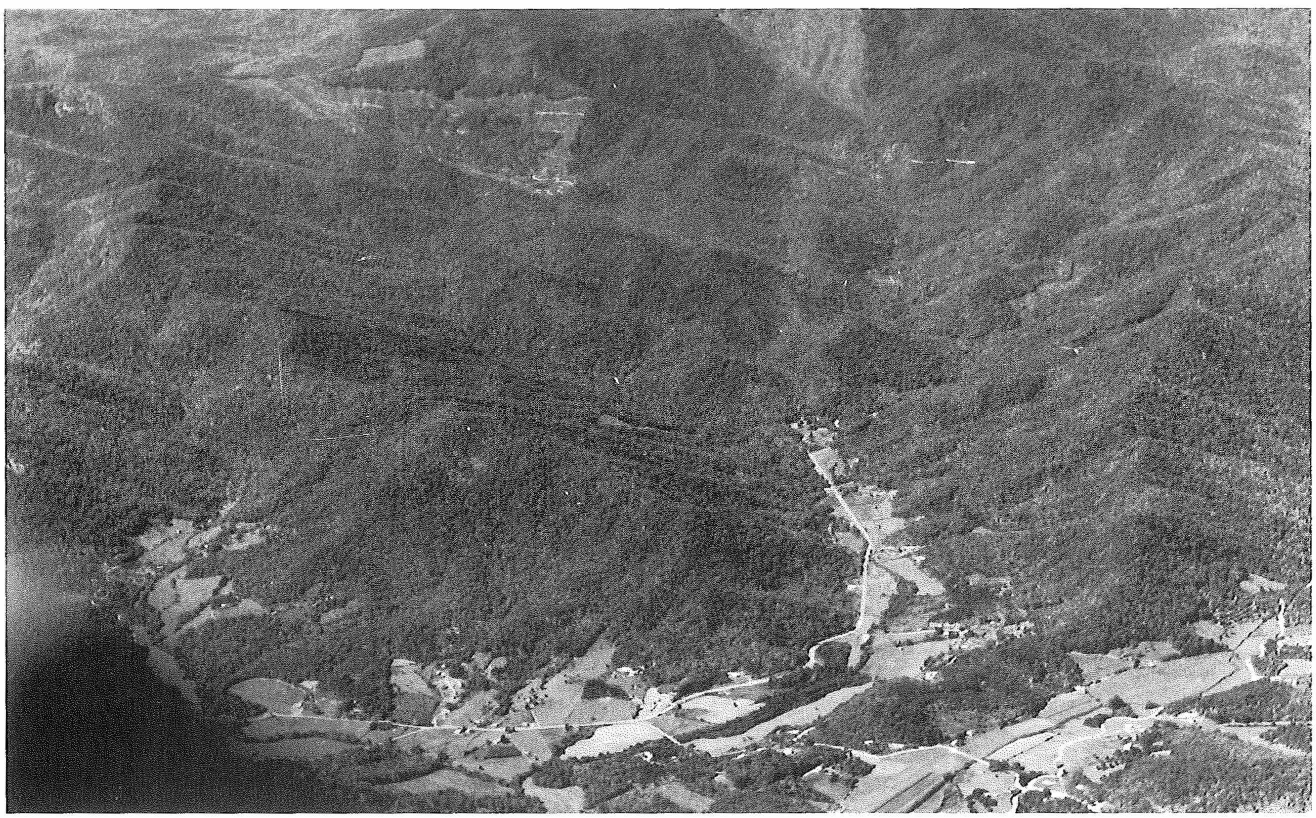
THE CLIMATES OF THE LONG-TERM ECOLOGICAL RESEARCH SITES

Edited by
David Greenland



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The Climates of the Long-Term Ecological Research Sites

Prepared by

The Climatology Committee
of the Long-Term Ecological Research Program

Editor: David Greenland

1987

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PREFACE

The Long-Term Ecological Research (LTER) Program funded by the National Science Foundation (NSF), Division of Biotic Systems, is mandated to pursue ecological research over long time periods at a variety of sites throughout the United States. The program is overseen by a coordinating committee formed of the principal investigators of each site and by normal NSF peer and panel review procedures.

The LTER Climate Committee was established by the Coordinating Committee to produce a) the document *Standardization of Meteorological Measurements for Long-Term Ecological Sites* which was issued in June 1986, b) the present monograph *The Climates of Long-Term Ecological Sites,* and c) to stimulate studies in bioclimatology in the LTER program. This monograph thus represents the completion of the second task of the LTER Climate Committee. It has been reviewed by all members of the LTER Climate Committee. Dr. Lloyd Swift, in particular, made extensive editorial comments and I am also grateful to Ms. Kathleen Salzberg for copy editing the whole manuscript and Ms. Wendy Stout for drafting the diagrams. The monograph represents the official baseline description of the climates of the sites.

David Greenland.
Niwot Ridge/Green Lakes Valley Site
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February 1987

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The LTER Climate Committee operates and disseminates material under a grant to the LTER Coordinating Committee from the National Science Foundation, Division of Biotic Systems and Resources.

THE CLIMATES OF LONG-TERM ECOLOGICAL SITES

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CHAPTER 1
INTRODUCTION

David Greenland

THE LONG-TERM ECOLOGICAL RESEARCH PROGRAM

The Long-Term Ecological Research (LTER) program encourages coherence in ecological research over the long term to take advantage of the fact that many parts of ecosystems operate over long time scales and show directionality and periodicity. Studies recognizing this (e.g. Hubbard Brook) have made fundamental contributions to ecology. Consequently, in 1980 and 1981, eleven LTER sites were established in varying biomes throughout the coterminous U.S. (Callahan, 1984).

The LTER sites (Table 1.1) are funded by the National Science Foundation (NSF) in 5 year renewable funding periods and overseen by a Central Coordinating Committee consisting of all site principal investigators and normal NSF peer review procedures. One driving force behind studies at these sites was the desire to describe human-derived and natural perturbations acting over long time periods, e.g. air pollution, acidification, CO_2. Studies at the sites are organized around five core themes which are 1) pattern and control of primary production; 2) spatial and temporal distribution of populations selected to represent trophic structure; 3) pattern and control of organic matter accumulation in surface layers and sediments; 5) patterns of inorganic input and movement through soils, groundwater and surface waters, and patterns and frequency of disturbance to the research site.

There is a strong need to sample common parameters for comparison between LTER sites. Furthermore, climatological information is essential, either directly or indirectly, to investigations of the five core themes and the LTER program as a whole. In many cases records of climatic variables are the only truly 'long-term' records initially available at individual LTER sites. Climatological analyses are a beginning method for comparison across all LTER sites.

Up to 1986, although the basis for uniformity of data collection had been laid (Swift and Ragsdale, 1985), the observation of climate data at LTER sites was performed on an ad hoc basis. Some sites had been collecting their own data for many years, while others relied on the existence of data collected by the National Weather Service or other agencies at locations on, or near, their sites. During 1986, the LTER Climate Committee issued a document outlining standardized methods for collecting meteorological data at LTER sites (Greenland, 1986).

The objectives of the program of standardized meteorological measurements were defined as follows:

1) to establish baseline meteorological measurements which both characterize and allow comparison among LTER Sites,

2) to document both cyclic and long-term changes in the physical environment,

3) to provide a record of the physical environment to support each LTER site's core research program to correlate with bio-ecological phenomena and to provide data for modeling,

4) to provide a basis for coordinating specialized or short-term meteorological measurements at two or more sites when such measurements are required for specific research problems.

Because the system of standardized data collection is only recently established, the present monograph relies on a variety of data sources. The need to have a baseline documentation of climatological data for the LTER sites demands the production of this monograph now rather than waiting for the establishment of the standardized data set from the LTER sites.

Not all sites have comparable climatic data, especially in record duration. Since we regard time compatibility as essential, certain strategies have been adopted. In some cases two data sets are used: a short data set obtained at the LTER site and the standard 30 year data set from a nearby station. In other cases the data set from the LTER site has been extended backwards by regression methods using data from a nearby site. The choice of the most suitable method to use was made by the Climate Committee member for that site using the criterion of the need to produce the most representative data set for the objectives of this monograph.

The LTER Climate Committee agreed upon the variables to be included in this monograph in January 1986. All Climate Committee members were responsible for providing the editor with the data, analysis, and description for their own site. The editor was responsible for attempting to obtain a certain uniformity within the site descriptions, helping those sites where little climatological expertise was available, performing the computations of potential and actual evapotranspiration for the sites, carrying out the analyses for the final chapter, and assembling the final monograph. Committee members have reviewed and edited the general material and the sections pertaining to their sites.

We believe that this report will be useful to all LTER sites and will serve as a base point for more advanced studies.

THE IMPORTANCE OF BIOCLIMATES IN ECOLOGY

Several components of the bioclimatic environment affect both plants and animals. The environment is the source of the radiant energy used in photosynthesis and the water, nitrogen, minerals and trace elements needed by plants. Light is a stimulus. Temperature and daylength determine the growth rates of plants, animal's demand for food and the onset of reproductive cycles in both plants and animals (Montieth, 1973).

Fundamental relationships between plant growth and bioclimatic variables operate for the individual

Table 1.1

THE ECOSYSTEM AND CLIMATE OF THE LTER SITES

SITE	ECOSYSTEM	CLIMATE
H.J.ANDREWS EXPT. FOREST (Oregon)	Coniferous Forest	Marine West Coast
CEDAR CREEK NAT HISTORY AREA (Minnesota)	Hardwood Forest/ Tallgrass Prairie	Humid Continental
CENTRAL PLAINS EXPT RANGE (Colorado)	High Plains Grassland	Mid-latitude Steppe
COWEETA HYDROL LAB (N.Carolina)	Deciduous Forest	Humid Sub - Tropical
ILL & MISSISSIPPI RIVERS (Illinois)	Temperate Freshwater	Humid Continental
JORNADA (New Mexico)	Desert	Sub-tropical Desert
KONZA PRAIRIE (Kansas)	Tallgrass Prairie	Mid-latitude Steppe
NIWOT RIDGE/ GREEN LAKES VALLEY (Colorado)	Alpine Tundra	Highland
NORTH INLET (S. Carolina)	Coastal Marine	Humid Sub - Tropical
NORTHERN LAKES (Wisconsin)	N Temperate Lake Mixed Forest	Humid Continental
OKEFENOKEE NAT WILDLIFE REFUGE (Georgia)	Freshwater Wetland	Humid Sub - Tropical

plant, groups of plants, and large areas of vegetation. Thus, there are different scales of study in bioclimatology. Microscale studies tend to concentrate on the many aspects of flows of energy and water to and from the plants. These studies are often organized around the energy budget of the plant or the vegetated surface (Greenland, 1984). Mesoscale, or regional scale, studies are concerned with the interaction of bioclimates with groups of plants and might examine, for example, water relations and crop yield or atmospheric factors determining the location of the northern treeline. Global scale studies examine the overall world pattern of vegetation related to the global climate. These studies have a long tradition in bioclimatology ranging from the the work of Humboldt (1807) to that of Box (1981).

In documenting the climates of the LTER sites in this monograph, we are cognizant of two points: First, the ideal measurement of flows of energy and materials to and from plants measurements have yet to be made at most sites, so the secondary indices such as observations of temperatures and precipitation amounts will be employed. Second, because of the wide geographic distribution of LTER sites, we will be operating on a regional scale and concentrating on the larger differences between sites rather than finer points and differences within sites.

THE ORGANIZATION OF THE MONOGRAPH

The LTER Climate Committee's objectives for this monograph are as follows:

1) to describe the climates at all LTER sites, and

2) to insure that these descriptions will also allow comparison between the climates at all the LTER sites.

There are certain restraints under which the excercise has been carried out.

First, we have had to confine ourselves to data sets obtained from the simplest levels of LTER site observations, plus data obtained from nearby National Weather Service observing sites. For the most part, only temperature and precipitaion data are available. Thus, these variables, and parameters derived from them, are employed.

DATA COLLECTION AND AVAILABILITY AT LTER SITES

The period 1951-1980 was chosen as the standard climatic normal for climatic descriptions used in this monograph. This corresponds with the World Meteorological Organization climatic normal period. Although the normal period does not include the first five or six years of the LTER program between 1980 and 1986, we felt that this standardization would be advantageous to other workers.

The variables and parameters ideally to be included in this monograph for all site are given in Table 1.2. Because of restraints already mentioned, few sites include all of these variables. Variables were chosen because of their relation to some aspect of vegetation growth or faunal activity.

In analyzing the data, basic descriptive statistics are used in order to meet the objective of defining the major climatic differences between all the sites without taxing the type of data being used. However, an attempt has been made to employ some derived statistics that are particularly relevant to bioclimatic environments. These include the use of water budget parameters which have been shown by Box (1981) to be particularly important in their association with particular types of plant physiognomy, and the ratio of thawing degree days to growing season precipitation. The latter to some degree mimicks the "Radiational Index of Dryness" which Budyko (1958) found very useful in delimiting different vegetation types on a global basis.

Other special treatments of data are the following:

1) In the case of the means and standard deviations of the temperatures of the warmest and coldest months, the temperatures of the warmest or coldest months for any individual year were extracted first and then the statistics were computed. Thus it was not assumed, for example, that the warmest and coldest months of the site for any one year occurred in July and January, respectively. Each year was examined for its warmest and coldest months the values of which were extracted to form a thirty year data set from which the means and standard deviations were computed.

2) The Thornthwaite method of computing evapotranspiration and other water budget parameters is employed (Thornthwaite and Mather, 1957), using an adaptation of a program by Willmott and Rowe (1985), which is more fully described by Wilmott (1977). The technique is not fully applicable for all sites owing to its neglect of such factors as evaporation in winter, wind speed, humidity conditions and net radiation input. However, the Thornthwaite water balance values give a relative comparison between sites. In most cases, field capacity input data were supplied by the site climatologist and in all cases a linear drying with time curve (curve C in the Wilmott and Rowe program) was employed for the soil.

3) Instead of using standard deviation or upper and lower quintiles to describe the variability of the precipitation statistics, we use the range between the highest and lowest values in the 30 year record.

4) The term "Heating Degree Days" or sometimes "Thawing Degree Days" (working from a 0 deg. C base) is substituted for "Growing Degree Days" because of our difficulty in defining the temperature base and obtaining the data for the latter.

5) The value of 15 deg. C is selected to determine the number of warm months above this threshold following Levitt (1972) who uses this value to define the point above which some heat injury will occur for the least heat-resistant group of vegetation.

6) The temperature graphs for each site plot the trend in mean temperature month by month through the year except for the trend between December and January. This does not mean to imply a discontinuity in temperature values between these two months.

7) Dr. Bark, of the Konza site, has pointed out with respect to the analyses in the final chapter that, in some cases, ranking sites by the highest or lowest valued item in the 30 year record might lead to an unrepresentative ranking for some sites. He has suggested that the fourth highest or lowest value be used for ranking. Time limits precluded such an analysis for the present monograph, but the idea will be examined in a later publication.

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Table 1.2

Variables and Parameters Employed in the Climatic Descriptions.

Air temperature (degrees C)
- Annual mean and standard deviation (SD) for record period
- Monthly mean
- Monthly mean maximum temperatures
- Monthly mean minimum temperatures
- Mean temperature of the warmest month and SD
- Mean temperature of the coldest month and SD
- Annual range of monthly mean temperatures
- Number of months with mean temperature above 0 deg. C
- No of months with mean temperature above 15 deg. C
- Highest and lowest monthly mean in record period

Precipitation (mm)
- Monthly mean and mean annual total
- Monthly and annual total during the wettest and driest year on the record
- Total precipitation of months with temp above 0 deg. C

<u>For Terrestrial Sites</u>

- Potential and Actual Evapotranspiration, Soil Moisture Status (calculated by Thornthwaite method)
- Annual total and SD
- Monthly totals
- No of months with soil moisture surplus
- No of months with soil moisture deficits

<u>For Sites Where Data Are Available and Where Analysis Is Practicable</u>

Air temperature
- Mean no of heating degree days per year (from 0 deg. C base)
- Highest and lowest absolute monthly means in the record
- Mean daily maximum temperature of warmest month
- Mean daily minimum temperature of coldest month
- Mean duration of frost free period in days

Water Vapor Pressure (mb)
- Annual mean
- Monthly means

Wind Velocity (m/s)
- Annual mean
- Monthly means and peak gusts

Wind Direction (nearest 10 degrees from N)
- Annual wind rose (percentage of time with winds from different directions)

Global Radiation
- Annual total
- Monthly totals

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CHAPTER 2

H.J. ANDREWS EXPERIMENTAL FOREST, OREGON

Arthur McKee and Frederick Bierlmaier

SITE DESCRIPTION

The H.J. Andrews Experimental Forest is located on the western slope of the Cascade Range about 80 km (50 mi) east of Eugene, Oregon. It includes the entire watershed of Lookout Creek, about 6400 ha (15,800 acres), and ranges in elevation from 410 to 1630 m (1350 to 5340 ft). Slopes are steep and stream drainages are deeply incised. When established in 1948, it was unroaded virgin forest and about two-thirds remain pristine today. Broadly representative of the rugged mountainous landscape of the Pacific Northwest, it contains excellent examples of the region's conifer-dominated forest and stream ecosystems (Fig. 2.1).

Intra-site climatic variation is typical of mountainous terrain. Temperature varies with elevation, aspect, and topographical shading. Temperature inversions are common. Precipitation generally increases with elevation as does the proportion that falls as snow.

Climatic data (Tables 2.1 - 2.3, Figs. 2.3, 2.4), with the exception of precipitation, are taken from the primary meteorological station (Fig. 2.2). This station, established May 1972, is located in a clearing on a Pleistocene alluvial terrace at 426 m. Temperature data for the period from January 1951 through May 1972 have been estimated by regression analysis between data from the primary station and a NOAA reporting site at Leaburg (elev 206 m) 48 km away. Precipitation data are from another Andrews site 0.2 km away. Only 1951 precipitation data had to be estimated. The valley bottom site location and close proximity (less than 3 tree heights distant) of 76 m tall old growth Douglas-fir trees are considerations in data interpretation.

VEGETATION

Old-growth conifer forest with greater than 400 year old dominant trees covers about 45 percent of the H.J. Andrews Forest. Mature conifer stands with dominants 100-130 years old occupy about 25 percent of the Andrews Forest, and about 30 percent has young stands which have grown up following logging during the past 30 years. The lower elevation forest is composed of stands dominated by Douglas-fir *(Pseudotsuga menziesii),* western hemlock *(Tsuga heterophylla),* and western red cedar *(Thuja plicata).* Upper elevation stands consist of mixtures of true firs *(Abies procera, Abies amabilis)* and mountain hemlock *(Tsuga mertensiana).* As elevation increases, the western hemlock in the lower elevation stands is replaced by silver fir *(Abies amabalis)* and Douglas-fir and western red cedar decline in importance. A number of forest communities are associated with moisture and temperature gradients at different elevations.

SYNOPTIC CLIMATOLOGY

The general climate of the H.J. Andrews Forest is controlled by its close mid-latitude proximity to the Pacific Ocean and by the orientation of the Coast and Cascade mountain ranges perpendicular to the prevailing westerly flow. The Andrews Forest is located near the border between temperate maritime and temperate continental climates as a result of these mountains which present barriers to the passage of air masses. Temperatures are moderated at all times of the year by maritime air, particularly in winter.

Winter precipitation is high. Low pressure areas and associated storms are steered into the area by the polar jet stream. Passage of the usually strongly occluded fronts is slowed by the mountains resulting in long duration but generally low intensity storms. Temperatures associated with these storms are often mild enough that rain falls at lower elevations of the forest while snow falls at higher elevations, usually producing a deep (2 to 4 m), long lasting snowpack above approximately 1050 m. Summertime precipitation is usually low to nonexistent. The North Pacific anticyclone intensifies and bulges to the northeast along the coast, blocking the passage of cyclonic storms and stabilizing the air.

