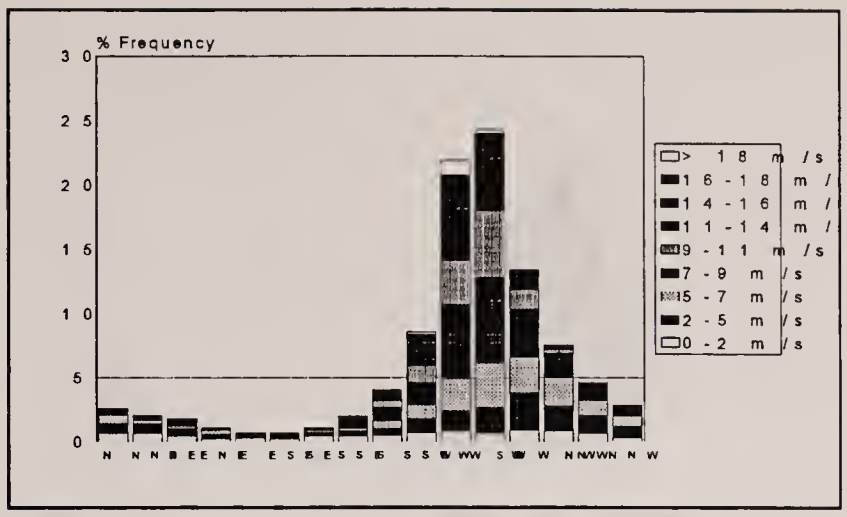

January
Height (meters AGL)
4500
3900
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
0
100
200
300
400
500
Number
uil
sle
mfr
geg
boi
wmc

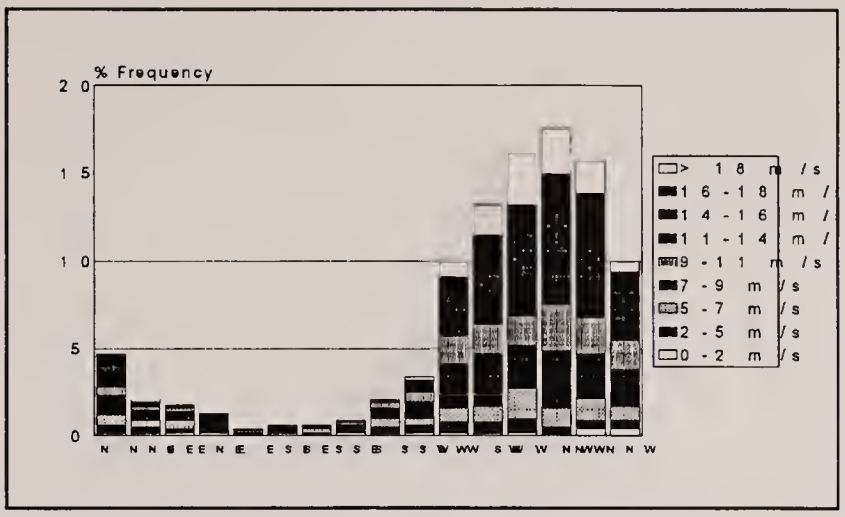

April
Height (meters AGL)
4500
3900
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
0
100
200
300
400
500
Number
uil
sle
mfr
geg
boi
wmc


July
Height (meters AGL)
4500
3900
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
0
100
200
Number
300
400
500
uil
sle
mfr
geg
boi
wmc


October
uil
sle
mfr
geg
boi
wmc
Height (meters AGL)
4500
3900
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
0
100
200
300
400
500
Number


% Frequency
25
20
15
10
5
0
N N N E E N E E S S E S S S S S W W W S W W N N W N W
> 18 m /s
16 - 16 m /
14 - 16 m /
11 - 14 m /
9 - 11 m /s
7 - 9 m /s
5 - 7 m /s
2 - 5 m /s
0 - 2 m /s


% Frequency
30
25
20
15
10
5
0
N N N E E E N E E S S E E S S S S S W W W S W W N N W N N W
> 18 m /s
16 - 18 m /
14 - 16 m /
11 - 14 m /
9 - 11 m /s
7 - 9 m /s
5 - 7 m /s
2 - 5 m /s
0 - 2 m /s


% Frequency
2 0
1 5
1 0
5
0
N N N E E E N E E S S E S S E S S S S W W W S W W N N W N N W
> 1 8 m /s
1 6 - 1 8 m /
1 4 - 1 6 m /
1 1 - 1 4 m /
9 - 1 1 m /s
7 - 9 m /s
5 - 7 m /s
2 - 5 m /s
0 - 2 m /s

