Appendix A

Climate Classification of the Mid-Columbia Region

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What is the proper description of the climate of the Mid-Columbia Region? The local Tri-City Herald has a Sunday newspaper section called "Desert Living." Numerous place names in eastern Washington contain the word "desert," since people commonly regard any region that is too dry to support trees, except perhaps in river bottoms, as desert. On the other hand, popular and other publications of both the Nature Conservancy and the National Audubon Society carefully describe this region as a shrub-steppe.

The classification of the climate of the Mid-Columbia Region has not been consistent among the numerous meteorological and ecological publications that have described the area, either. In these publications, one finds the Mid-Columbia alternately described as shrub-steppe (or semi-arid) and desert (or arid)—sometimes within the same publication (e.g., Rogers and Rickard 1988; p. 1ff and p. 8). To further confuse the issue, the terms "arid" or "desert" and "semiarid" or "steppe" are used as a subdivision of the general term "arid," which represents a climatic condition in which the potential evaporation exceeds precipitation on average (American Meteorological Society 2000). In fairness to Rogers and Rickard, their use of "arid" cited above was most likely intended in the general sense rather than as a contrast to "semiarid."

Climate, an abstract concept of the weather conditions at a particular location over a long period of time, is popularly understood among laypeople and scientists alike in terms of its effects. In their introductory text on climate, Trewartha and Horn (1980) note that climate fundamentally controls the distribution of natural things such as plants, animals, and soils. They further comment (p. 218) that if "one disregards the distribution of non-climatic phenomena [e.g., plants, animals, and soils], it is difficult to provide meaningful temperature-rainfall limits of climatic types." In other words, assessing the climate of a particular area, especially near boundaries of climate types, requires consideration of not only meteorological variables but also those natural things that respond to them.

The non-climatic phenomenon that is most frequently associated with climate is the distribution of vegetation. Because the vegetation distribution is heavily determined by temperature and available moisture, most of the classification systems for climate have been empirically developed by correlating vegetation and some measure of temperature and humidity. In fact, the general correspondence between patterns of climate variables and patterns of vegetation is so strong that categories of some climate types are named for the dominant vegetation type (e.g., tropical rainforest or steppe) that they generate. Climate classification systems have generally sought to create indices that are indicative of specific climate types for specified ranges of the index variable.

A.1 Climate Classification Systems

Numerous classification schemes have been developed for climate. Gedzelman (1985) in his introductory chapter to the *Handbook of Applied Meteorology* provides a helpful and detailed overview of the more prominent of these systems. Much of the discussion that follows is based on his writing.

One of the earliest and still most widely used climate classification schemes was developed by Köppen in the early twentieth century. This system sought to describe regions of similar vegetation in terms of temperature and humidity, whose cumulative effect Köppen expressed in terms of combinations of three letters. The first letter (A-E) denotes temperature, except for "B," which indicates a lack of moisture. The second letter indicates quantity of precipitation, and the third, if present, relates to mean monthly temperatures. As the scheme applies to the Columbia Basin, the classification is either BS (steppe) or BW (desert), and is determined as follows:

(a) If 70% or more of the mean annual precipitation $\overline{R}$ occurs in the six cooler months (October through March in the Northern Hemisphere), then the classification is given in terms of $\overline{R}$ (cm) and the mean annual temperature $\overline{T}$ (°C) as

$\overline{T} \leq \overline{R} < 2\overline{T}$ station climate is steppe (BS)
$\overline{R} < \overline{T}$ station climate is desert (BW)

(b) If 70% or more of $\overline{R}$ occurs in the six warmer months, then the classification is

$\overline{T} + 14 \leq \overline{R} < 2\left(\overline{T} + 14\right)$ station climate is BS

$\overline{R} < \overline{T} + 14$ station climate is BW

(c) If precipitation is evenly distributed throughout the year [i.e., neither (a) nor (b) applies], then the classification is

$\overline{T} + 7 \leq \overline{R} < 2\left(\overline{T} + 7\right)$ station climate is BS

$\overline{R} < \overline{T} + 7$ station climate is BW

Note that the boundary between desert and steppe in each of these sets of inequalities occurs at half the value of precipitation required for the boundary between steppe and humid climates.