WATER BALANCE

The H.J. Andrews site has one of the most remarkable water balances of all of the LTER sites (Table 2.4, Fig. 2.5). It is notable for its very large winter precipitation which leads to significant soil water surpluses and implied runoff in this season. The runoff is not as large as implied in Table 2.4, however, because some of the precipitation especially at the higher elevations is in the form of snow. It is also noteworthy that a soil water deficit occurs during the summer of most years because of the low rainfall. The actual evapotranspiration value is also not high compared to some of the LTER sites because of the relatively low summer temperatures and the lack of rainfall at this season.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

Summer drought, mild, wet winters, a heavy snowpack above 1050 m, and light to nonexistent snowpack below 762 m are factors affecting the flora and fauna. Late summer moisture stress of the forest plays an important part in determining the composition and structure of various forest communities. Snow and lower temperatures at upper elevations play an important role in the formation of a distinctly different forest zone through mechanical force and modification of temperature and moisture regimes. Large animals such as elk and deer are forced to lower elevations by the heavy, upper elevation snowpack, while smaller animals use it for shelter and cover. At lower elevations the mildness and wetness of the winters combined with little snow produces a nearly stress free environment for plants and animals. The mild climate also results in a long growing season.

Fig. 2.1. General view of the H.J. Andrews Experimental Forest.

Fig. 2.2. The primary meteorological station.

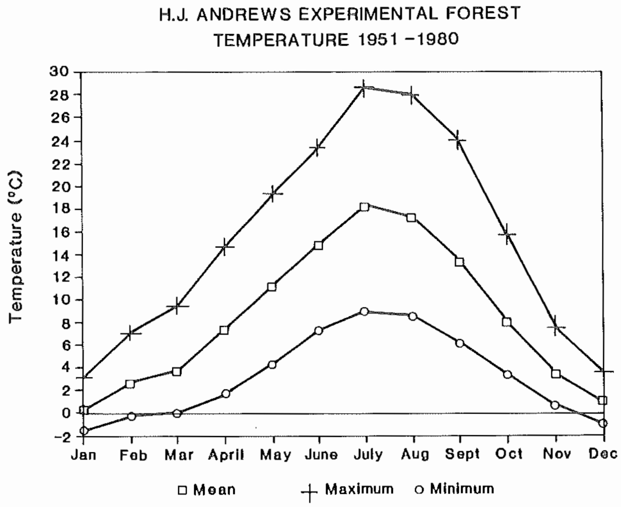

Fig. 2.3. Average annual temperature values at H.J. Andrews Experimental Forest.

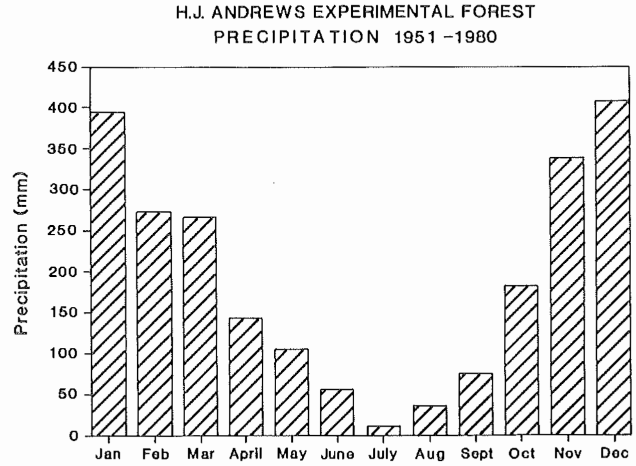

Fig. 2.4. Average annual precipitation totals at H.J. Andrews Experimental Forest.

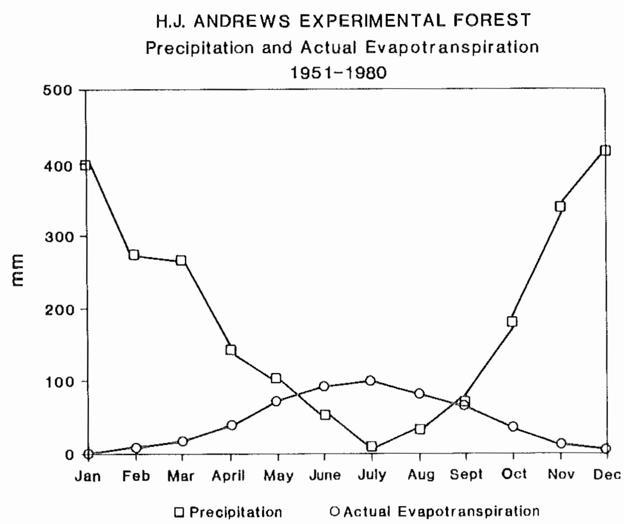

Fig. 2.5. Monthly water budget values at H.J. Andrews Experimental Forest.

Table 2.1

SUMMARY STATISTICS H.J. ANDREWS EXPERIMENTAL FOREST

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	0.30	2.70	3.80	7.40	11.30	14.90	18.30	17.40	13.50	8.10	3.50	1.10
An Mean	8.60	St Dev	0.70									
Mean Mx T	3.20	7.00	9.40	14.60	19.30	23.30	28.70	28.00	24.10	15.80	7.50	3.60
Mean Mi T	-1.50	-0.20	0.10	1.70	4.40	7.30	9.00	8.60	6.30	3.40	0.70	-0.90
Mean Temp Warmest Month			18.60	St Dev	1.10							
Mean Temp Coldest Month			-0.40	St Dev	1.50							
Annual Range of Monthly Mean Temps				18.00								
Num months with mean temp >0				12								
Num months with mean temp >15				2								
Highest monthly mean				20.80								
Lowest monthly mean				-3.10								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	394.6	273.5	266.4	143.5	105.8	56.1	11.6	36.2	74.9	181.8	338.3	407.3
Mean annual total		2289.2										
Wettest year in period			3055									
Driest year in period			1503									

Monthly totals during wettest year in period — Year 1953

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
783	420	253	143	177	79	0	78	42	87	506	488

Monthly totals during driest year in period — Year 1952

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
282	209	273	73	45	68	2	4	35	8	72	422

Total precip in months with temp >0 — 2290

Table 2.2

ADDITIONAL SUMMARY STATISTICS H.J. ANDREWS EXPERIMENTAL FOREST

These statistics were extracted from data from the Andrews primary meteorological station which has existed since May 1972.

AIR TEMPERATURE
Deg. C.

Mean annual heating degree days	5585	
Overall maximum	44.4	(1981)
Mean max warmest month	29.2	
Mean min coolest month	-2.65	
Mean frost free period length	134 days	

VAPOR PRESSURE (mb)
(Calculated by Teten's equa (see Greenland, 1986))

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	6.40	6.90	7.70	8.20	9.80	11.90	13.80	13.30	11.30	9.30	7.40	6.40
An Mean	9.40											

WIND VELOCITY (m/sec)

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	0.31	0.32	0.37	0.57	0.71	0.76	0.85	0.79	0.48	0.27	0.26	0.25
An Mean	0.53											

No peak gust data. Wind direction not measured.

GLOBAL RADIATION (J/sq.cm)

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	338.20	513.20	955.20	1420.30	1755.60	2084.60	2238.30	1910.90	1412.40	864.40	406.50	252.00
An Mean	1176.3											

FIELD CAPACITY OF ROOTING ZONE (mm) : 495. Rooting zone 0 to 1.22 m.

Table 2.3

NOTES ON ESTABLISHMENT OF THE 30 YEAR TEMPERATURE AND PRECIPITATION DATA SET FOR THE H.J. ANDREWS EXPERIMENTAL FOREST

The temperature data set started June 1972 and earlier data were estimated by regression analysis. A NWS site at Leaburg, 48 km away, was used for the independent variables. The precipitation data set is more complete with only data for one year being estimated. Below is a list of correlation coefficients for values between the sites. The values of some coefficients lack strength. Standard errors are usually less than 0.2 deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
TEMPERATURE												
Mean												
Corr Coef	0.77	0.72	0.89	0.77	0.75	0.61	0.62	0.82	0.66	0.43	0.77	0.81
St. Error	0.18	0.24	0.15	0.26	0.21	0.21	0.22	0.19	0.18	0.24	0.19	0.15
Mean maximum												
Corr Coef	0.67	0.72	0.92	0.87	0.87	0.64	0.74	0.79	0.93	0.94	0.79	0.75
St. Error	0.22	0.25	0.15	0.17	0.15	0.23	0.15	0.20	0.10	0.18	0.18	0.17
Mean minimum												
Corr Coef	0.87	0.59	0.72	0.63	0.54	0.29	0.39	0.72	0.46	0.64	0.81	0.86
St. Error	0.12	0.26	0.18	0.27	0.29	0.23	0.46	0.2	0.23	0.24	0.18	0.13
PRECIPITATION												
Corr Coef	0.90	0.92	0.90	0.73	0.85	0.78	0.82	0.91	0.86	0.91	0.91	0.89
St. Error	0.10	0.07	0.10	0.11	0.08	0.08	0.07	0.06	0.09	0.08	0.08	0.10

Table 2.4.

WATER BUDGET FOR H.J. ANDREWS EXPERIMENTAL FOREST

Water budget for Latitude 44.2 N, Longitude 122.2 W
Field capacity 495.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	0.3	1	1	395	393	495	0	1	0	393	0	0
Feb	2.7	13	11	274	263	495	0	11	0	263	0	0
Mar	3.8	19	19	266	247	495	0	19	0	247	0	0
Apr	7.4	37	41	144	102	495	0	41	0	102	0	0
May	11.7	58	74	106	31	495	0	74	0	31	0	0
Jun	14.9	75	97	56	-40	456	-39	95	2	0	0	0
Jul	18.3	92	120	12	-109	366	-90	102	18	0	0	0
Aug	17.4	88	105	36	-69	318	-48	84	21	0	0	0
Sep	13.5	68	70	75	5	323	5	70	0	0	0	0
Oct	8.1	40	38	182	144	468	144	38	0	0	0	0
Nov	3.5	17	14	338	325	495	27	14	0	297	0	0
Dec	1.1	5	4	407	403	495	0	4	0	403	0	0
	Yearly Totals:		593	2290				552	41	1738		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 3

CEDAR CREEK NATURAL HISTORY AREA, MINNESOTA

John Tester and David Greenland

SITE DESCRIPTION

Cedar Creek Natural History Area is a 2185 ha Experimental Ecological Reserve on a large, glacial outwash, sand plain (Fig. 3.1). It includes a large variety of habitat types, ranging from oak savanna to prairie to deciduous hardwood forest (Moore, 1973). The soils, which are mainly derived from glacial outwash sand, include five of the ten major soil orders. The terrain of the area is slightly undulating, and includes rather dry sandy uplands and numerous streams, bogs, lakes, swamps, and marshes. Thus there are many different microclimates within the area.

Climate data (Table 3.1) for the site are taken from the National Weather Service observation station at Cambridge, which is within 15 km of the Natural History Area (Fig. 3.2).

VEGETATION

The principal biomes represented in the Cedar Creek site are hardwood forest and tall grass prairie. The main plant communities are oak savanna, oak forest, conifer bog, Great Lakes pine forest, herbaceous communties on abandoned fields, and wetland marsh and carr. Among the most common species in the tall grass prairie are big bluestem, little bluestem, Indian grass, prairie clover, goldenrod, pasque flower, and shrubs such as roses and wolfberry. In and near the marshes can be found blue-joint grass, sedges, reeds, cattails, bull rushes and wild rice. Burr and Hill's oak dominate the hardwood forest but elm, ash, sugar maple, aspen, basswood and some jack pine are present (Borchert and Gustafson, 1980).

SYNOPTIC CLIMATOLOGY

The mid-latitude continental location of Cedar Creek leads it to experience influences of both polar and tropical air masses and, especially in the cooler part of the year, the presence of the polar front, its associated jet stream, and frequent passages of mid-latitude cyclonic storms. In summer the site comes under the influence of the southerly airflow from the extreme edge of the subtropical high pressure zone in the southern part of the North Atlantic ocean. This airflow provides moisture for summer convectional storms. As a result of this overall situation, the climate is characterized by four distinct seasons and changing weather both within and between seasons.

The last spring frost occurs on the average between 2 and 11 May and the first fall frost occurs between 26 September and 5 October giving a frost free season of between 140 and 160 days. The location receives about two thirds of its annual precipitation during the five month growing season when the source of moisture is the tropical part of the Atlantic Ocean and the Gulf of Mexico. During the winter months moisture comes more frequently, but in smaller quantities from the Pacific Ocean (Borchert and Gustafson, 1980). Climate data are presented in Tables 3.1 and Figs. 3.3 and 3.4.

WATER BALANCE

The water balance at Cedar Creek shows typical features for a mid-latitude continental site (Table 3.2, Fig. 3.5). These include the minimal evapotranspiration loss during winter and the summer maximum of precipitation. The current water balance calculations suggest the possibility of a short period in the summer when actual evapotranspiration exceeds potential evapotranspiration.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

Precipitation is most critical in the growing season from May through September, and year to year changes in rainfall values during this period may have marked effects on the primary productivity levels. This effect can be accentuated by the high variability of the soil moisture across the Cedar Creek site from the marshland to the drier, sandy soils of higher elevations. The proximity of the site to the boundary between forest and prairie makes growing season precipitation even more critical. Longer term climatic changes together with the effects of fires, windstorms, insect infestations, plant diseases, and successional events in wetlands have meant that the details of vegetational mosaics have been continually shifting (Borchert and Gustafson, 1980). There are about 110 days per year with more than 2.5 mm of snow on the ground.

Literature Cited

Borchert, J.R. and Gustafson, N.C., 1980. *Atlas of Minnesota: Resources and Settlement.* Center for Urban and Regional Affairs, University of Minnesota, Minneapolis, and the Minnesota State Planning Agency. 3rd Ed. 308 pp.

Moore, J.W. 1973 *A Catalog of the Flora of Cedar Creek Natural History Area, Anoka and Isanti Counties, Minnesota. Bell Museum of Natural History, University of Minnesota, Occasional Paper,* 12:1-28.

Fig 3.1. Old field succession on the oak-savanna outwash sand plain.

Fig.3.2. The observing site at the Cedar Creek Natural History Area laboratory.

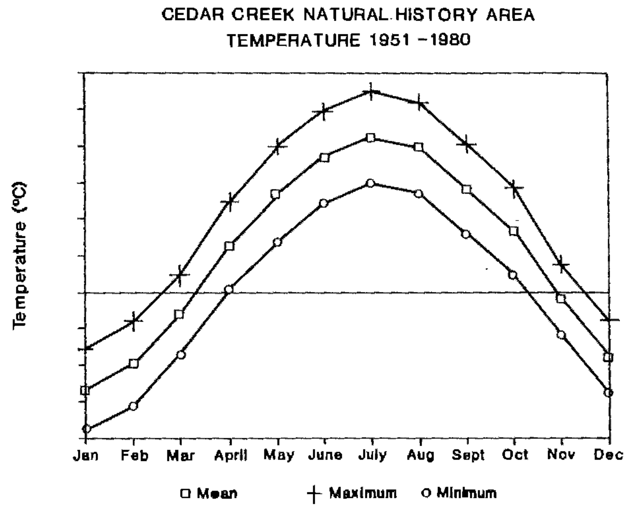

Fig. 3.3. Average annual temperature values at Cedar Creek Natural History Area.

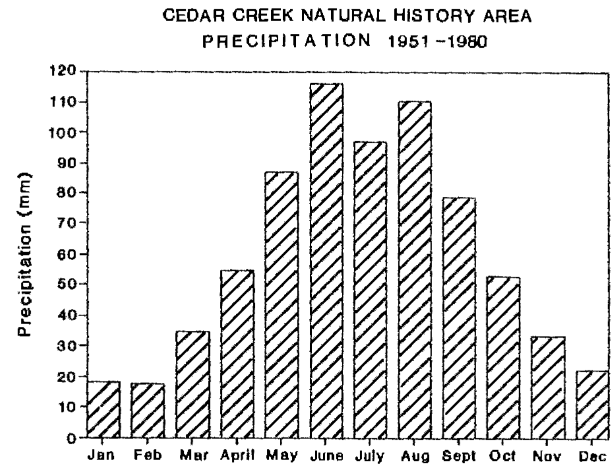

Fig. 3.4. Average annual precipitation totals at Cedar Creek Natural History Area.

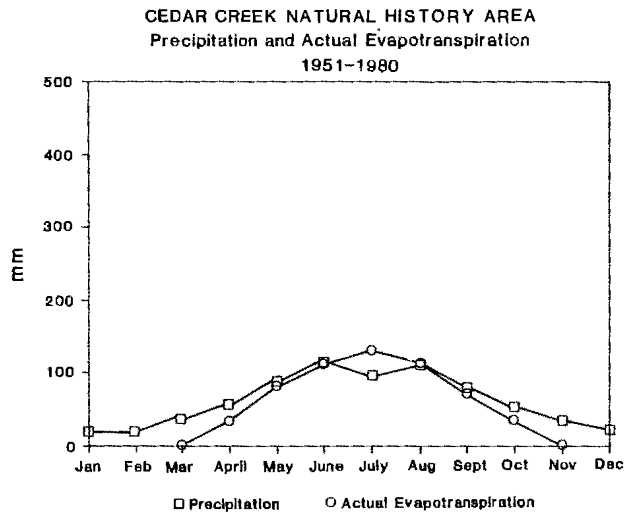

Fig. 3.5. Monthly water budget values at Cedar Creek Natural History Area.

Table 3.1

SUMMARY STATISTICS CEDAR CREEK NATURAL HISTORY AREA

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	-13.45	-9.81	-3.00	6.39	13.43	18.54	21.19	19.78	14.19	8.42	-0.87	-8.84
An Mean	5.50	St Dev	0.66									
Mean Mx T	-7.93	-3.95	2.47	12.42	19.94	24 82	27.50	26.06	20.27	14.31	3.90	-3.92
Mean Mi T	-18.97	-15.67	-8.48	0.35	6.92	12.26	14.87	13.51	8.10	2.53	-5.64	-13.75
Mean Temp Warmest Month			21.19	St Dev	1.40							
Mean Temp Coldest Month			-13.45	St Dev	2.81							
Annual Range of Monthly Mean Temps				34.64								
Num months with mean temp >0				7								
Num months with mean temp >15				3								
Highest monthly mean				24.20								
Lowest monthly mean				-19.50								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	18.2	17.6	34.6	55.1	87.1	116.2	97.2	110.7	79.1	53.6	33.9	22.6
Mean annual total		726.0										
Wettest year in period			1037									
Driest year in period			327									

Monthly totals during wettest year in period — Year 1975

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
76	11	43	135	60	235	63	179	84	27	116	8

Monthly totals during driest year in period — Year 1976

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
24	28	53	24	59	59	25	21	9	6	9	10

Total precip in months with temp >0 599

Table 3.2.

WATER BALANCE DATA FOR CEDAR CREEK NATURAL HISTORY AREA

Water budget for Latitude 45.4 N, Longitude 93.2 W
Field capacity 100.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	-13.5	0	0	18	0	100	0	0	0	0	0	41
Feb	-9.8	0	0	18	0	100	0	0	0	0	0	58
Mar	-3.0	0	0	35	0	100	0	0	0	0	0	93
Apr	6.4	29	33	55	23	100	0	33	0	116	93	0
May	13.4	64	82	87	5	100	0	82	0	5	0	0
Jun	18.4	91	118	116	-2	98	-2	118	0	0	0	0
Jul	21.2	106	139	97	-42	64	-34	131	8	0	0	0
Aug	19.8	98	119	111	-8	59	-5	116	3	0	0	0
Sep	14.2	68	71	79	8	68	8	71	0	0	0	0
Oct	8.4	39	36	54	18	85	18	36	0	0	0	0
Nov	-0.9	0	0	34	34	100	15	0	0	19	0	0
Dec	-8.8	0	0	23	0	100	0	0	0	0	0	23
	Yearly Totals:		597	726				586	11	140		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 4

CENTRAL PLAINS EXPERIMENTAL RANGE SITE, COLORADO

William Parton and David Greenland.