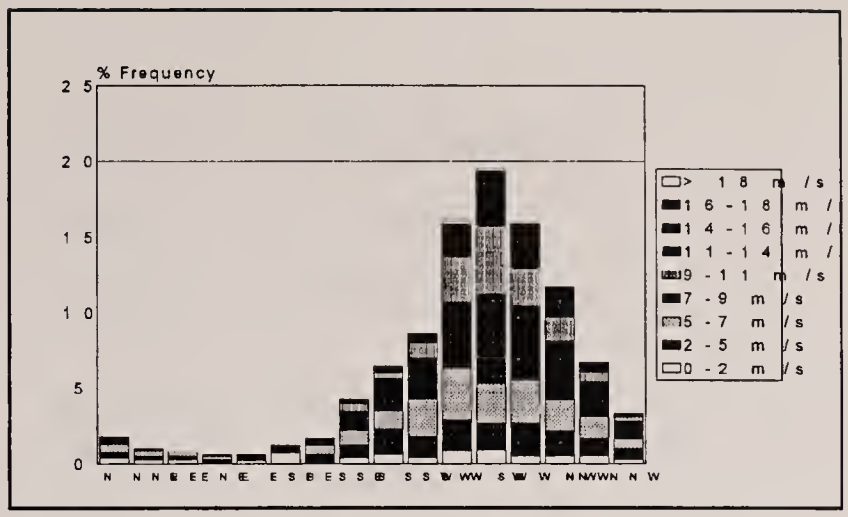

% Frequency
2 5
2 0
1 5
1 0
5
0
N N N E E E N E E S S E S S S S S S W W W S W W W N N W N N W
> 1 8 m /s
1 6 - 1 8 m /
1 4 - 1 6 m /
1 1 - 1 4 m /
9 - 1 1 m /s
7 - 9 m /s
5 - 7 m /s
2 - 5 m /s
0 - 2 m /s

Table 1.

Dataset Name	Begin Year	Basin Sites	Time Step	Duration	Measurement
HCN	1895	9	daily	annual	T, ppt
Coop	varies >1895	>300	daily	annual	T, ppt
SNOTEL	1978	45	daily	annual	T, ppt, SWE
Snow Course	1930	50	monthly	winter	H, SWE
RAWS	1985	~200	hourly	summer	T, Tf, RH, ppt, W
SAMSON	1961	10	hourly	annual	T, Td, RH, W, P, Q
RAOBS	1948	2	2/day	annual	T, Td, W, P (multiple heights)

Table 2a. Climate summary for ERU 01 (26 weather stations). The range of station elevations (meters) are shown. Data from available HCN and COOP weather observation stations having records of 10 years or more were used to calculate monthly mean values (°C) of maximum daily temperature [T(max)], minimum daily temperature, daily range in temperature [del T], average daily temperature [T(avg)], and monthly total values of daily precipitation [PPT] in millimeters and snowfall in centimeters. In addition, the ratio of snowfall to precipitation [% Water] is given to help show water content of snow.

Station Elevations:	Min	Max	Avg	Range
	195	1207	603	1012

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 2b. ERU 01 seasonal trends in daily temperature range (delT), average temperature (Tavg) and precipitation (PPT), as approximated by data from Cle Elum, Washington (588 meters elevation and 64 years of record). Significant

trends in winter precipitation after about 1975 and summer precipitation after about 1960 and 1985 also are shown.

Winter Trend	del T	T(avg)	PPT	PPT >1975	
	-0.5	0	0%	-35%	
Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT>1985
	-2.5	0	+50%	+50%	+10%

Table 3a. Climate summary for ERU 02 (18 weather stations). Same as in Table 2a except for ERU 02.

Station Elevations:	Min	Max	Avg	Range
	30	1475	848	1445

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 3b. ERU 02 seasonal trends. Same as in Table 2b except from Bend, Oregon (1116 meters elevation and 67 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	+0.5	0	0%	-40%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-1	-1	0%	+75%	+10%

Table 4a. Climate summary for ERU 03 (12 weather stations). Same as in Table 2a except for ERU 03.

Station Elevations:	Min	Max	Avg	Range
	1231	1972	1370	741

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 4b. ERU 03 seasonal trends. Same as in Table 2b except from Lake View, Oregon (1457 meters elevation and 67 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	-0.5	+1	-10%	-70%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-3	0	+50%	+50%	-30%

Table 5a. Climate summary for ERU 04 (22 weather stations). Same as in Table 2a except for ERU 04.