From the historical averages through 2000 at the Hanford Meteorological Station (HMS), the mean annual temperature is 53.4°F (11.9°C), and the mean annual precipitation is 6.79 inches (17.2 centimeters) of which 66.6% falls from October through March. Since this percentage falls just short of Köppen's criterion of 70% for a winter maximum of precipitation, one might infer that (c) applies and the climate classification is BW, or desert. These formulas exhibit an inconsistent behavior, however. If the precipitation were the same in the winter but less in the summer months by 0.33 inch, the appropriate formulas would be (a) in which case the climate classification would be BS, or steppe. Thus, by *reducing* *annual rainfall* in this manner, the Hanford Site would move to a *more moist* Köppen classification. This suggests that it is not useful to be too inflexible in the application of classification formulas, especially near zone boundaries.

Patton (1962) offered a simplification of Köppen's system that expressed the boundary between humid and semiarid climates as a single, easily memorized equation:

$$R' = \frac{1}{2}T' - \frac{1}{4}P'w$$

where R' = annual precipitation in inches
T' = temperature in degrees Fahrenheit
$P'w$ = the percentage of precipitation that falls in the winter months.

Mean precipitation greater than R' results in a humid climate. Precipitation less than R' but greater than $1/2R'$ generates a steppe climate, and less than $1/2R'$ generates desert conditions. This formula was shown to give results that are not significantly different from Köppen's set of three relations. Patton's relation, incidentally, also solves the problem of the inconsistency noted above in Köppen's formulas near the precipitation regime boundaries. Applying Patton's result to the HMS data

$$\begin{aligned} \frac{1}{2}R' &= \frac{1}{4}T' - \frac{1}{8}P'w \\ &= \frac{1}{4}(53.4) - \frac{1}{8}(66.6) \\ &= 5.03 \text{ in} \end{aligned}$$

This precipitation value for the boundary between steppe and desert is significantly lower than the HMS mean annual precipitation of 6.79 inches, placing the Hanford Site in a steppe climate by this representation of the Köppen system.

Another classification for climate that has been widely used is that given by Thornthwaite (1931). Thornthwaite was the first to attempt to develop a numerical index by which climate zones could be defined. In fact, he developed two climate indices: a "temperature efficiency" index *TE* and a "precipitation effectiveness" index *PE*. Like Köppen, he based his indices on temperature and humidity for a region in such a way as to try to make them representative of patterns of plant communities. These indices are defined as follows:

$$TE = \frac{1}{4}\sum_{k=1}^{12}\left(\overline{T_k} - 32\right)$$

where $\overline{T_k}$ is the mean temperature in *ºF* for month *k*, and

$$PE = 115 \sum_{k=1}^{12} \left(\frac{\overline{r_k}}{\overline{T_k} - 10} \right)^{10/9}$$

where $\overline{r_k}$ is the mean precipitation for month *k* in inches.

Using the same HMS data as those for calculating the Köppen classification above, the Thornthwaite indices for the Hanford Site are $TE = 64.5$ and $PE = 16.1$. The *TE* value is near the boundary of 63.5 between Thornthwaite's "microthermal" (cool) and "mesothermal" (warm, but not hot) climates. The *PE* value for the Hanford Site, of primary interest here, places the HMS in a semiarid climate but is very near Thornthwaite's boundary value between arid (PE<16) and semiarid ($16 \le PE < 31$).

Thornthwaite (1948) updated his classification in an effort to tie it more closely to the physical water balance. The result was more philosophically satisfying but also considerably more complicated, since not only temperature and precipitation but also soil characteristics must be considered. Daubenmire (1988), in his definitive study of eastern Washington vegetation, found that the resulting values of Thornthwaite's Moisture Index overlapped distinct steppe zones and that the index was not as practical as simpler formulations. Knapp (1985) suggested that Thornthwaite's index may not be applicable to dry regions because its correlations were developed from the humid zones of the central and eastern United States.