SITE DESCRIPTION

The Central Plains Experimental Range (CPER) site is a 6280 ha tract of shortgrass prairie rangeland administered by the USDA Agricultural Research Service (ARS). It was the site of intensive research for the Grassland Biome portion for the International Biological Programme (IBP). The land is gently undulating between ridges and swales and thus provides opportunity, especially in summer time, for the development of soil catenas and well marked soil moisture differences (Fig. 4.1).

Climate data (Table 4.1) reported here come from two nearby sites. Data were collected at the main CPER site from 1951 to 1969 and at the IBP site (Fig. 4.2) from 1969 onwards. There was a period of 42 months where data were collected at both sites thus permitting comparisons to be made. Correlation in values between the sites is good, and thus the data were treated as if they came from one location. Regression coefficients for 42 months of temporally overlapping data between the main CPER observation site and the IBP site are as follows: Maximum Temperature, 0.99, Minimum Temperature, 0.98, Mean Temperature, 0.99, Precipitation, 0.74.

VEGETATION

Within this grassland biome the main communities are shortgrass steppe, flood plain shrubland, and salt meadow. The shortgrass steppe is dominated by shortgrasses (64%), succulents (21%), and half shrubs (8%). The main species of these groups are *Bouteloua gracilis* and *Buchloe dactyloides; Opuntia polyacantha;* and *Chrysothamnus nauseosus, Guteriezia sarothrae,* and *Erigonum effusum,* respectively. Major differences in the vegetation structure occur in saltgrass meadows dominated by *Distichlis stricta* and *Sporobolus asper,* and on the flood plains where the shrub *Atriplex canescens* is important (Halfpenny and Ingraham, 1984).

SYNOPTIC CLIMATOLOGY

The site is located in mid latitudes and in mid continent and thus is subject to polar front storm tracks in winter and a dominant mid-continental, high pressure zone in summer. Its location far from moisture sources is exaggerated by its being in the rain shadow of the Rocky Mountains. Consequently, there is extreme daily, seasonal, and long term climate variability in both range of temperature and precipitation and their predictability. During the winter the site is subject to precipitation from cyclonic storms and cold fronts usually entering from the northwest or west. Approximately 70% of the mean annual precipitation comes during the April to September growing season as a result of isolated convectional storms. These storms can provide a high intensity of rainfall and are sometimes accompanied by hail of varying severity. Climate data are presented in Table 4.1 and Figs. 4.3 and 4.4.

WATER BALANCE

The CPER water balance (Table 4.2, Fig.4.5) is interesting for the small amount of precipitation relative to most other LTER sites. Although there is a summer precipitation maximum, this does not meet the needs for potential evapotranspiration. Consequently there is a significant soil moisture deficit in the summer at the site. A daily water balance model developed at the site (Parton, 1978) indicates generally larger amounts of actual evapotranspiration (Table 4.3). This is probably more realistic, and the underestimate of the Thornthwaite method may well be due to its failure to take into account atmospheric humidity and the possibility of advection of warm dry air which sometimes occurs at the CPER site. Also of interest is the fact that maximum soil water recharge occurs in April and May rather than earlier as indicated by the Thornthwaite calculations.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

One of the most important factors at the site is the interplay between the hydrologic cycle and such factors as primary production, key microbial responses, plant succession, plant and animal population dynamics, and organic matter aggregation or degradation. The majority of precipitation comes in summer convectional storms, and these are erratically distributed in time and space. Consequently, the pulses of soil moisture provided by these storms are critical in triggering activity in other ecosystem processes. Investigations are also being made into the influence of atmospheric gases, aerosols, and particulates on primary production and nutrient cycles.

Literature Cited

Halfpenny, J.C. and Ingraham, K.P. 1984. *Long Term Ecological Research in the United States: A Network of Research Sites.* LTER Network, Forest Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331. 28 pp.

Parton, W.J. 1978. Abiotic section of ELM. In G.S. Innis (ed.), *Grassland Simulation Model. Ecological Studies.* 26. Springer-Verlag, New York, 31-35.

Fig. 4.1. General view of the landscape at the Central Plains Experimental Range.

Fig. 4.2. On site climate recording instrumentation.

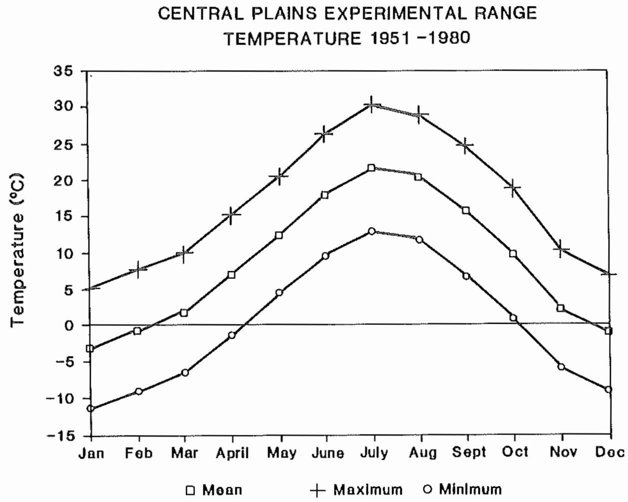

Fig. 4.3. Average annual temperature values at Central Plains Experimental Range.

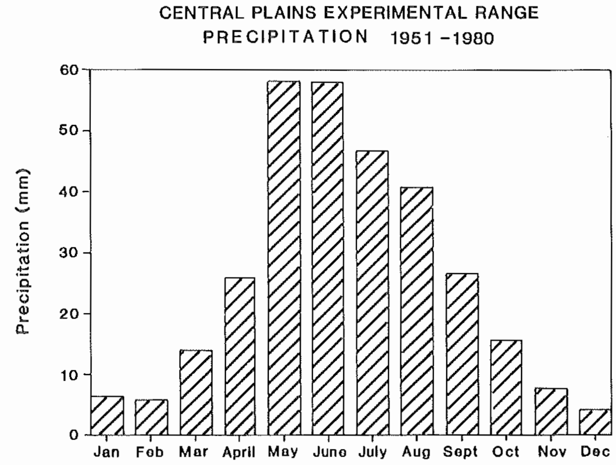

Fig. 4.4. Average annual precipitation totals at Central Plains Experimental Range.

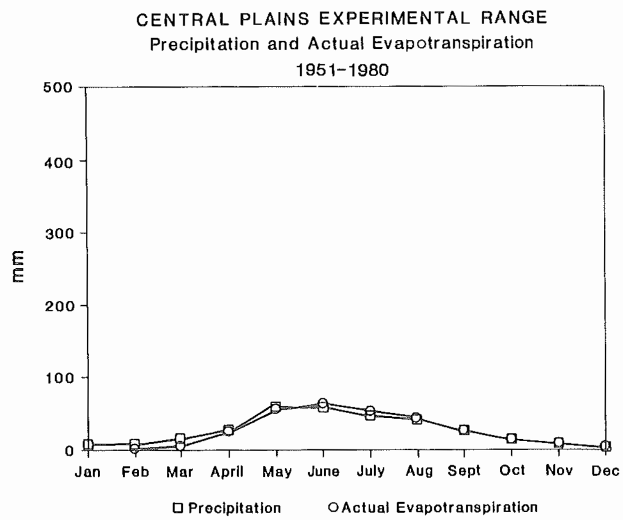

Fig. 4.5. Monthly water budget values at Central Plains Experimental Range.

Table 4.1

SUMMARY STATISTICS CENTRAL PLAINS EXPERIMENTAL RANGE

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	-3.10	-0.64	1.71	7.00	12.46	17.91	21.55	20.43	15.78	9.85	2.24	-1.08
An Mean	8.68	St Dev	1.26									
Mean Mx T	5.23	7.69	9.98	15.21	20.44	26.30	30.24	29.11	24.81	18.78	10.41	6.93
Mean Mi T	-11.43	-8.98	-6.55	-1.22	4.48	9.52	12.86	11.75	6.75	0.93	-5.93	-9.09

Mean Temp Warmest Month	21.55	St Dev	1.83
Mean Temp Coldest Month	-3.10	St Dev	2.38
Annual Range of Monthly Mean Temps		24.65	
Num months with mean temp >0		9	
Num months with mean temp >15		4	
Highest monthly mean		25.20	
Lowest monthly mean		-8.85	

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	6.2	5.7	13.8	25.8	58.3	58.1	46.8	40.7	26.5	15.4	7.6	4.0

Mean annual total	309.0
Wettest year in period	588
Driest year in period	108

Monthly totals during wettest year in period — Year 1967

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
19	10	14	56	126	166	106	29	32	7	10	14

Monthly totals during driest year in period — Year 1952

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	1	9	27	17	19	11	10	9	0	1	3

Total precip in months with temp >0 293

Table 4.2.

WATER BALANCE FOR CPER

Water budget for Latitude 40.8 N, Longitude 104.8 W
Field capacity 100.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	-3.1	0	0	6	0	1	0	0	0	0	0	10
Feb	-0.6	0	0	6	6	7	6	0	0	10	10	0
Mar	1.7	6	6	14	7	14	7	6	0	0	0	0
Apr	7.0	31	34	26	-8	13	-1	27	7	0	0	0
May	12.5	58	73	58	-14	11	-2	60	13	0	0	0
Jun	17.9	87	109	58	-51	7	-5	63	47	0	0	0
Jul	21.6	107	136	47	-90	3	-4	51	86	0	0	0
Aug	20.4	100	119	41	-78	1	-2	42	77	0	0	0
Sep	15.8	76	78	27	-51	1	-1	27	51	0	0	0
Oct	9.9	45	43	15	-27	1	0	16	27	0	0	0
Nov	2.2	8	7	8	1	1	1	7	0	0	0	0
Dec	-1.1	0	0	4	0	1	0	0	0	0	0	4
	Yearly Totals:		605	309				299	306	10		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

Table 4.3.

Water Balance Computations from the Parton Model for the Central Plains Experimental Range.
(Units are in mm except for temperature which is deg C.
Column headings are the same as for Table 4.2)

MON	TEMP	APE	PREC	DIFF	ST	DST	AE
Jan	-3.1	38.5	5.9	-32.6	8.5	0.8	5.8
Feb	-0.6	48.7	5.4	-43.3	8.6	0.1	5.8
Mar	1.7	67.8	14.7	-53.1	9.9	1.3	12.4
Apr	7.0	113.8	26.7	-87.1	11.2	1.3	27.7
May	12.5	159.0	59.3	-99.7	16.0	4.8	55.1
Jun	17.9	176.3	58.5	-117.8	16.7	0.3	73.3
Jul	21.6	187.0	50.9	-136.1	9.9	-6.8	56.7
Aug	20.4	162.0	40.7	-121.3	7.5	-2.4	52.6
Sep	15.8	115.0	28.2	-86.8	6.0	-1.5	30.9
Oct	9.9	76.4	15.2	-61.2	7.2	1.2	15.7
Nov	2.2	39.4	7.9	-31.5	7.7	0.5	7.9
Dec	-1.1	31.9	4.2	-28.0	7.7	0.0	4.3
	Yearly Total:		317.6				348.2

CHAPTER 5

COWEETA HYDROLOGIC LABORATORY, NORTH CAROLINA

Lloyd W. Swift

SITE DESCRIPTION

The Coweeta Hydrologic Laboratory covers two adjacent, east-facing, bowl-shaped valleys in the Nantahala Mountain chain of the Southern Appalachian Mountains in western North Carolina (Fig. 5.1). Streams drain into headwaters of the Little Tennessee River. Most research activity and all climatic data collection are centered on the larger, 1625 ha upper Coweeta Creek drainage. Elevations range from 675 m at the lower boundary to 1592 m at Albert Mountain on the dividing ridge between the Upper Nantahala and Little Tennessee rivers. Coweeta Creek divides near the lower research area boundary into Ball Creek and Shope Fork, two subdrainages of about equal size. Gaged experimental watersheds are located along the north-facing boundary of the Ball Creek drainage and the south-facing boundary of Shope Fork drainage with six additional watersheds in the headwaters of the east-facing, high elevation slope.

Climatic data in this chapter are collected primarily at station CS01 on the valley floor at elevation 685 m, latitude 35° 04'N, longitude 83° 26'W (Fig. 5.2). Data from this station is published monthly as "Coweeta Exp. Station", North Carolina Cooperative Observer No 2102, by the National Climatic Data Center. Data collection began in August 1934. CS01 is shielded by adjacent topography from north-northeast to southwest and opens only on the east to terrain of the same elevation. The vertical angle from the climatic station to ridgelines is 15 degrees to the south and north and 12 degrees to the west. The station is in a large grassy field, about 65 m from the nearest forest edge and 20 m from Shope Fork. CS01 experiences the usual phenomenon for a valley bottom site, i.e. diurnal cool air drainage and frequent fall morning fog cover. Solar radiation input is blocked by surrounding topography only during the beginning and ending hours of daylight when the solar altitude and intensity are least. Wind speed and direction are expected to be considerably different from conditions on the exposed high slopes or ridges. High humidities persist longer at CS01 than on the south-facing slopes. Thus, CS01 probably best represents the local climate along the streams and on the north-facing watersheds. Other climatic stations at Coweeta are at 820 m on the south-facing slope, 890 m on the north-facing slope, and 1190 m on the east-facing slope.

VEGETATION

The vegetation of the Coweeta Basin historically is in the oak-chestnut forest association but *Castanea dentata,* the dominant species, was lost from the overstory through chestnut blight in the 1930s and the forest is now classified as oak-hickory association. The plant communities are still changing, typically diverse, and distributed over highly varied topography in relation to temperature and moisture. Throughout the four major forest types, the predominant species composition is a mix of deciduous oaks and other species with abundant patches of evergreen undergrowth of *Rhododendron maximum* and *Kalmia latifolia.* The Northern Hardwood Type, characterized by *Betula lutea, Quercus rubra,* and other cooler climate species, occurs at higher elevations, mainly above 1200 m. The Cove Hardwood Type, found in moist coves and stream bottoms, is dominated by *Liriodendron* and *Tsuga canadensis* and other mesic species. The Oak Type is widely distributed over all slopes. *Quercus prinus* is the predominant species with *Q. coccinea* on drier slopes, *Q. alba* and *Q. velutina* at lower elevations and Carya on the moister north-facing slopes. *Pinus rigida* is a significant component in the Oak-Pine Type on ridges and drier slopes at low elevations. The natural deciduous forest is interrupted by three plantations of *Pinus strobus.*

SYNOPTIC CLIMATOLOGY

The climate of the Appalachian Mountains is distinguished from that of surrounding lowlands by characteristics of high precipitation, moderate temperatures and sustained evaporation rates. Under Köppen's system, Coweeta's climate is classed as Marine, Humid Temperate (Cfb). The lower elevations of the Coweeta Basin, including station CS01, are borderline between Marine and Humid Subtropical because the mean monthly temperatures in June and July are near 22 deg. C. According to Thornthwaite's classification, Coweeta is in the wet, mesothermal, adequate rainfall (AB'r) climate whereas his modified classification is perhumid, mesothermal with water surplus in all seasons.

Moist marine air masses are uplifted by the Appalachian mountains and annual rainfalls regularly exceed those for other locations in the eastern United States. Typically, storm fronts approach from the northwest, and winter storms tend to have longer durations if the cold air masses meet moist ones at the southern edge and movement is slowed by passage over the mountains. Short duration thundershowers are typical for mid-summer and fall with random occurrences of large rainfalls stimulated by hurricane disturbances near the Atlantic or Gulf coasts. Forty-nine percent of the 133 storms each year have total precipitation amount less than 5 mm, and 69 percent of the annual precipitation falls with an intensity less than 10 mm/h. Coweeta does not experience a distinct dry or low rain season; the probability of measurable precipitation for any date is 30 to 40 percent.

Temperatures are moderate because of the combination of low latitude and high (for the eastern United States) elevations. Snow is a minor part of the annual precipitation, averaging 2 to 5 percent depending upon elevation. Snow cover rarely lasts for more than 3 or 4 days, even on the upper slopes. Compared with other mountain sites, wind speeds at Coweeta appear to be low and even imperceptible in the valley bottom at CS01. The majority of precipitation falls when wind speed is less than 2.2 m/s and over 90 percent falls when wind is low or blowing from the south. Even so, wind action seems to cause precipitation catches to be reduced on or near ridgelines but greater on the north-facing slopes. Climatic data are presented in Table 5.1 and Figs. 5.3 and 5.4.

WATER BALANCE

Coweeta receives relatively large quantities of precipitation throughout the year which allows the values of potential evapotranspiration to be met in all seasons in most years. Lower values of actual evapotranspiration in the dormant season lead to a considerable soil moisture surplus which is realized primarily as streamflow. In summer, values of both potential and actual evapotranspiration are close to precipitation values suggesting that in some years localized soil moisture deficits will occur. Water balance data are given in Table 5.2 and Fig. 5.5.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

In most years, winter precipitation totally recharges soil water storage so that growing seasons begin in May with an adequate moisture supply. Although high evapotranspiration rates exceed summer rainfall, soil moisture stress in plants typically does not appear until late summer. On warm sunny days in the dormant season, evapotranspiration continues and this is a significant factor in the greater water use by conifer over deciduous forest. Fifty-year mean annual precipitation ranges from 1812 mm at CS01 to 2386 mm at Mooney Gap near the Appalachian Trail (1364 m elevation). The 30-year moving average for CS01 ranges between 1775 and 1872 mm for the total period of record. Solar radiation intensity in mid summer is nearly equivalent on north- and south-facing slopes but in mid winter, the radiant energy received by a south slope does not fall below that for a horizontal surface in March. Winter ice damage of forest vegetation occurs in some years. Streams may be bridged by ice for a few days in some winters. Due to the southern latitude, stream temperatures are near the upper limit for a cold-water mountain aquatic habitat ranging from a mean minimum 6-8 deg. C in winter to a mean maximum of 16-18 deg. C on a south-facing slope in midsummer. Within the forest, soils are rarely frozen. For example, on the coldest day from the 50 year record at Coweeta, soil temperature at 10 cm stayed above 1 degree C even on the cold north-facing slope.

Fig. 5.1. Aerial view of Coweeta Hydrological Laboratory looking west toward the Nantahala Mountains from the Little Tennessee River.

Fig. 5.2. The main climatic station CS01. Instrumentation includes samplers for atmospheric chemistry studies.

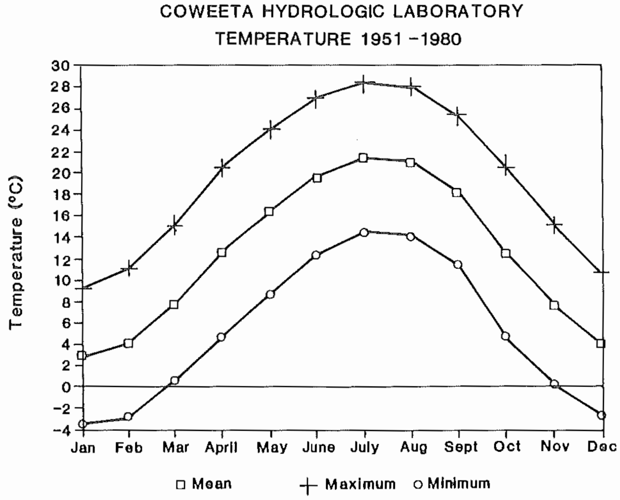

Fig. 5.3. Average annual temperature values at Coweeta Hydrological Laboratory.