Station Elevations:	Min	Max	Avg	Range
	1253	1713	1355	460

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 5b. ERU 04 seasonal trends. Same as in Table 2b except from Squaw, Oregon (1420 meters elevation and 58 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	0	+1	0%	-30%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-2	0	+10%	+50%	0%

Table 6a. Climate summary for ERU 05 (87 weather stations). Same as in Table 2a except for ERU 05.

Station Elevations:	Min	Max	Avg	Range
	58	1902	566	1844

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 6b. ERU 05 seasonal trends. Same as in Table 2b except from Moscow, Idaho (810 meters elevation and 95 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	-0.5	0	0%	-35%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	+2	-1	+30%	+60%	-10%

Table 7a. Climate summary for ERU 06 (34 weather stations). Same as in Table 2a except for ERU 06.

Station Elevations:	Min	Max	Avg	Range
	363	1506	959	1143

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 7b. ERU 06 seasonal trends. Same as in Table 2b except from Union, Oregon (844 meters elevation and 67 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	+0.5	0	0%	-30%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-0.5	0	+50%	+45%	-15%

Table 8a. Climate summary for ERU 07 (52 weather stations). Same as in Table 2a except for ERU 07.

Station Elevations:	Min	Max	Avg	Range
	250	1795	796	1545

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 8b. ERU 07 seasonal trends. Same as in Table 2b except from Fortine, Montana (719 meters elevation and 95 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	-2	+0.5	-25%	-40%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-2	+1	0%	+30%	n/a

Table 9a. Climate summary for ERU 08 (29 weather stations). Same as in Table 2a except for ERU 08.

Station Elevations:	Min	Max	Avg	Range
	658	1817	882	1159

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 9b. ERU 08 seasonal trends. Same as in Table 2b except from Haugan, Montana (890 meters elevation and 43 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	-2	+2	-25%	-50%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-2	+0.5	+40%	+40%	n/a

Table 10a. Climate summary for ERU 09 (21 weather stations). Same as in Table 2a except for ERU 09.

Station Elevations:	Min	Max	Avg	Range
	1030	1847	1367	817

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 10b. ERU 09 seasonal trends. Same as in Table 2b except from Butte, Montana (1689 meters elevation and 95 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	0	0	-50%	-45%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	0	0	0%	+35%	0%

Table 11a. Climate summary for ERU 10 (62 weather stations). Same as in Table 2a except for ERU 10.

Station Elevations:	Min	Max	Avg	Range
	652	2146	1124	1494

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 11b. ERU 10 seasonal trends. Same as in Table 2b except from Caldwell, Idaho (722 meters elevation and 90 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	-1	-0.5	-25%	-60%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-2	+2	0%	+50%	-70%

Table 12a. Climate summary for ERU 11 (22 weather stations). Same as in Table 2a except for ERU 11.

Station Elevations:	Min	Max	Avg	Range
	1268	1798	1409	530

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 12b. ERU 11 seasonal trends. Same as in Table 2b except from Aberdeen, Idaho (1344 meters elevation and 81 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	0	0	0%	-75%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-2	-1	0%	+80%	+10%

Table 13a. Climate summary for ERU 12 (12 weather stations). Same as in Table 2a except for ERU 12.

Station Elevations:	Min	Max	Avg	Range
	1603	2487	1959	884

Month	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 13b. ERU 12 seasonal trends. Same as in Table 2b except from Ashton, Idaho (1603 meters elevation and 47 years of record).

Winter Trend	del T	T(avg)	PPT	PPT >1975
	0	0	0%	-50%

Summer Trend	del T	T(avg)	PPT	PPT >1960	PPT >1985
	-2	+1	+50%	+80%	-35%

Table 14a. Climate summary for ERU 13 (51 stations). Same as in Table 2a except for ERU 13.

Station Elevations:	Min	Max	Avg	Range
	485	2225	1371	1740

MONTH	T(max)	T(min)	del T	T(avg)	PPT	Snowfall	%Water
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

Table 14b. ERU 13 seasonal trends. Same as in Table 2b except from McCall, Idaho (1533 m elevation and 65 years of record).

Winter Trend	delT	T(avg)	PPT	PPT >1975
	-1	+2	0%	-50%

Summer Trend	delT	T(avg)	PPT	PPT >1960	PPT >1985
	+2	-0.5	+50%	+60%	-20%