A.2 Reliability of Precipitation

Another important distinction between desert and steppe climates is the reliability of precipitation. True desert regions are generally characterized by sporadic albeit sometimes heavy precipitation events. Because of this, the routine availability of moisture is often much less than would be suggested by the mean annual precipitation value. Thus, one region, with long periods between significant precipitation events, may only be able to support desert vegetation while another, with a similar mean value of temperature and precipitation, may support the grasses and shrubs of the steppe. Daubenmire (1988) criticized the Thornwaite index for this reason because it uses mean annual rainfall rather than the probably more appropriate median value.

Under the definition of "semiarid zone," the *Glossary of Meteorology* (American Meteorological Society 2000) notes that the coefficient of variation for arid zones exceeds 50%, while the value for semiarid zones is 30–50%. This quantity is defined as

$$C_r = 100 \frac{\sigma_r}{\overline{r}}$$

where $\overline{r}$ = the mean of the annual precipitation.
σ_r = its standard deviation.

Using historical data from the HMS through 2000, this value is $C_r = 30.5\%$, far from the variability that characterizes desert regions.

A.3 Vegetation of the Mid-Columbia Region

Vegetation may be viewed as an integrator of weather that reflects the climate. The Mid-Columbia region, where the surface is undisturbed, is characterized by a substantial cover of xerophytic shrubs (i.e., those adapted to dry regions, such as sagebrush) and perennial grasses. From Daubenmire's (1988) perspective

> "reasonable limits would be to consider *desert* as regions too dry to support a noticeable cover of perennial grasses on zonal soils, and *steppe* as regions with moisture relations adequate to support an appreciable cover of perennial grasses on zonal soil, yet not enough for arborescent vegetation. Since even the driest part of eastern Washington can support a heavy cover of perennial grasses wherever there is a zonal soil, a continuous film of cryptogams covers the soil surface, and at least 0.7 metric tons/ha/yr of dry matter is produced, its classification as steppe rather than desert seems preferable."

Some writers have attempted to disregard vegetation in classifying the climate of the intermountain West. In a recent textbook, Bailey (1996) relied on an apparently rigid application of the Köppen-Trewartha system to conclude that, despite the widespread support of semi-desert shrubs and other vegetation, the Great Basin and Columbia Basin were true deserts. This is a curious result, since the climate mapping produced by Trewartha himself (Trewartha and Horn 1980) classifies the northern Great Basin and the Columbia Basin as steppe.

A.4 Summary

From virtually all perspectives but the popular criterion of lack of naturally growing trees, the climate of the Hanford Site as well as the rest of the Mid-Columbia region is best classified as steppe (or, equivalently, semiarid), although it is on the dry side of that classification. With respect to classification schemes, only the most rigid application of the Köppen formulation places the area in the desert class. The precipitation falls with a reliability that is characteristic of steppes rather than deserts, and the vegetation that is present is considered typical of a shrub-steppe ecosystem. For these reasons, we believe that the most appropriate term for the local climate is "steppe."

Table A.1 organizes the terminology discussed above.

Table A.1. Description of the Uses of the Terms "Arid" and "Semiarid" with Respect to Climate

Arid Climate			
Conventional Boundary of Classification:	On an annual average, more moisture can leave the vegetation and soil surfaces than falls as precipitation		
Effect:	No arborescent vegetation (i.e., trees), except perhaps in river bottoms		
Equivalent Terms:	None in this general sense, except perhaps "dry climate"		
Semiarid Climate		**Arid Climate**	
Conventional Boundary of Classification:	Within the general arid designation, the annual precipitation is half or more of the moisture that could escape to the atmosphere from the soil and plant surfaces	Conventional Boundary of Classification:	Within the general arid designation, the annual precipitation is less than half of the moisture that could escape to the atmosphere from the soil and plant surfaces.
Effect:	Widespread coverage of undisturbed soil surface by annual and perennial grasses and, in some areas, by shrubs adapted to dry climates	Effect:	Sparse coverage of undisturbed soil surface by shrubs and perhaps grasses; a significant fraction of the soil surface is free of vegetation
Equivalent Terms:	steppe, shrub-steppe (if shrubs are present), semi-desert	Equivalent Term:	desert

NOTE that "arid" can mean either "dry" or "desert" depending on context. Because of the tight link between climate and vegetation, terms that fundamentally describe ecosystems, such as "steppe," are widely used interchangeably with terms such as "semiarid" that describe the physical water balance of a region.

A.5 References

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