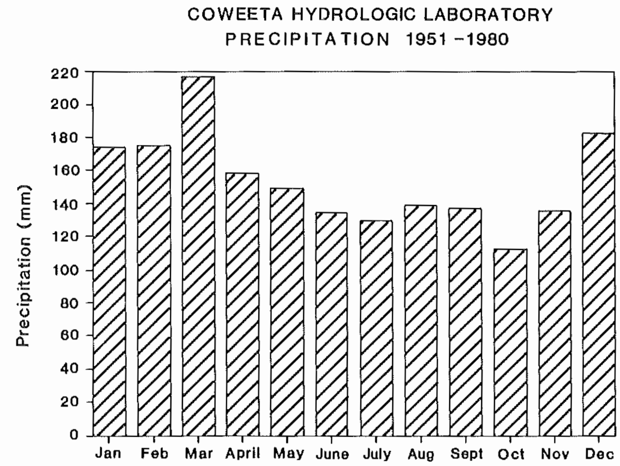

Fig. 5.4. Average annual precipitation totals at Coweeta Hydrological Laboratory.

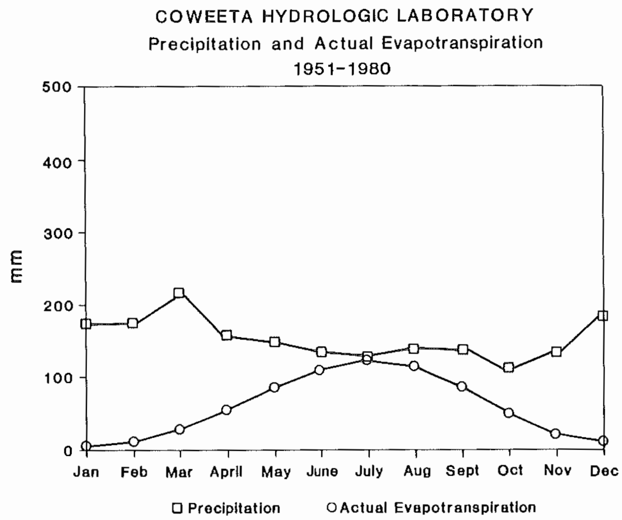

Fig. 5.5. Monthly water budget values at Coweeta Hydrological Laboratory.

Table 5.1

SUMMARY STATISTICS COWEETA HYDROLOGIC LABORATORY

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	2.95	4.22	7.89	12.70	16.41	19.75	21.50	21.24	18.46	12.74	7.74	4.13
An Mean	12.48	St Dev	0.47									
Mean Mx T	9.26	11.18	15.07	20.56	24.06	27.00	28.45	28.23	25.37	20.72	15.27	10.76
Mean Mi T	-3.38	-2.75	0.71	4.84	8.76	12.49	14.57	14.27	11.55	4.78	0.26	-2.51
Mean Temp Warmest Month			21.65	St Dev	0.75							
Mean Temp Coldest Month			1.87	St Dev	1.84							
Annual Range of Monthly Mean Temps				19.78								
Num months with mean temp >0				12								
Num months with mean temp >15				5								
Highest monthly mean				23.09								
Lowest monthly mean				-3.02								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	174.0	175.0	217.0	159.0	149.0	135.0	130.0	139.0	137.0	113.0	136.0	183.0
Mean annual total		1848.0										
Wettest year in period			2315									
Driest year in period			1392									
Monthly totals during wettest year in period					Year		1979					
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	246	164	279	253	229	77	229	161	245	95	281	57
Monthly totals during driest year in period					Year		1978					
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	258	30	152	72	146	68	83	203	28	7	111	234
Total precip in months with temp >0				1848								

Table 5.2

WATER BALANCE FOR COWEETA HYDROLOGIC LABORATORY

Water budget for Latitude 35.0 N, Longitude 83.5 W
Field capacity 70.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	3.0	7	6	174	168	70	0	6	0	168	0	0
Feb	4.2	12	10	175	165	70	0	10	0	165	0	0
Mar	7.9	27	28	217	189	70	0	28	0	189	0	0
Apr	12.7	51	55	159	104	70	0	55	0	104	0	0
May	16.4	71	86	149	63	70	0	86	0	63	0	0
Jun	19.8	91	110	135	25	70	0	110	0	25	0	0
Jul	21.5	102	125	130	5	70	0	125	0	5	0	0
Aug	21.2	100	116	139	23	70	0	116	0	23	0	0
Sep	18.5	83	86	137	51	70	0	86	0	51	0	0
Oct	12.7	51	49	113	64	70	0	49	0	64	0	0
Nov	7.7	26	22	136	114	70	0	22	0	114	0	0
Dec	4.1	11	10	183	173	70	0	10	0	173	0	0
	Yearly Totals:		702	1847				702	0	1145		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 6
ILLINOIS RIVERS, ILLINOIS

Wayne Wendland

SITE DESCRIPTION

The Illinois Rivers LTER sites are placed at two locations on the Mississippi River and at one location on the Illinois River (Figs. 6.1 and 6.2). The two sites on the Mississippi River are (1) Pool 19, upstream from Keokuk IA, and (2) Pool 26, upstream from Grafton IL; the Illinois River site is a pool just above Peoria Illinois (Table 6.1).

Climatic data were compiled from the records of LaHarpe, Illinois and Monmouth, Illinois. The former is a National Weather Service (NWS) Cooperative station and the latter is an automatic station of the Illinois Water Survey. Means of the former are for the data period 1951-1980 and are those quoted in the data summary tables. Data for the latter site are from 1980. All temperature data reported here have been adjusted to eliminate error due to time of day of observation following the methods of Karl et al. (1986).

Topographic relief of the region is relatively flat, with difference in elevation limited to about 100 m over distances of 1 to 10 km, and generally much less. Since the LTER sites are located along the rivers, the study areas tend to be channelled north-south and have greater relief than the flatter areas adjacent to the river basins.

The data summary comparable with other LTER sites is given in Table 6.2. Additional data are found in Table 6.3. Soil moisture data are from monthly observations during the winter and semi monthly observations during the growing season. Mean monthly vapor pressure is calculated based on mean relative humidities at 1400 local time and the mean maximum temperature for the month. Global radiation values are interpolated from NWS observations from Madison, Wisconsin, Indianapolis, Indiana, Columbia, Missouri, and Nashville, Tennessee (Hendrie and Wendland, 1981).

VEGETATION

The natural vegetation of all three sites was the long grasses of the eastern limits of the prairie peninsula, although the deciduous forest from the east migrated into the area from time to time during the Holocene. Today the region is almost totally cultivated with row crops, which include corn and soybeans, except along the river valleys where oak and maples dominate.

SYNOPTIC CLIMATOLOGY

The climate of the region is determined first by latitude and continentality. At the next level of impact is the frequency of the various airmasses which dominate the region from season to season and from year to year. All three sites are dominated by maritime tropical (mT) air from the Gulf of Mexico for about 7.5 months per year, maritime polar (mP) air from the Pacific Ocean for about 2 months of the year, and continental polar air (cP) from Canada for 2.5 months of the year (Wendland and Bryson, 1981). These values vary from year to year and affect interannual values of temperature and precipitation. Maritime tropical air is the warmest of the three, and the most moist, while the cP air is coldest and driest. Marine polar air from the Pacific has lost much of its moisture by the time it reaches Illinois due to its passage across the Rockies.

The mix of these airmasses yields the climate for Illinois. Spring and summer days are dominated by partly cloudy conditions under maritime tropical air. As the day progresses cumulus clouds develop, often forming into thunderstorms by late afternoon and evening. The highest frequency of severe thunderstorms is in late spring and early summer. Highest humidity is generally from mid July to August. Autumn is the least cloudy season, with relatively low humidities permitting warm days and cool nights. Winter weather is mostly cyclonically generated, characteristically having several days with continuous cloud cover and 12 to 36 hour periods of precipitation. Climatic data are presented in Tables 6.2 and 6.3 and Figs 6.3 and 6.4.

WATER BALANCE

The water balance for land surfaces near the Illinois rivers is normal for a mid-latitude continental site. Precipitation values exceed both potential and actual evapotranspiration values in the colder months resulting in a soil moisture surplus at this time. Most of this surplus takes the form of a snowpack. In the summer, actual evapotranspiration values exceed precipitation values, but soil moisture is plentiful and is used to sustain the evapotranspiration rates. Consequently, in most years, there would be only small soil moisture deficits in this season. Water balance data are presented in Table 6.4 and Fig.6.5.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

Several climatic factors play a role in affecting the flora and fauna at this site. Both flora and fauna have to adjust to the seasonal extreme temperatures and especially the fact that the rivers can freeze over in January and February. With more than 60 percent of the annual precipitation falling in the growing season and the proximity of the ground water from the river, there is usually little or no soil moisture stress for the vegetation.

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Wendland, W.M. and Bryson, R.A. 1981. Northern Hemisphere airstream regions. *Monthly Weather Review,* 109:255-270.

Fig. 6.1. A pool at the Illinois Rivers site (Photo by Nani Bhowmik)

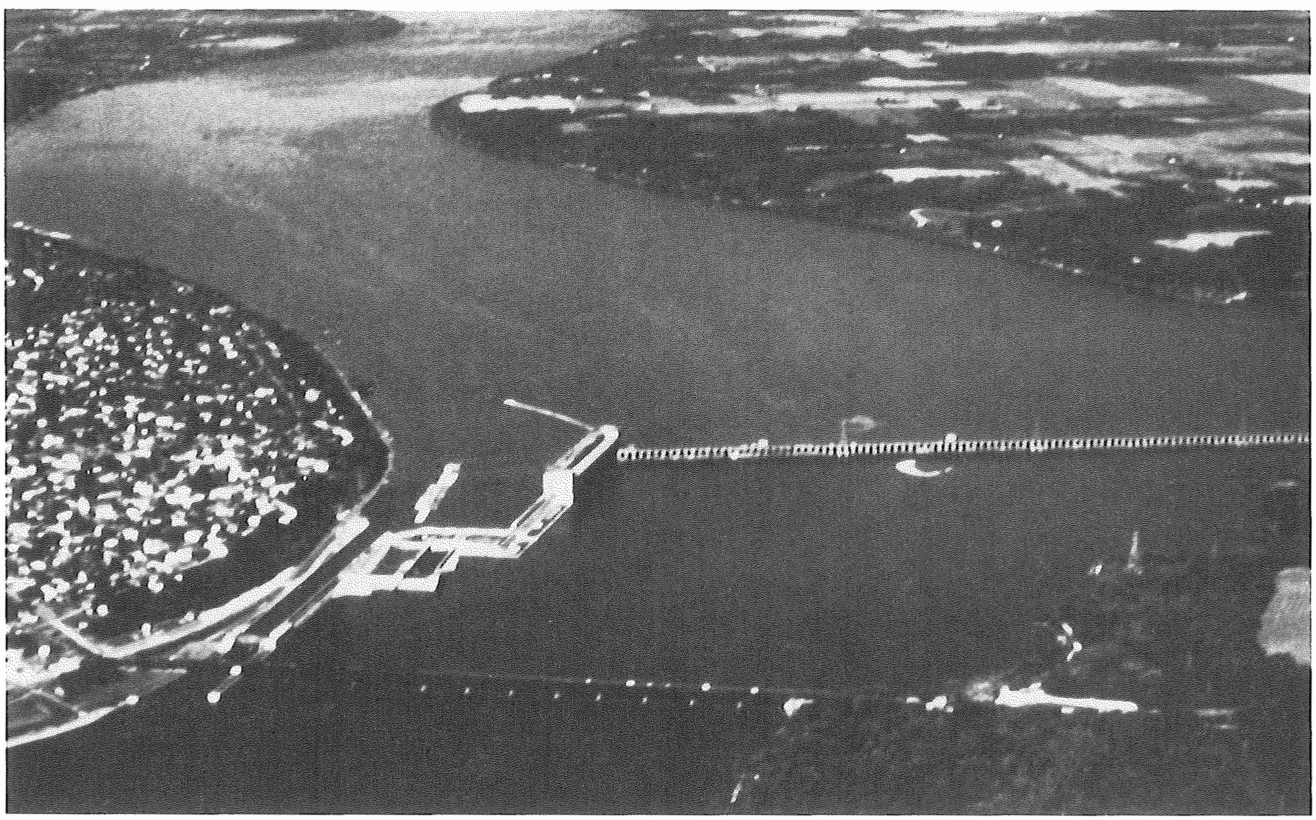

Fig. 6.2. A lock and dam at the Illinois Rivers site (Photo by Richard Anderson).

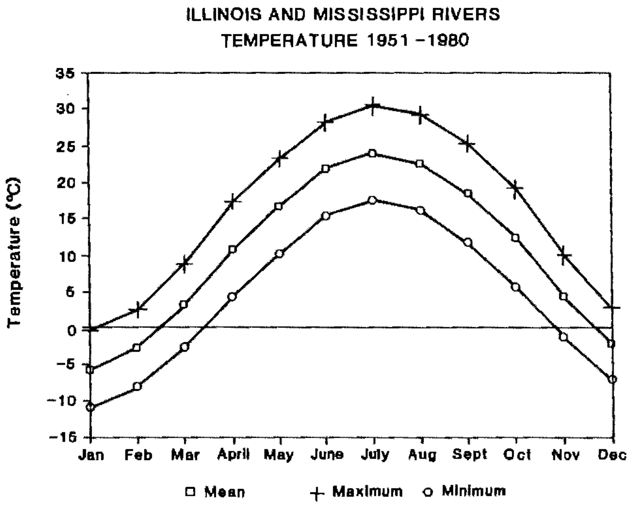

Fig. 6.3. Average annual temperature values at Illinois Rivers.

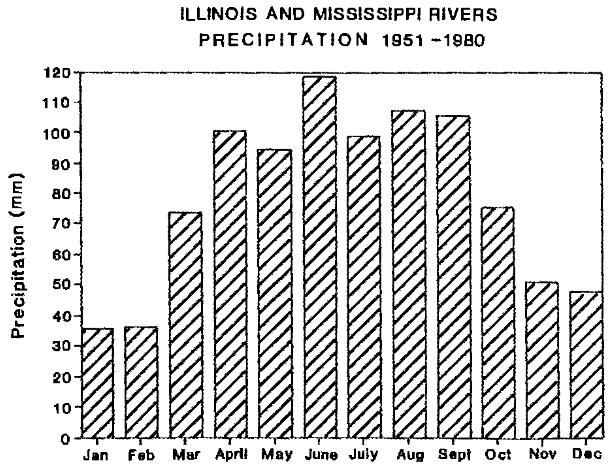

Fig. 6.4. Average annual precipitation totals at Illinois Rivers.

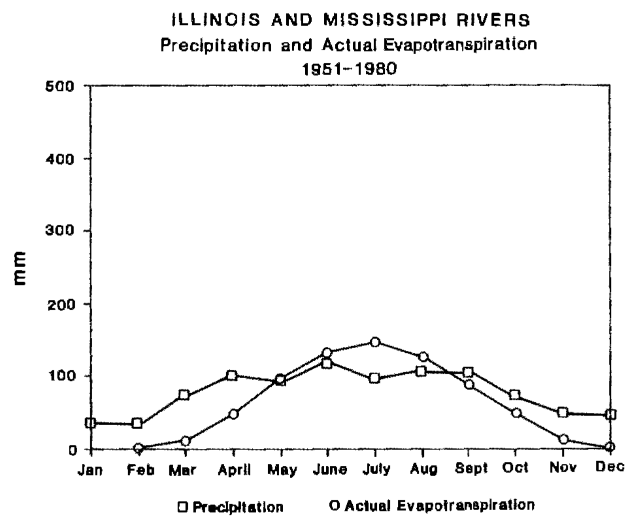

Fig. 6.5. Monthly water budget values at Illinois Rivers.

Table 6.1

Location information for Illinois rivers LTER and climatic sites.

SITE	LAT (Deg, min)		LONG (Deg, min)		ELEV (asl in m)
	North		West		
Pool 19	40	25	91	14	154
Pool 26	38	58	90	27	131
Peoria Pool	40	40	89	41	198
LaHarpe	40	35	90	58	213
Monmouth	40	55	90	38	235

Table 6.2

SUMMARY STATISTICS ILLINOIS RIVERS

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	-5.70	-2.70	3.20	10.90	16.80	21.80	24.00	22.70	18.50	12.50	4.40	-2.10
An Mean	10.36	St Dev	0.67									
Mean Mx T	-0.40	2.70	8.90	17.40	23.40	28.30	30.50	29.20	25.40	19.30	10.10	2.80
Mean Mi T	-11.00	-8.00	-2.60	4.40	10.10	15.40	17.60	16.20	11.70	5.70	-1.30	-7.10
Mean Temp Warmest Month			24.00	St Dev	1.24							
Mean Temp Coldest Month			-5.70	St Dev	2.72							
Annual Range of Monthly Mean Temps				29.70								
Num months with mean temp >0				9								
Num months with mean temp >15				5								
Highest monthly mean				27.34								
Lowest monthly mean				-12.23								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	35.6	36.2	73.5	100.4	94.6	118.3	98.6	107.3	105.9	75.2	51.0	48.0
Mean annual total		944.6										
Wettest year in period			1300									
Driest year in period			603									

Monthly totals during wettest year in period — Year 1973

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
67	48	98	160	178	87	164	66	130	149	58	95

Monthly totals during driest year in period — Year 1963

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
11	15	89	53	66	13	132	77	42	14	69	22

Total precip in months with temp >0	825

Table 6.3

EXTRA SUMMARY STATISTICS ILLINOIS RIVERS

EXTREME MONTHLY MEAN TEMPERATURES IN PERIOD 1951 - 1980
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Max	-1.60	3.60	7.90	14.10	23.00	24.60	26.60	25.20	20.80	18.60	8.40	3.90
Year	1967	1954	1973	1977	1962	1952	1955	1980	1960	1963	1964	1965
Min	-12.50	-9.20	-5.50	8.00	13.90	19.60	21.50	20.00	15.30	8.70	0.50	-8.90
Year	1977	1978	1960	1975	1954	1955	1971	1967	1974	1976	1959	1963

SOIL MOISTURE IN UPPERMOST METER (at Momouth Ill. June 1981 to June 1986) cm.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Max	41.0	41.0	43.0	42.0	40.5	39.0	39.0	38.0	40.0	42.0	39.0	40.5
Min	39.0	40.0	39.0	31.0	29.5	29.0	28.5	27.5	29.0	31.0	39.0	37.0
Median	40.0	40.5	40.5	38.5	35.0	32.0	33.0	34.0	36.0	37.0	39.0	38.0

MEAN MONTHLY VAPOR PRESSURE (mb)

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
4.9	5.2	7.9	12.2	16.5	21.8	23.8	22.6	17.8	12.4	8.5	6.0

WIND (for St Louis. Mo)

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Prevailing Direction	NW	NW	WNW	WNW	S	S	S	S	S	S	S	WNW
Velocity (m/sec)	4.6	4.8	5.3	5.1	4.2	3.9	3.5	3.4	3.5	3.9	4.4	4.6

GLOBAL RADIATION (interpolated for the area) MJ/sq.m/day

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
6.58	9.71	13.17	17.37	20.89	23.62	23.56	20.72	16.18	11.92	7.38	5.39

Mean annual total 5,388.42 MJ/sq.m.

Table 6.4

WATER BALANCE DATA FOR ILLINOIS RIVERS

Water budget for Latitude 40.6 N, Longitude 91.0 W
Field capacity 400.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	-5.7	0	0	36	0	400	0	0	0	0	0	84
Feb	-2.7	0	0	36	0	400	0	0	0	0	0	120
Mar	3.2	8	9	74	65	400	0	9	0	185	120	0
Apr	10.9	42	47	100	54	400	0	47	0	54	0	0
May	16.8	74	92	95	2	400	0	92	0	2	0	0
Jun	21.8	104	131	118	-13	388	-12	131	0	0	0	0
Jul	24.0	118	150	99	-52	341	-47	146	5	0	0	0
Aug	22.7	110	130	107	-23	322	-19	126	4	0	0	0
Sep	18.5	84	87	106	19	341	19	87	0	0	0	0
Oct	12.5	50	48	75	28	369	28	48	0	0	0	0
Nov	4.4	13	11	51	40	400	31	11	0	9	0	0
Dec	-2.1	0	0	48	0	400	0	0	0	0	0	48
	Yearly Totals:		703	945				695	9	250		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON Month of the year
TEMP Mean monthly air temperature in deg. C.
UPE Unadjusted potential evapotranspiration
APE Adjusted potential evapotranspiration
PREC Precipitation
DIFF PREC minus APE
ST Soil moisture storage
DST Change in storage from preceeding month
AE Actual evapotranspiration
DEF Soil moisture deficit
SURP Soil moisture surplus
SMT Snowmelt
SST Water equivalent held in snowpack.

CHAPTER 7

JORNADA, NEW MEXICO

David Greenland

SITE DESCRIPTION

The Jornada LTER site is a watershed of 580 ha located on the much larger USDA Jornada Experimental Range-New Mexico State University Ranch rangeland research complex. It is representative of a desert biome. The area is some 50 km north west of Las Cruces, New Mexico. The experimental site consists of two transects running from the foot of the Dona Ana mountains at 1501 m elevation for several kilometers to a playa at 1318 m elevation (Fig. 7.1 and 7.2). Apart from the grade along the transect and the abrupt rise of the mountain at the southern end, there are no marked topographical features. The transect does, however, pass through several distinct desert plant communities.

Data for this chapter were extracted from National Weather Service Data (NWS) summaries. These summaries did not have separate maximum and minimum temperatures for the year 1951. Consequently the averages for maximum and minimum temperature values in Table 7.1 are 29 year averages instead of 30 year averages. No great error should be caused by this since the annual mean temperature for 1951 of 15.49 deg. C. is not far removed from the 30 year average of 14.58 deg. C. The NWS record contained a few missing temperature values. The long term mean values was substituted for these missing values.

VEGETATION

The main plant communities include playa grassland, swale shrubland, basin grassland, bajada shrubland, piedmont grassland, and mountain shrubland. The first five of these communities are dominated respectively by vine-mesquite grass *(Panicum obtusum)*, mesquite*(Prosopis glandulosa)*, fluffgrass, creosote bush *(Larrea tridentata)*, and black grama *(Bouteloua eripoda)*. Other common species include yucca *(Yucca elata)* and fourwing saltbush *(Atriplex canescens)*.

SYNOPTIC CLIMATOLOGY

The relatively low latitude of this site brings it generally under high surface atmospheric pressure. It also finds itself under the influence of easterly winds during most months with surface level airstreams having passed over the Gulf of Mexico. However the site is in the rain shadow of both the San Andres mountains to the east and, for westerly flows, the Black Range and other ranges of the southern part of the western cordillera. Despite this rain shadow effect, in summer the Gulf air can provide moisture for intense convectional thunderstorm activity. This is especially the case when moist Gulf air meets dry air from the Arizona desert. During winter a southerly Pacific airflow can penetrate to Jornada but it is generally limited to the area west of the southern Rockies. Also, although frontal and cyclonic activity is not frequent, it is possible in winter for the area to come under the influence of cold air masses from the north.

As a result of the synoptic influences the climate is characterized by high amounts of solar radiation, a wide diurnal temperature range, low relative humidities, and high potential rates of evaporation. Fifty two percent of the precipitation occurs between the months of July and September. Climatic data are presented in Table 7.2 and Figs. 7.3 and 7.4.

WATER BALANCE

The Jornada site has the least precipitation of all the LTER sites and because of the relatively high temperatures, clear skies, and low latitude location it displays the highest annual value for potential evapotranspiration (Table 7.2, Figs. 7.5. and 7.6). However, despite the fact that there is a summer maximum of precipitation, all of this precipitation is consumed in actual evapotranspiration. The latter is therefore restrained by the low values of the former. These monthly computations mask the fact that in the summer following convection storms there can be adequate soil moisture that might last for several days. Two plots of the water balance are provided. The first (Fig. 7.5) is scaled to be comparable to the diagrams for the other sites and clearly demonstrates both the lack of precipitation and the limited actual evapotranspiration. The second (Fig. 7.6) suggests the possibility of soil moisture utilization from March to May to sustain low actual evapotranspiration rates and, more importantly, illustrates how the - summer precipitation is consumed by actual evapotranspiration.

CLIMATIC PARAMETERS AFFECTING THE FLORA AND FAUNA

Extremes of moisture conditions affect the flora. The general dryness of the climate causes the xerophytic vegetation to adopt numerous strategies for water conservation. These strategies include long root systems, and waxy, impermeable skin surfaces. The existence of a caliche layer in the soil acts as a barrier to moisture loss, giving rise to long term moisture availability to plants during dry seasons (Conley and Conley, 1984:8). Water conservation methods by the flora are important in light of the five severe droughts that have occurred at the site in the last 100 years (Halfpenny and Ingraham, 1984). At the other extreme, occasionally a series of convectional storms can leave surface water in the playa. When this happens a number of species, not normally active, can take advantage of the moisture conditions and flourish for a short time.

The high diurnal temperature range (Fig. 7.3) and the high radiation loads during the day cause many of the fauna to be nocturnal in their feeding habits.

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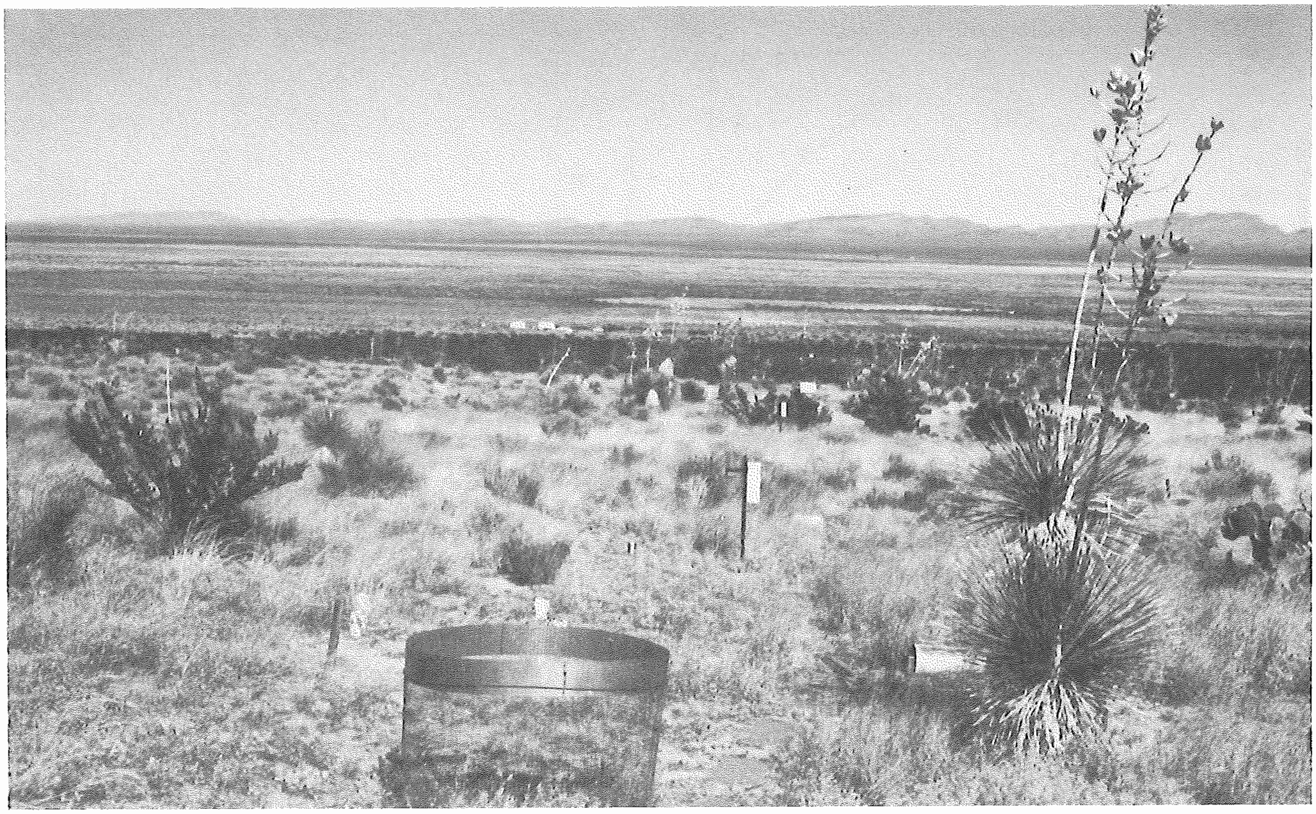

Fig. 7.1. The line of the transect at the Jornada site.

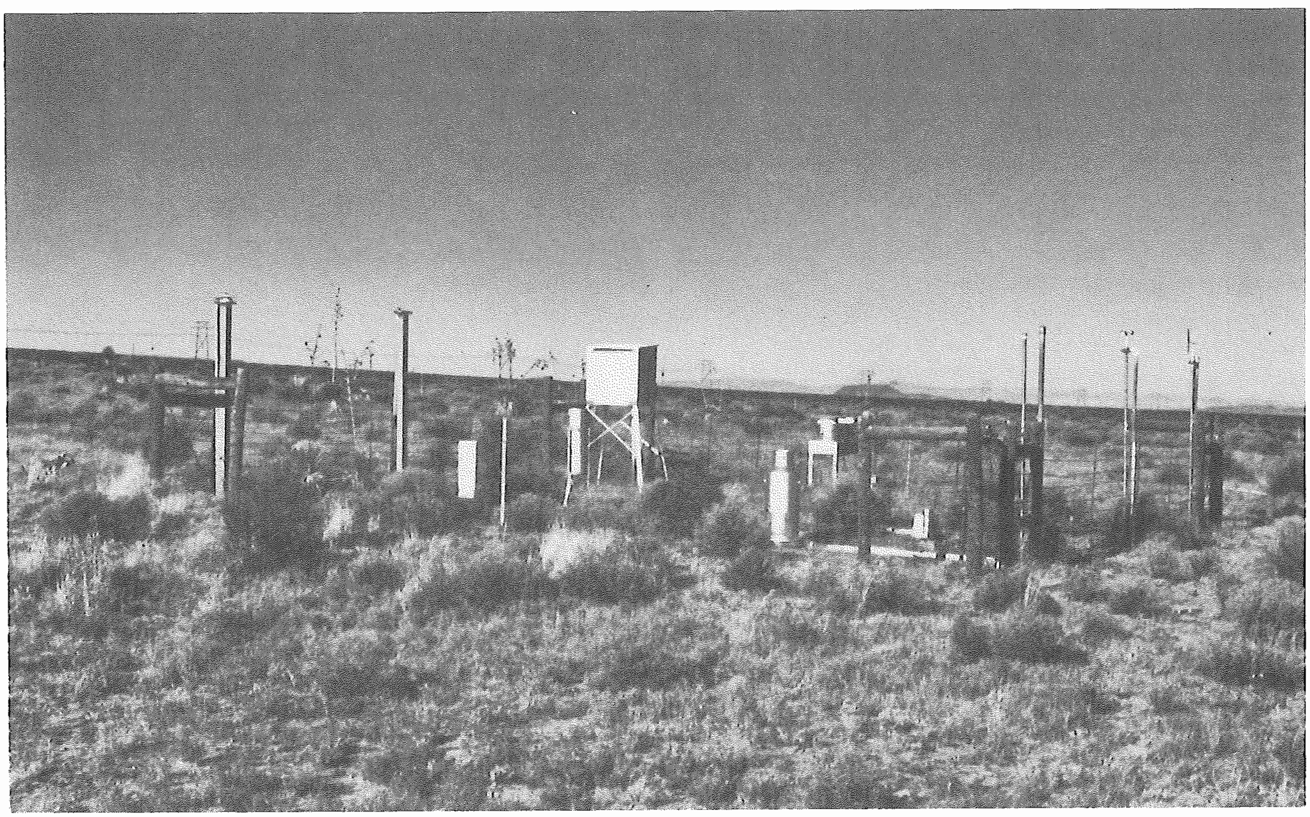

Fig. 7.2. The meteorological observing station at the Jornada site.

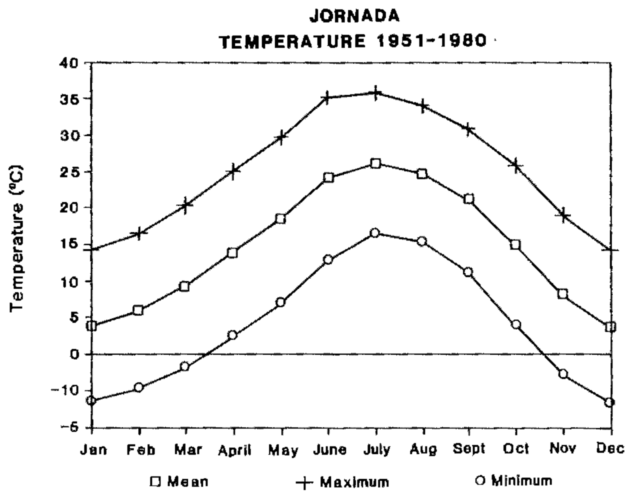

Fig. 7.3. Average annual temperature values at Jornada.

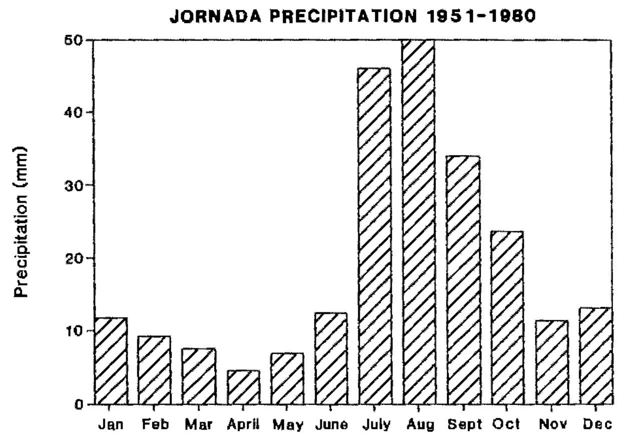

Fig. 7.4. Average annual precipitation totals at Jornada.

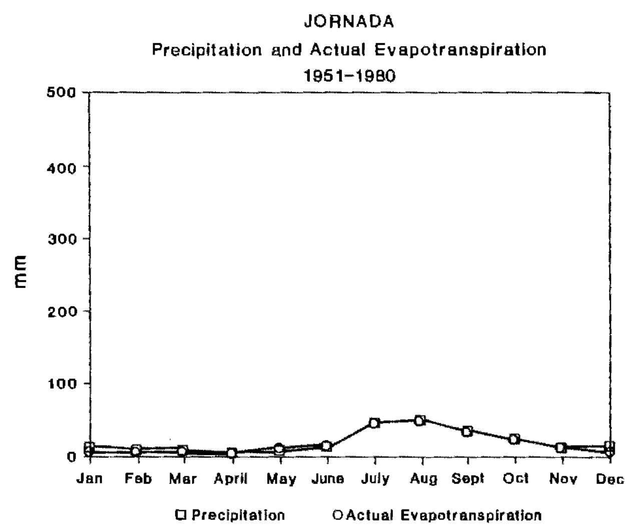

Fig. 7.5. Monthly water budget values at Jornada (scaled as other water budget diagrams).

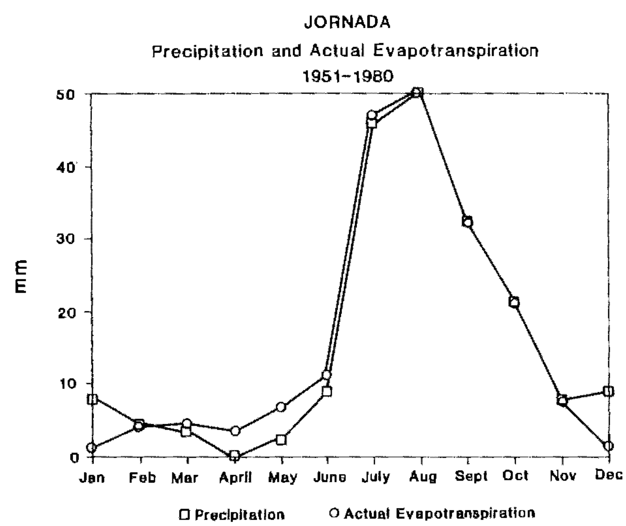

Fig. 7.6. Monthly water budget values at Jornada (scaled to local conditions).

Table 7.1

SUMMARY STATISTICS JORNADA EXPERIMENTAL RANGE

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	3.97	6.03	9.41	13.92	18.47	24.06	26.03	24.70	21.17	15.01	8.21	3.83
An Mean	14.58	St Dev	0.68									
Mean Mx T	14.35	16.64	20.48	25.18	29.78	35.23	35.70	33.98	30.96	25.84	19.13	14.12
Mean Mi T	-6.42	-4.55	-1.69	2.63	7.04	12.95	16.59	15.30	11.24	4.07	-2.70	-6.59
Mean Temp Warmest Month			26.33	St Dev	1.08							
Mean Temp Coldest Month			3.16	St Dev	1.34							
Annual Range of Monthly Mean Temps				22.20								
Num months with mean temp >0				12								
Num months with mean temp >15				6								
Highest monthly mean				28.63								
Lowest monthly mean				-0.06								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	11.9	9.2	7.5	4.5	6.9	12.5	46.1	49.8	34.1	23.8	11.6	13.4
Mean annual total		231.4										
Wettest year in period			413									
Driest year in period			91									

Monthly totals during wettest year in period — Year 1974

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
22	9	2	0	0	3	132	76	53	87	9	21

Monthly totals during driest year in period — Year 1953

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
0	17	7	8	0	13	20	2	0	11	12	1

Total precip in months with temp >0: 413

Table 7.2

WATER BALANCE FOR JORNADA

Water budget for Latitude 32.5 N, Longitude 106.8 W
Field capacity 150.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	3.8	7	6	12	6	14	6	6	0	0	0	0
Feb	6.0	13	11	9	-2	14	0	9	2	0	0	0
Mar	9.4	27	27	8	-20	12	-2	9	18	0	0	0
Apr	13.9	49	53	5	-49	9	-3	8	45	0	0	0
May	18.5	77	91	7	-84	5	-4	11	81	0	0	0
Jun	24.1	116	138	13	-125	2	-3	15	122	0	0	0
Jul	26.0	130	158	46	-112	1	-1	47	110	0	0	0
Aug	24.7	120	138	50	-88	1	0	50	87	0	0	0
Sep	21.2	95	97	34	-63	0	0	34	63	0	0	0
Oct	15.0	55	54	24	-30	0	0	24	30	0	0	0
Nov	8.2	22	19	12	-7	0	0	12	7	0	0	0
Dec	3.8	7	6	13	8	8	8	6	0	0	0	0
	Yearly Totals:		797	231				231	566	0		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 8

KONZA PRAIRIE RESEARCH NATURAL AREA, KANSAS

Dean Bark

SITE DESCRIPTION

Konza Prairie Research Natural Area, dominated by native tallgrass prairie, is a 3487 ha site located approximately 11 km south of Manhattan, Kansas (Fig. 8.1). As part of the Flint Hills region, this site is a dissected upland with hard chert- and flint-bearing limestone layers exposed on steep-sided hills. Elevations on Konza range from 320 to 444 m. The ridges are characteristically flat with shallow rocky soils, whereas the larger and wider valleys have deep permeable soils. The weather station, which is accessible through the year, is located in the northwest corner of the Konza Prairie approximately 100 m below the ridge tops (Fig. 8.2). This permanent station is equipped with a Campbell Scientific data logger and National Atmospheric Deposition Program collection devices. The close proximity of Konza prairie to Manhattan and Kansas State University allows the large weather data bank of the Kansas Experiment Station to be used to describe any long term climatic changes which may have taken place since 1891.

VEGETATION

Most of Konza Prairie is dominated (greater than 90%) by native prairie grasses, forbs, and shrubs. The dominant plant species on most soils are big bluestem *(Andropogon geradii,* indiangrass *(Sorghastrum nutans)* and little bluestem *(A. scoparius)* Switchgrass *(Panicum virgatum)* is locally abundant. Six percent of Konza Prairie is forested by trees lining intermittent to permanent reaches of streams. These riparian forests are dominated by bur oak *(Quercus macrocarpa)*, hackberry *(Celtis occidentalis)* and chinquapin oak *(Q. muehlenbergii)*. For the entire site, over 440 species of vascular plants have been identified. A account of the vascular plants is given by Freeman and Hulbert (1985).

SYNOPTIC CLIMATOLOGY

Kansas, located halfway between the poles and the equator, is in that part of the global circulation dominated by major cyclones and anticyclones that drift slowly eastward across the continent. The path followed by these pressure systems is largely determined by the jet stream which is strongest in the winter season and positioned farther south. It weakens and shifts northward in summer. As a consequence, the weather fronts associated with the low pressure systems are strongest and slower moving in winter. In summer, contrasts between warm and cold air masses are small; fronts are weak and their movement is more rapid. Precipitation in winter is slow and steady, often lasting days. On the other hand, summer rainfall occurs from strong thunderstorms that are not always associated with fronts. These storms produce heavy showers of short duration accompanied by lightning and strong wind gusts.

Kansas is located in the center of a very large landmass far from the thermal moderating influences of the oceans. Thus in the winter, cold air arriving from the north over frozen — often snow-covered — ground is modified little before it reaches this latitude. Similarly, warm air moving northwards in the summer remains warm, or becomes warmer as it moves over dry ground heated by intense daytime solar radiation. All mid-continental regions are characterized by large temperature extremes. In Manhattan the average date of the last freeze is 23 April, and the first in fall is 16 October, providing a freeze-free period of 176 days on the average.

The great distances from the oceans also play a role in the amount and timing of the precipitation received. Since evaporation from oceans is the source of much of the precipitation over land areas, it is not surprising that mid-continental areas are dryer than coastal areas. Not only is Kansas located far from such sources of moisture, but it is just downwind from the Rocky Mountain chain. Since the general movement of storms is from the west, the moisture laden winds from the Pacific Ocean must pass over these mountains before reaching Kansas. This orographic lifting produces precipitation on the west sides of the mountains and little moisture is left when they reach Kansas. For that reason, winter months are relatively dry.

In spring and summer, as the sun moves northward, so does the path of the migratory cyclones and anticyclones. At this time, circulation in Kansas is more influenced by the sub-tropical high pressure center in the Atlantic Ocean. The clockwise circulation is such that southerly winds sweep large quantities of moisture into Kansas from the Gulf of Mexico. The surface warms as the season progresses making the atmosphere very unstable. Such instability often triggers thunderstorms. These storms are very restricted in areal extent and time of duration, but they can spawn intense precipitation. Heavy storms can often produce 25 to 125 mm of rain in a few hours. Unfortunately, it is not uncommon for these heavy rains to be followed by dry periods of several weeks duration. Such dry spells are common during the mid-summer growing periods. Since the source of moisture for most of the precipitation that occurs in Kansas is the Gulf, it follows that that part of the state farthest from the Gulf receives the least precipitation. Annually, southeast Kansas receives more than 1000 mm, while locations along the western border receive 380 mm or less. Manhattan receives over 800 mm a year, 75 percent of it during April to September.

The thunderstorms that provide moisture can sometimes be severe. At those times damaging wind and crop destroying hail can occur. Fortunately these are also localized and do not affect large areas at any given occurrence. However, they are frequent enough to have a significant effect on plant production in the state.

Climate data are presented in Table 8.1 and Figs. 8.3 and 8.4.

WATER BALANCE

Precipitation exceeds actual evapotranspiration for most of the year except for summer (Table 8.2. Fig. 8.5). During the summer the reverse is true but for much of the time soil moisture can be used to sustain the actual evapotranspiration rates. Consequently, there is only a small soil moisture deficit during the summer and a small surplus during the spring at the Konza Prairie.

CLIMATIC FACTORS AFFECTING FLORA AND FLORA

Tallgrass prairie results from the dynamic interaction of the plants, animals, soil, climate, and fire. Precipitation is sufficient in most years such that, without fire, trees grow well in lowlands, while trees invade slowly on shallow upland soils and are killed by severe droughts. Frequent burning kills shrubs and trees, but not prairie grasses. These grasses are well adapted to survive grazing, fire and drought but severe water stress occurs on average once every ten growing seasons and can have a detrimental effect on the grasses. While soil type and burning frequency control the distribution of many of the plant species, year to year climatic variation has an important effect on the abundance and production of vegetation.

NOTES ON THE CLIMATE DATA FOR KONZA PRAIRIE

The climate record at Konza Prairie itself is too short for developing a climatography of 30 years' data. The data for Tables 8.1 and 8.2 and Figs. 8.3, 8.4, and 8.5 are from the Manhattan station, which is a Cooperative Station of the National Weather Service. This station was started in May 1858 and should be representative of the climate on the Konza Prairie which is located 8 to 16 km away.

Regression equations between data values at the two sites are as follows (where Y = Konza and X = Manhattan):

Mean monthly temperature:

$Y = -0.7580 + 1.0028\,X$

r squared = 0.9978

Data points for May 1982 to March 1985

Number of data points (month's data) n = 35.

Monthly total precipitation:

$Y = 5.3342 + 0.81850\,X$

r squared = 0.8529

Data points for April 1982 to November 1985

Number of data points (month's data) n = 24.

Literature Cited

Freeman, C. C., and L, C. Hulbert. 1985. An annotated list of the vascular flora of Konza Prairie Research Natural Area, Kansas. *Transactions of the Kansas Academy of Science.* 88(3-4):84-115.

Fig. 8.1. General view of part of the Konza Prairie.

Fig. 8.2. The weather station at Konza Prairie.

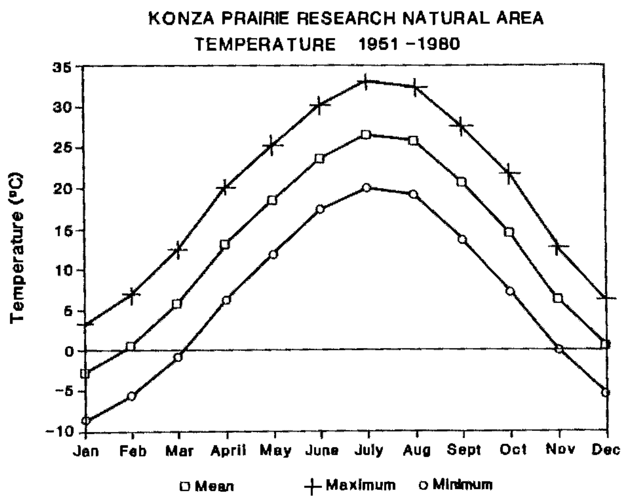

Fig. 8.3. Average annual temperature values at Konza Prairie.

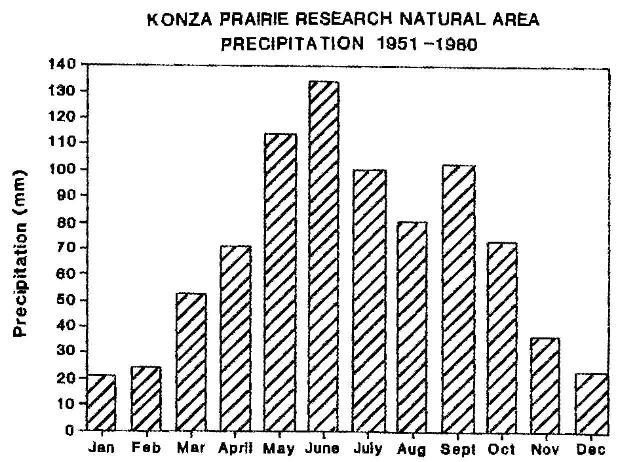

Fig. 8.4. Average annual precipitation totals at Konza Prairie.

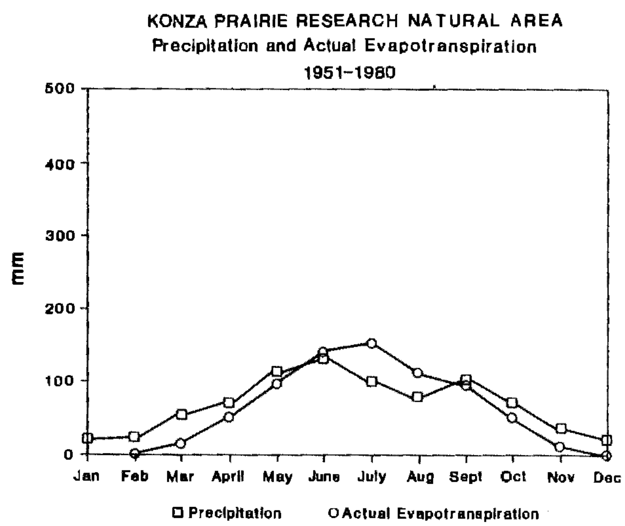

Fig. 8.5. Monthly water budget values at Konza Prairie.

Table 8.1

SUMMARY STATISTICS KONZA PRAIRIE

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	-2.70	0.60	5.80	13.10	18.60	23.70	26.60	25.80	20.70	14.50	6.30	0.40
An Mean	12.80	St Dev	0.70									
Mean Mx T	3.20	6.90	12.50	20.00	25.20	30.10	33.20	32.50	27.60	21.70	12.60	6.20
Mean Mi T	-8.60	-5.60	-0.80	6.20	11.90	17.40	20.00	19.10	13.80	7.30	0.00	-5.40
Mean Temp Warmest Month			26.60	St Dev	1.80							
Mean Temp Coldest Month			-2.70	St Dev	2.50							
Annual Range of Monthly Mean Temps				29.30								
Num months with mean temp >0				11								
Num months with mean temp >15				5								
Highest monthly mean				31.00								
Lowest monthly mean				-9.40								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	21.1	24.2	52.8	70.9	114.3	134.2	100.6	80.7	102.6	73.4	37.0	23.0
Mean annual total		834.9										
Wettest year in period			1534									
Driest year in period			392									

Monthly totals during wettest year in period				Year		1951					
Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
14	37	70	70	261	282	389	161	156	69	16	10

Monthly totals during driest year in period				Year		1966					
Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
18	17	2	53	48	44	60	91	15	20	2	23

Total precip in months with temp >0 814

Table 8.2

WATER BALANCE FOR KONZA

Water budget for Latitude 39.1 N, Longitude 96.6 W
Field capacity 150.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	-2.7	0	0	21	0	130	0	0	0	0	0	21
Feb	-0.6	0	0	24	24	140	10	0	0	35	21	0
Mar	5.8	14	14	53	38	150	10	14	0	28	0	0
Apr	13.1	47	52	71	19	150	0	52	0	19	0	0
May	18.6	79	98	114	16	150	0	98	0	16	0	0
Jun	23.7	114	141	134	-7	143	-7	141	0	0	0	0
Jul	26.6	136	171	101	-71	89	-54	155	17	0	0	0
Aug	25.8	129	152	81	-71	55	-34	114	37	0	0	0
Sep	20.7	93	96	103	7	62	7	96	0	0	0	0
Oct	14.5	55	52	73	21	83	21	52	0	0	0	0
Nov	6.3	16	13	37	24	107	24	13	0	0	0	0
Dec	0.4	0	0	23	23	130	23	0	0	0	0	0
Yearly Totals:			790	835				736	54	98		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 9

NIWOT RIDGE / GREEN LAKES VALLEY, COLORADO

David Greenland

SITE DESCRIPTION

The Niwot Ridge/Green Lakes Valley site is an alpine tundra site (Fig. 9.1). Its major components are the ridge itself which stretches eastwards from the continental divide and the glaciated Green Lakes Valley to the south. The complete site varies in elevation from just above the treeline at approximately 3500 m to about 4000 m. Both on the ridge and in the valley there are many distinct topoclimates associated with such factors as saddles and knolls, moraines and other glacial and periglacial features, semipermanent snowbanks, and permanent ice and lakes.

The climate data reported below (Table 9.1) are taken from the D1 site which is one of the highest, relatively accessible, locations on the ridge at 3750 m. It is located in a very exposed position over alpine tundra vegetation about 100 m from a point where the tundra merges into bare rock surfaces of the higher elevations. Missing data for 1951 and the first part of 1952 and a few other months are simulated using records from Allenspark (15 km to the north) and from other stations at the site. At, or near the LTER site, climate data for 30 years are available from other stations at 2200, 2500, and 3048 m, and at seven other stations for the LTER period. The D1 site has not been moved during the period of record, but a major discontinuity in the winter precipitation record occurred in 1964 when the pecipitation gage was first properly shielded. Adjustments to the earlier years of the record have been made to allow for this. Several other climate recording sites were established for the LTER program. The Saddle site (Fig. 9.2) is at 3536 m and is the site of much of the LTER and other work on the alpine tundra of Niwot Ridge itself. The climatic data in this chapter are derived from a variety of sources which have been reviewed by Greenland (1987). In particular the current site climatologist, Mr Mark Losleben, was very helpful in providing much of the data.

VEGETATION

Above the treeline the vegetation is dominated by herbaceous dicotyledons and lichens. The main plant communities are classified as dry fellfield tundra, dry and moist tundra, moist tundra, wet tundra, shrub tundra, moist shrub tundra, and snowbed and scree vegetation. Some of the most common species include *Silene acaulis, Kobresia myosuroides, Sibbaldia procumbens, Salix planifolia, Acomastylis rossii,* and *Caltha leptosepala*.

SYNOPTIC CLIMATOLOGY

The synoptic climatology of the Niwot Ridge/Green Lakes Valley site is controlled by the mid-latitude, continental location and by the elevational and topographical situation. The high elevation gives rise to very low air temperatures at all times of the year. Air temperatures are effectively further depressed by high velocities of the wind passing over snow and ice surfaces of the higher elevations. The mid-continental location leads to a large temperature range between summer and winter but this large range is more marked at the lower elevations. Precipitation carrying storms are brought over the site in the winter and spring by the upper westerly air flow. In these seasons, snow is brought from the west, at the higher elevations. It is also brought from the east, at the lower elevations by cyclonic easterly, upslope flow developing to the east of the divide. These storms are responsible for the spring maximum of precipitation. In the summer, rainfall is produced from localized convectional storms. Fall is the driest season. Climate data are presented in Table 9.1 and Figs. 9.3 and 9.4.

WATER BALANCE

The water balance (Table 9.2, Fig. 9.5) at this site is interesting for the very short growing season apparent in the fact that the actual evapotranspiration only occurs during the four summer months. Towards the end of the summer there is the possibility of some soil moisture deficit. However, a significant feature of the water balance is the snow-melt period from May to July when a large amount of water is released from the snowpack. The amount released is probably smaller than that indicated by the computations in Table 9.2 because much of the winter snow is blown from the ridge by high winds.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

Low temperatures and a short growing season, high winds, and the presence or absence of snowpack strongly affect the flora and fauna of this site. Much of the flora protects itself from the extreme thermal conditions by having a large proportion of its biomass under the ground. Plants grow quickly especially at the beginning of the short growing season. Their variations in type and productivity tend to be related to marked soil moisture gradients which, in turn, are related to the location of semi- permanent snowbanks. Many of the fauna take advantage of protection under the snowpack or the rocks of fellfields. Life in the aquatic systems is influenced by the presence of surface ice in the winter and by the pronounced flushing during the late spring melt period.

Literature Cited

Greenland, D. 1987. The Climate of Niwot Ridge. *Long-Term Ecological Research Data Report.* Institute of Arctic and Alpine Research. University of Colorado.(In press.)

Fig. 9.1 General view of the Niwot Ridge/Green Lakes Valley site looking northwest.

Fig. 9.2. The Saddle recording site on Niwot Ridge.

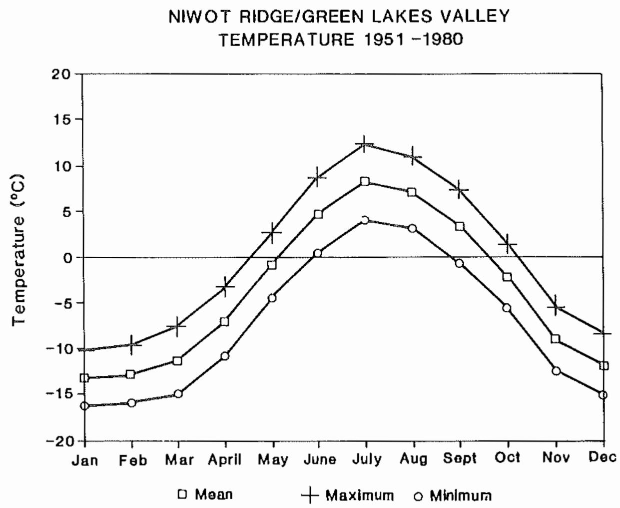

Fig. 9.3. Average annual temperature values at Niwot Ridge.

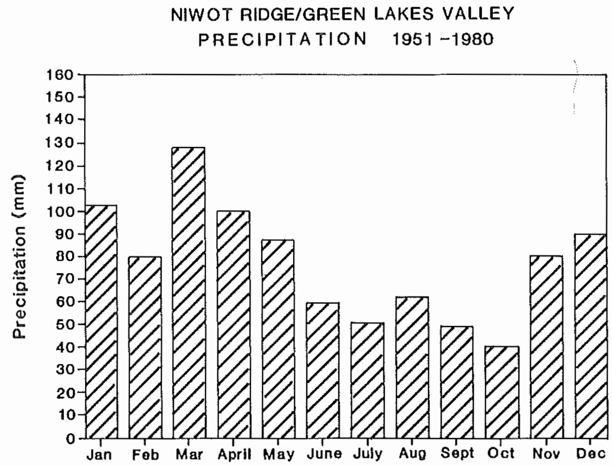

Fig. 9.4. Average annual precipitation totals at Niwot Ridge.

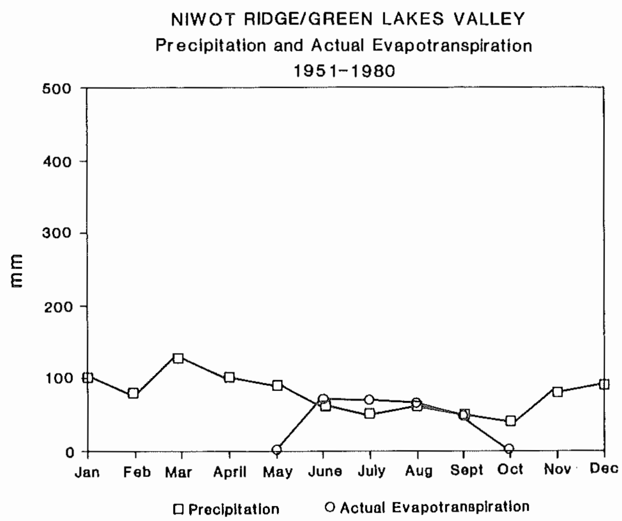

Fig. 9.5. Monthly water budget values at Niwot Ridge.

Table 9.1

SUMMARY STATISTICS NIWOT RIDGE (D1)

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	-13.15	-12.77	-11.23	-7.01	-0.86	4.60	8.23	7.06	3.39	-2.13	-8.94	-11.77
An Mean	-3.71	St Dev	0.64									
Mean Mx T	-10.09	-9.61	-7.60	-3.32	2.68	8.74	12.43	11.00	7.35	1.34	-5.39	-8.46
Mean Mi T	-16.21	-15.94	-14.86	-10.70	-4.40	0.46	4.03	3.11	-0.57	-5.59	-12.50	-15.07

Mean Temp Warmest Month	8.23	St Dev	0.88
Mean Temp Coldest Month	-13.15	St Dev	1.35
Annual Range of Monthly Mean Temps		21.38	
Num months with mean temp >0		4	
Num months with mean temp >15		0	
Highest monthly mean		10.48	
Lowest monthly mean		-17.58	

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	102.5	80.1	127.8	100.1	87.5	59.5	50.5	62.1	49.1	40.3	80.3	90.1

Mean annual total	930.0	
Wettest year in period		1427
Driest year in period		541

Monthly totals during wettest year in period — Year 1974

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
209	121	235	220	45	100	96	12	49	104	79	157

Monthly totals during driest year in period — Year 1954

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
22	20	54	52	71	16	61	48	64	35	55	43

Total precip in months with temp >0 221

Table 9.2

WATER BUDGET FOR NIWOT RIDGE (STATION D1)

Water budget for Latitude 40.0 N, Longitude105.0 W
Field capacity 100.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	-13.2	0	0	103	0	15	0	0	0	0	0	313
Feb	-12.8	0	0	80	0	15	0	0	0	0	0	393
Mar	-11.2	0	0	128	0	15	0	0	0	0	0	521
Apr	-7.0	0	0	100	0	15	0	0	0	0	0	621
May	-0.9	0	0	88	88	15	0	0	0	90	3	618
Jun	4.6	57	71	60	-11	15	0	71	0	445	456	163
Jul	8.2	79	100	51	-50	19	3	71	29	139	163	0
Aug	7.1	73	86	62	-24	15	-4	66	20	0	0	0
Sep	3.4	47	49	49	0	15	0	49	0	0	0	0
Oct	-2.1	0	0	40	0	15	0	0	0	0	0	40
Nov	-8.9	0	0	80	0	15	0	0	0	0	0	121
Dec	-11.8	0	0	90	0	15	0	0	0	0	0	211
	Yearly Totals:		306	930				257	49	674		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 10

NORTH INLET, SOUTH CAROLINA

William Michener and Bjorn Kjerfve

SITE DESCRIPTION

The North Inlet marsh-estuarine system is located along the northeast-southwest oriented coastline, 70 km northeast of Charleston, South Carolina on Hobcaw Barony (a 7085 ha tract of maritime forest). The primary research areas are a 2,630 ha high-salinity *Spartina alterniflora* marsh and 715 ha estuarine zone which are separated from the Atlantic Ocean by sandy barrier islands and bordered on the west by loblolly and long leaf pine forests (Fig 10.1). Hydrographic characteristics include a salinity range of 30-34 parts per thousand, average channel depth of 3 m, and a seasonal water temperature range of 3 to 33 deg. C. Wetland habitats include exposed and sheltered sandy beaches; intertidal mudflats and oyster beds; submerged macroalgal mats; sand shell and mud benthic habitats; rock jetties; and bird rookery islands. More than 1200 ha of brackish and freshwater marshes border the Winyah Bay side of Hobcaw Barony.

The North Inlet estuarine system experiences a semidiurnal tidal regime with a mean range of 1.5 m. The maximum observed range is 2.5 m, mean spring tidal range 1.8 m, and mean neap tide range 1.0 m. Associated peak tidal currents typically reach 1.3 m/s but have been recorded as high as 2.2 m/s. The tidal form number (Defant, 1960) measures 0.25. Harmonic analysis of the tidal water level records from 1978-81 indicated that M_2 was the dominant constituent tide (Table 10.1). The annual sea level constituent, Sa, has an amplitude of 0.1 m and reaches a high in September.

VEGETATION

The portion of the marsh which is exposed to tidal water is dominated by saltmarsh cordgrass *(Spartina alterniflora)*. Marsh areas slightly higher in elevation are vegetated by big cordgrass *(Spartina cynosuroides)* and black needle rush *(Juncus roemerianus)*. High marsh flats and areas adjacent to the forest edge are characterized by salt meadow hay *(Spartina patens)*, Salicornia spp., and several other species. A transitional shrub community is comprised of marsh elder *(Iva frutescens)* and southern red cedar *(Juniperus silicola)*. The adjacent maritime forest is dominated by loblolly pine *(Pinus taedo)* and live oak *(Quercus virginica)*.

SYNOPTIC CLIMATOLOGY

The climatology of the North Inlet site is controlled by the low elevation and the coastal location. The climate is temperate to subtropical. Temperatures are modulated due to the proximity of the Atlantic Ocean and the Gulf Stream giving rise to both relatively lower temperature maxima and relatively higher temperature minima than would be found farther inland. Tropical storms or hurricanes impact the South Carolina coast approximately once every 2.6 years (Gentry, 1971) and can be responsible for 10-15 percent of the total annual precipitation at North Inlet (Cry, 1967).

Since 3 June 1982 climatic and hydrographic data have been measured from a meteorological tower (elevation 10 m) which is located at an exposed site above the North Inlet marsh and creeks (Fig 10.2), approximately 1 km from the nearest forest habitat. During the period 1970 through the present, standard meteorological data have been collected at a site located 4 km from the University of South Carolina field laboratory, within the maritime coastal forest. In addition, limited climatic data have been collected in nearby Georgetown, South Carolina since 1935. Summary statistics for Georgetown climatic data are used to prepare Table 10.2 and Figs 10.3 and 10.4. These statistics were calculated by the National Climatic Data Center and represent the 1951-80 normals.

WATER BALANCE

The water balance of the terrestrial areas of this site (Table 10.3 and Fig. 10.5) displays one of the highest amounts of actual evapotranspiration of all LTER sites. This is due to the presence of adequate amounts of precipitation throughout the year and the high temperatures especially in the summer. Consequently there is virtually no soil water deficit at any time. However, there is a soil moisture surplus in the cooler months of the year and this surplus usually takes the form of runoff.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

Mild temperatures, high humidity, and long growing season affect the flora and fauna of the North Inlet site. Controlling factors include timing of spring and fall freezes (generally March or April and November) and aperiodic high rainfall events. Aquatic flora and fauna are affected by storm-induced flushing events, which temporarily can lower the salinity drastically. In general, however, the back and forth oscillatory movement of saline estuarine waters as a result of tidal action is the main regulatory factor in vegetation zonation within the marsh environment.

Literature Cited

Cry, G.W. 1967. Effects of tropical cyclone rainfall on the distribution of precipitation over the eastern and southern United States. *U.S. Environmental Sciences Services Administration. Professional paper* No. 1. Ashville, N.C. 67 pp.

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Gentry, R. C. 1971. Hurricane, One of the major features of air-sea interaction in the Caribbean Sea. *In: Symposium on Investigations and Resources of the Caribbean and Adjacent Regions.* UNESCO, Paris.

Fig. 10.1. General view of the laboratory and surrounding area at the North Inlet Site.

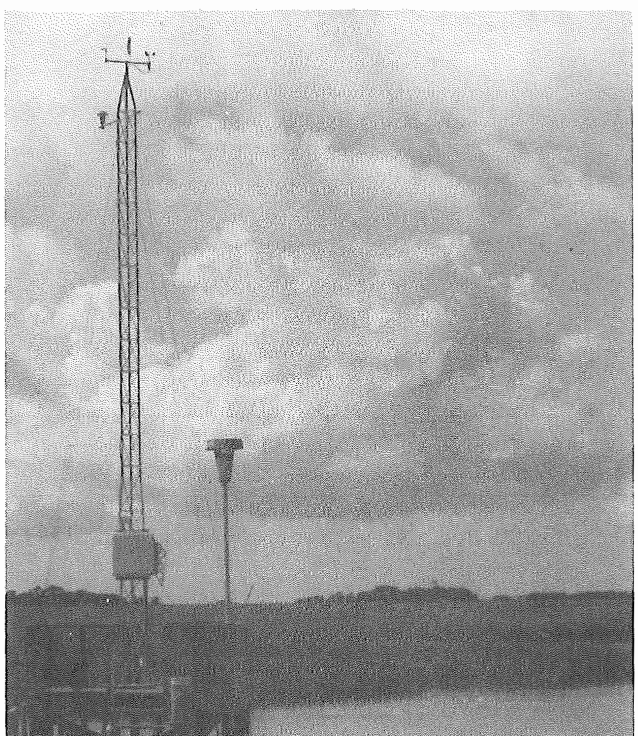

Fig. 10.2. The climate recording site at North Inlet.

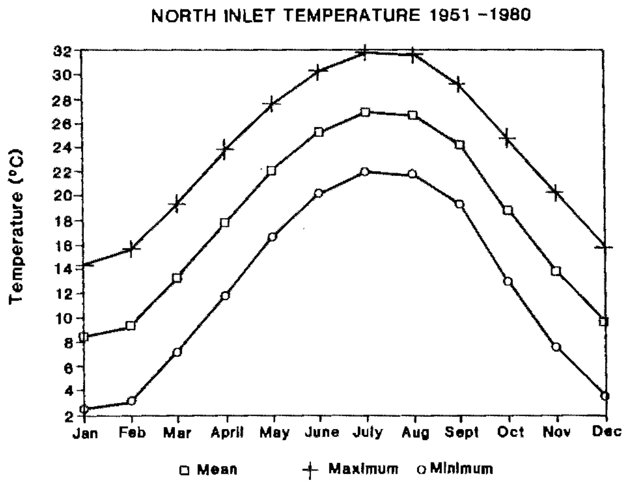

Fig. 10.3. Average annual temperature values at North Inlet.

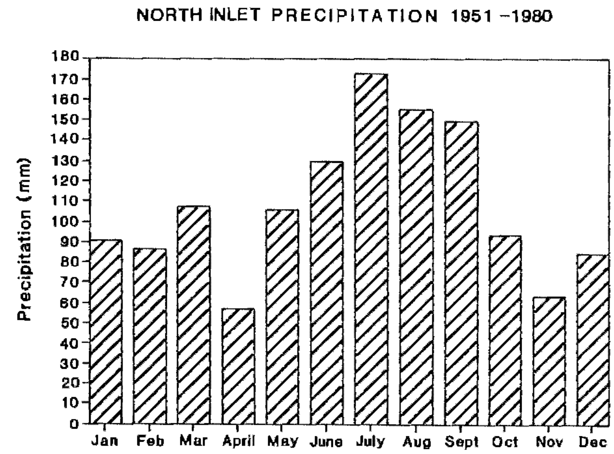

Fig. 10.4. Average annual precipitation totals at North Inlet.

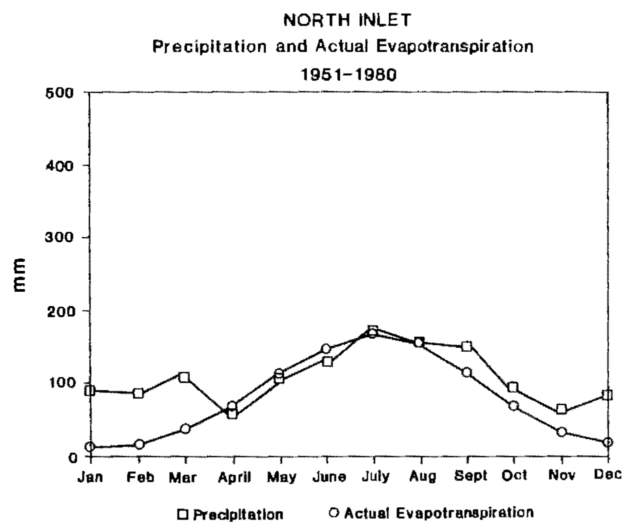

Fig. 10.5. Monthly water budget values at North Inlet.

Table 10.1

The main tidal constiuents based on harmonic analysis of a 3 year North Inlet water level record.

Constituent		Amplitude (cm)	Epoch (G deg.)	Period
Solar annual	Sa	10	186	365 d
Principal lunar diurnal	O_1	8	189	25.8 h
Luni-solar-diurnal	K_1	10	199	23.9 h
Principal lunar semidiurnal	M_2	62	352	12.4 h
Principal solar semidiurnal	S_2	9	24	12 h

Table 10.2

SUMMARY STATISTICS NORTH INLET

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	8.44	9.39	13.28	17.83	22.11	25.28	26.94	26.72	24.22	18.83	13.89	9.67
An Mean	18.06	St Dev										
Mean Mx T	14.33	15.56	19.28	23.83	27.61	30.33	31.78	31.67	29.17	24.72	20.22	15.89
Mean Mi T	2.56	3.17	7.22	11.83	16.67	20.17	22.06	21.78	19.28	12.89	7.50	3.50
Mean Temp Warmest Month			26.94	St Dev								
Mean Temp Coldest Month			8.44	St Dev								
Annual Range of Monthly Mean Temps				18.50								
Num months with mean temp >0				12								
Num months with mean temp >15				7								
Highest monthly mean												
Lowest monthly mean												

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	90.7	86.4	107.4	56.9	106.4	129.8	173.2	156.0	150.0	94.2	64.0	85.1
Mean annual total		1300.0										
Wettest year in period												
Driest year in period												

Monthly totals during wettest year in period — Year

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec

Monthly totals during driest year in period — Year

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec

Total precip in months with temp >0 1300

Table 10.3

WATER BALANCE FOR NORTH INLET

Water budget for Latitude 33.5 N, Longitude 79.2 W
Field capacity 500.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	8.4	15	13	91	78	500	0	13	0	78	0	0
Feb	9.4	18	15	86	71	500	0	15	0	71	0	0
Mar	13.3	35	36	107	71	500	0	36	0	71	0	0
Apr	17.8	62	67	57	-10	490	-10	67	0	0	0	0
May	22.1	94	113	106	-7	483	-6	113	0	0	0	0
Jun	25.3	123	147	130	-17	467	-16	146	1	0	0	0
Jul	26.9	139	169	173	4	472	4	169	0	0	0	0
Aug	26.7	137	157	156	-1	470	-1	157	0	0	0	0
Sep	24.2	112	115	150	35	500	30	115	0	5	0	0
Oct	18.8	69	67	94	27	500	0	67	0	27	0	0
Nov	13.9	38	33	64	31	500	0	33	0	31	0	0
Dec	9.7	19	16	85	69	500	0	16	0	69	0	0
	Yearly Totals:		949	1300				948	1	352		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 11

NORTHERN LAKES, WISCONSIN

Dale Robertson

SITE DESCRIPTION

The Northern Lakes site is located in the Northern Highlands Lake District of north-central Wisconsin. This area encompasses 10,000 sq km and has one of the largest concentrations of lakes in the world. There are also a number of streams and marshes present. The land area is generally flat and wooded. The elevation of the site is approximately 500 m. Snow and ice on the lakes are present for approximately six months of the year. LTER studies are focussed around Trout Lake where a field station is operated by the University of Wisconsin (Figs. 11.1 and 11.2).

The climate data reported below (Table 11.1 and 11.2, Figs 11.3 and 11.4) are taken from the National Weather Service (NWS) Cooperative Weather Station at the Minocqua Dam. The Minocqua Dam site is 15 km south of the Trout Lake Field Station, in a small clearing in the forest behind the observer's home approximately 200 m from Minocqua Lake. Data are available for this site from 1903 to the present, with a small break during 1943 and 1944. Missing values for these years as well as single missing values required for this report were interpolated from three nearby NWS Cooperative Weather Stations. Daily observations of wind speed and relative humidity are available from 1934 to the present from a Wisconsin Department of Natural Resources Station located in Mercer, approximately 38 km northwest of the Trout Lake Station. Daily total solar radiation data are available from 1977 to the present from the NWS Cooperative Weather station at the Rainbow Flowage operated by the Wisconsin Valley Improvement Cooperation, which is approximately 20 km southeast of the Trout Lake station.

VEGETATION

The original vegetative cover of the area was a mixed conifer-hardwood forest on the better soils. In other places there was an uninterupted pinery containing principally white pines with a little Norway and Jack pine. Most of the area now is covered with a second growth. Marshes and bogs are found in low-land areas. The soils are mainly gray sands and sandy loams.

SYNOPTIC CLIMATOLOGY

The climate is continental characterized by long cold, snowy winters and relatively short summers with warm days and cool nights. There is considerable seasonal fluctuation in temperature and precipitation. Areas near lakes usually have a smaller range in daily temperature extremes than in areas away from water during the open water period. The area is influenced by atmospheric pressure centers that move south from Canada, those which move across the country from west to east, and lake effects from Lake Superior. Summary climate statistics are presented in Table 11.1. Precipitation in the five-month period May through September has about 65 percent of the annual precipitation. Winter months are dominated by overcast skies. There is an average snowfall of 2257 mm per year (Table 11.2). Prevailing winds are from the northwest from late fall until early spring, and southerly during the remainder of the year.

WATER BALANCE

The water balance of the land area at the Northern Lakes site generally shows that adequate precipitaion is available to sustain potential evapotranspiration values (Table 11.3, Fig 11.5). The only exception to this is the possibility of a slight soil moisture deficit in July. This deficit would be more marked in dry years. Another interesting feature of the Northern Lake water balance is the snowmelt that occurs in April and May and which is manifested in high runoff values especially in the former month. In reality, however, most of the snowmelt goes directly into groundwater and the levels of streams and rivers do not show large fluctuations during the spring melting period. During the winter there are four to five months with negligible evapotranspiration rates.

CLIMATIC FACTORS AFFECTING THE FLORA, FAUNA, AND INLAKE PARAMETERS

Life in the aquatic systems is strongly influenced by the presence of surface ice and snow, which persists for almost half the year. The presence of surface ice divides the year into two distinct seasons, the open water season and the ice covered season. The open water season is subdivided into spring overturn, summer stratification, and fall overturn. Most growth and reproduction occurs during the open water season. The ice covered season is a time of little growth for most in-lake species. The terrestrial flora and fauna are also strongly influenced by the presence or absence of snow.

Fig. 11.1. A general of Trout Lake.

Fig. 11.2. Sampling on Trout Lake.

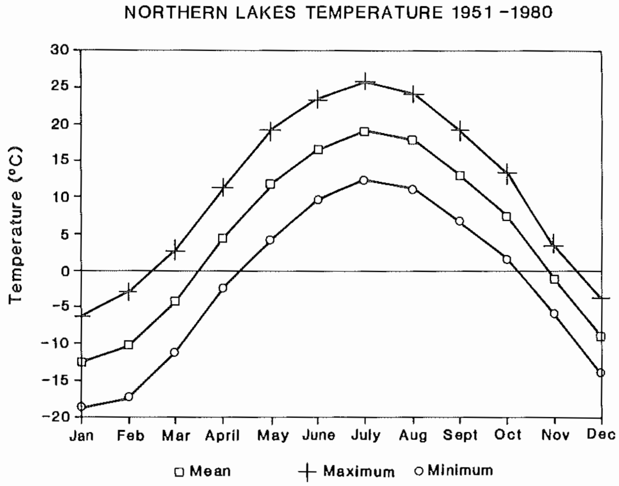

Fig. 11.3. Average annual temperature values for Northern Lakes.

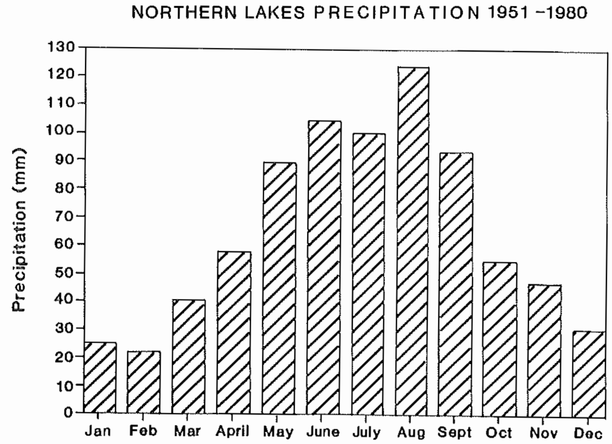

Fig. 11.4. Average annual precipitation totals at Northern Lakes.

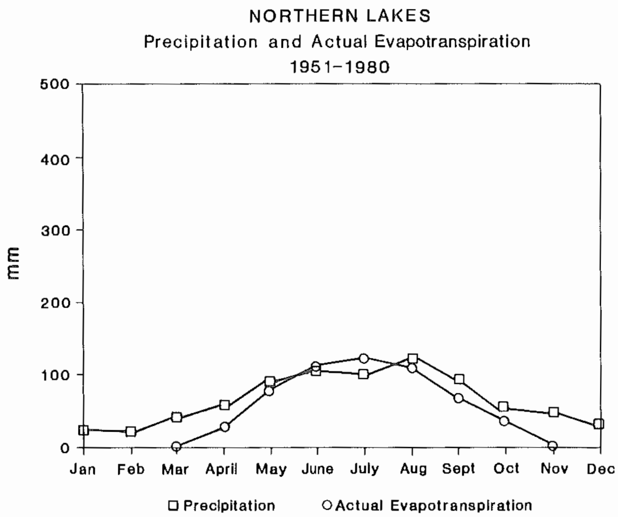

Fig. 11.5. Monthly water budget values, Northern Lakes.

Table 11.1

SUMMARY STATISTICS NORTHERN LAKES

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	-12.51	-10.16	-4.23	4.40	11.68	16.54	19.10	17.80	12.98	7.49	-1.24	-9.04
An Mean	4.40	St Dev	0.70									
Mean Mx T	-6.36	-2.98	2.72	11.17	19.15	23.39	25.77	24.33	19.14	13.39	3.42	-3.82
Mean Mi T	-18.65	-17.34	-11.18	-2.37	4.21	9.68	12.42	11.27	6.82	1.59	-5.91	-14.26
Mean Temp Warmest Month			19.29	St Dev	1.08							
Mean Temp Coldest Month			-13.05	St Dev	2.25							
Annual Range of Monthly Mean Temps				32.34								
Num months with mean temp >0				7								
Num months with mean temp >15				3								
Highest monthly mean				22.30								
Lowest monthly mean				-19.00								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	25.1	22.0	40.7	57.9	89.9	105.1	100.4	124.4	93.7	54.8	47.1	30.5
Mean annual total		791.5										
Wettest year in period			1063									
Driest year in period			408									
Monthly totals during wettest year in period					Year		1951					
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	11	48	79	82	151	126	136	101	167	84	46	32
Monthly totals during driest year in period					Year		1976					
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	56	37	55	35	39	40	35	79	13	5	11	4
Total precip in months with temp >0				626								

Table 11.2

SUMMARY SNOWFALL STATISTICS NORTHERN LAKES

SNOWFALL DEPTH
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	485.3	361.2	369.4	167.9	34.3	0.1	0.1	0.0	0.1	37.4	285.9	515.3
Mean annual total		2257.0										
Most snowfall in a winter (Jul-Jun)				4110								
Least snowfall in a winter				952								
Most snowfall for each month												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	1328	1283	838	495	254	1	1	0	1	229	673	1524
Least snowfall for each month												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	76	25	13	0	0	0	0	0	0	0	1	79
Snowfall in winter with most snowfall				Year		1969						
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
	0	0	0	51	673	1524	1118	279	389	51	25	0
Snowfall in winter with least snowfall				Year		1964						
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
	0	0	0	0	25	343	178	229	152	25	0	0

Table 11.3

WATER BALANCE FOR NORTHERN LAKES

Water budget for Latitude 46.0 N, Longitude 89.7 W
Field capacity 75.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	-12.5	0	0	25	0	75	0	0	0	0	0	103
Feb	-10.2	0	0	22	0	75	0	0	0	0	0	125
Mar	-4.2	0	0	41	0	75	0	0	0	0	0	165
Apr	4.4	23	26	58	32	75	0	26	0	198	165	0
May	11.7	60	77	90	13	75	0	77	0	13	0	0
Jun	16.5	84	110	105	-5	70	-5	110	0	0	0	0
Jul	19.1	97	128	100	-28	48	-22	122	6	0	0	0
Aug	17.8	90	110	124	15	63	15	110	0	0	0	0
Sep	13.0	66	68	94	25	75	12	68	0	13	0	0
Oct	7.4	38	35	55	20	75	0	35	0	20	0	0
Nov	-1.3	0	0	47	0	75	0	0	0	0	0	47
Dec	-9.0	0	0	31	0	75	0	0	0	0	0	78
	Yearly Totals:		554	792				548	6	244		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 12

OKEFENOKEE NATIONAL WILDLIFE REFUGE, GEORGIA

Joseph Schubauer and David Greenland

SITE DESCRIPTION

The Okefenokee National Wildlife Refuge swamp site, is an extensive freshwater wetland complex which occupies 382,000 ha (3826 sq. km) of southern Georgia and northern Florida (Figs. 12.1 and 12.2). The swamp is a temporally and spatially complex mosaic of aquatic and terrestrial habitat types. Technically, the basin is considered a perched watershed, because downward seepage is inhibited and it is above the regional water table. The basin is presently thought to have been formed in one of the following manners: 1) from a saltwater lagoon or salt marsh which was separated from the sea by a depositional feature (Trail Ridge) on the eastern side or 2) from a series of freshwater lakes which alternately receded and expanded within the basin. Water enters the swamp primarily through direct precipitation and secondarily through runoff. Evapotranspiration is the major cause of water loss from the system (greater than 78 percent), with only 22 percent being lost via the drainages of the St. Mary's and Swannee rivers. Both natural and anthropogenic disturbances such as drought, fire, and hydroperiod, and lumbering, channelization, and sill construction, have played a major role in habitat development and succession within the swamp.

The climate data presented here (Table 12.1, Figs. 12.3 and 12.4) were monitored at a National Oceanic and Atmospheric Administration (NOAA) Cooperative weather station (#918609; Waycross 4NE) located near the northern border of the swamp.

VEGETATION

The most extensive habitats within the swamp are swamp forests of large trees and shrubs, shrub thickets and marshes with grasses, sedges and aquatic macrophytes. However, a number of characteristic vegetation types have been classified and mapped. Tree islands cover 8 percent of the swamp and have vegetation similar to that of the uplands, which are dominated by a pine-flatwoods complex. Two types of marsh (referred to as "prairies") exist in the swamp: floating and submerged hydrophyte prairies and emergent macrophyte prairies. Together they cover 21 percent of the swamp's area. The floating and submerged hydrophyte prairies dominated by water lilies *(Nymphaea and Nuphar)*, beak-rush *(Rhynchospora)*, and pipewort *(Eriocaulon)*, and the emergent macrophyte prairies by the sedge *Carex*, grasses such as *Panicum* and *Andropogon* and *Sphagnum* moss. Shrub communities (comprised of *Lyonia, Cyrilla, Ilex*, etc.) cover a large area of the swamp, as does mixed cypress forest *(Taxodium*, cypress; *Nyssa*, blackgum; *Gordonia*, bay; etc.). Only limited areas are pure cypress.

SYNOPTIC CLIMATOLOGY

The climate of the Okefenokee swamp is influenced greatly by it's close proximity to the warm oceanic waters of the southwestern Atlantic to the east and the eastern Gulf of Mexico to the southwest. Thus the air temperatures are moderated in the winter resulting in a somewhat semitropical climate (Fig. 12.3). The site's close proximity to the ocean also influences precipitation patterns there (Fig. 12.4). The swamp receives most of its precipitation in the form of rain from localized convectional storms in the summer (June - September) and thus can be quite variable in amount from year to year. However, some rainfall is generally received in all months of the year. Local winds can occasionally be quite strong, especially during convectional storms. Snow is a rare event here.

WATER BALANCE

Water balance calculations (Table 12.2 and Fig. 12.5) for the Okefenokee site are made for a land area which is assumed to have ample soil moisture all the year with a field capacity of 300 mm depth. Consequently because of the ample precipitation and high temperatures all the year round this site displays the highest actual evapotranspiration rates of all of the LTER sites. In the summer the AET rates exceed the available precipitation but usually the soil is moist enough to sustain potential evapotranspiration rates. In the first three months of the year there is a soil moisture surplus which usually takes the form of runoff. These water balance computations assume no human interference such as deliberate manipulation of the water table. However, such manipulation does occur from time to time.

CLIMATIC FACTORS AFFECTING FLORA AND FAUNA

High temperatures, a long growing season and ample rainfall help to produce lush terrestrial and aquatic vegetation which provides both food and refuges for many species of animals. In particular many species of migratory and resident birds, many of them on endangered or threatened species lists, benefit from these habitats. In pre-sill days (before the US Fish and Wildlife Service controlled the water level in the swamp by a sill or dike), droughts and periods of low water and, as a consequence, fires were more common. Fires and fluctuating water levels are important disturbances which influence the vegetative diversity and function of the swamp system.

Fig. 12.1. General view of the swamp from the ground.

Fig. 12.2. General view of the swamp from the air.

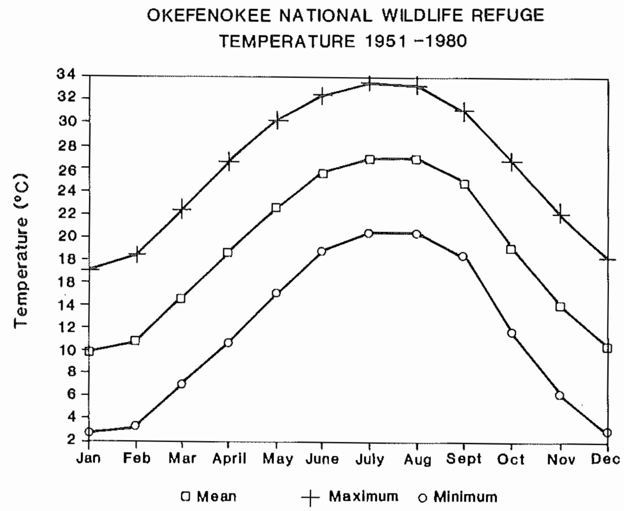

Fig. 12.3. Average annual temperature values at Okefenokee.

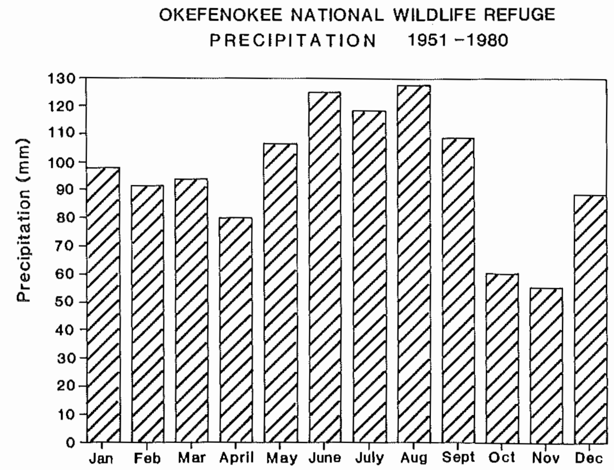

Fig. 12.4. Average annual precipitation totals at Okefenokee.

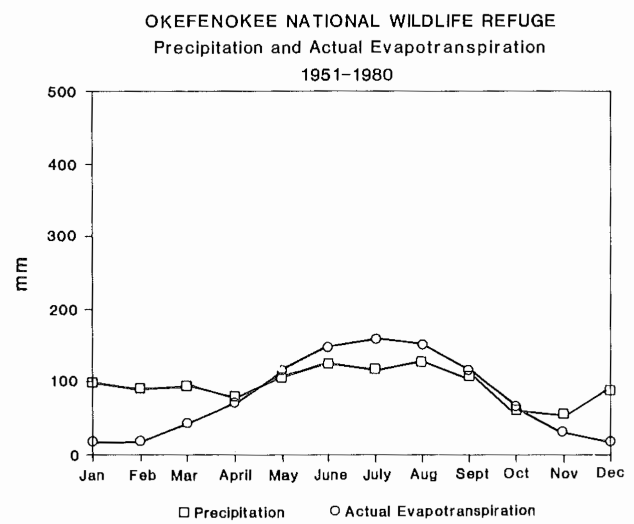

Fig. 12.5. Monthly water budget values at Okefenokee.

Table 12.1

SUMMARY STATISTICS OKEFENOKEE

TEMPERATURE
Deg. C.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon Mean	9.86	10.84	14.66	18.72	22.61	25.66	26.99	26.91	24.82	19.19	14.17	10.58
An Mean	18.75	St Dev	0.68									
Mean Mx T	17.04	18.34	22.32	26.63	30.14	32.47	33.51	33.38	31.13	26.65	22.16	18.19
Mean Mi T	2.67	3.34	7.01	10.82	15.09	18.84	20.46	20.44	18.51	11.73	6.17	2.98
Mean Temp Warmest Month			26.99	St Dev	0.62							
Mean Temp Coldest Month			9.86	St Dev	2.86							
Annual Range of Monthly Mean Temps				17.13								
Num months with mean temp >0				12								
Num months with mean temp >15				7								
Highest monthly mean				28.68								
Lowest monthly mean				4.17								

PRECIPITATION
mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mon mean	97.9	91.4	93.9	80.3	106.3	125.3	118.1	127.6	108.5	60.6	55.3	88.6
Mean annual total		1153.7										
Wettest year in period			1507									
Driest year in period			772									

Monthly totals during wettest year in period — Year 1964

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
226	113	99	121	80	77	14	174	189	207	34	174

Monthly totals during driest year in period — Year 1954

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
38	31	33	120	67	46	139	34	136	16	42	72

Total precip in months with temp >0 1154

Table 12.2

WATER BALANCE DATA FOR OKEFENOKEE

Water budget for Latitude 30.7 N, Longitude 82.4 W
Field capacity 300.0 mm Resistance curve C

MON	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP	SMT	SST
Jan	9.9	18	16	98	82	300	13	16	0	68	0	0
Feb	10.8	22	19	91	73	300	0	19	0	73	0	0
Mar	14.7	41	42	94	52	300	0	42	0	52	0	0
Apr	18.7	66	71	80	9	300	0	71	0	9	0	0
May	22.6	97	115	106	-8	292	-8	115	0	0	0	0
Jun	25.7	126	148	125	-23	270	-22	147	1	0	0	0
Jul	27.0	139	167	118	-49	229	-41	159	8	0	0	0
Aug	26.9	139	158	128	-30	207	-22	150	8	0	0	0
Sep	24.8	117	120	109	-11	199	-8	116	4	0	0	0
Oct	19.2	70	68	61	-8	194	-5	66	3	0	0	0
Nov	14.2	38	33	55	22	216	22	33	0	0	0	0
Dec	10.6	21	18	89	70	287	70	18	0	0	0	0
	Yearly Totals:		976	1154				952	24	202		

Explanation for Water Balance Columns. (All units are millimeters depth of water unless otherwise specified.)

MON	Month of the year
TEMP	Mean monthly air temperature in deg. C.
UPE	Unadjusted potential evapotranspiration
APE	Adjusted potential evapotranspiration
PREC	Precipitation
DIFF	PREC minus APE
ST	Soil moisture storage
DST	Change in storage from preceeding month
AE	Actual evapotranspiration
DEF	Soil moisture deficit
SURP	Soil moisture surplus
SMT	Snowmelt
SST	Water equivalent held in snowpack.

CHAPTER 13

OVERVIEW

David Greenland

INTRODUCTION

Availability of climatic data from LTER sites makes possible the interesting intersite comparisons in this chapter. The bioclimates of the sites, as opposed to more standard climatographies, are the focal point of this study.

Three measures of the bioclimates are used, each of which tend to group the eleven LTER sites into subgroups having common traits for aridity/moisture, cold/warm, or desert/grassland/forest. The first section uses temperature and precipitation graphically and in tables which rank annual and monthly means, extremes, and ranges. The second section uses the Thornthwaite potential evapotranspiration (PET) and actual evapotranspiration (AET) values to compare water balances and moisture surplus or deficits for the various sites. The third section lists Köppen's and Thornthwaite's classifications for the sites.

ANNUAL TEMPERATURE AND PRECIPITATION

The LTER sites cover wide ranges of both annual temperature and precipitation (Fig. 13.1). Similarities of climate are shown by close pairings of the southeastern sites of Okefenokee and North Inlet compared with the relatively high latitude mid-continental sites of Northern Lakes and Cedar Creek. A further group, characterized by moderate annual temperatures, is represented in terms of decreasing annual precipitation by Andrews, Coweeta, Illinois, Konza, Central Plains, and Jornada characterized by pairings for high, moderate, and low preciptation. Niwot forms an outlier at the low temperature end of the scale. Alternatively the CPER and Jornada sites could be viewed as a separate group characterized by low precipitation and moderate temperatures.

A useful index for bioclimatic description and discrimination is the ratio of growing season thawing degree days (GSTDD) to growing season precipitation (GSPPT) (Greenland et al., 1985). Here the growing season thawing degree days are defined, for expediency, as the number of days in all the months with a mean temperature above zero multiplied by the number of degrees above zero for any particular month. Precipitation is summed for the same set of months, which is different for each site. The input variables and the value of the ratio for the sites are given in Table 13.1. The ratio allows certain groupings to become distinct (Table 13.2). The first is the forest sites (Andrews and Coweeta); the last is the dry sites (Jornada and Central Plains). Niwot ranks between the forest sites and all others with ratios of 4 to 6. Ranking by growing season thawing degree days manifests, for the most part, a latitudinal distribution. Ranking by growing season precipitation shows the forested sites and coastal sites at one extreme and the dry sites at the other, but does not clearly differentiate remaining continental sites.

The site temperature values show considerable variation in all variables except the standard deviation of the 30 annual mean temperatures at each site (Table 13.3). This would suggest that the annual mean temperature is a rather conservative and characteristic property of an individual site. Ranking sites by annual mean temperature (Table 13.4) shows a general inverse relation to latitude. The exceptions are the altitudinal effect for the Niwot site and the influence of the proximity of warm ocean near the Andrews site. The mean temperature value of the warmest months (Table 13.4) shows both low latitude and mid-continental sites ranking high. Four sites share a value of 26 deg. C. on this index. The summer temperatures at Jornada, although high are not as high as might be expected for a desert owing to the relatively high elevation of this site. Ranking by the mean temperatures of the coldest months (Table 13.4) indicate the severe cold winter environments of both the high alpine and the mid-continental sites; indeed, the coldest monthly mean temperature for Cedar Creek is lower than that of the high altitude alpine site at Niwot Ridge. The maritime influence at the Andrews site is apparent in both of these rankings.

Somewhat surprising rankings among the sites emerge when the highest and lowest (Table 13.5) recorded monthly mean value in the 30 year record period are inspected. In the former case the mid-continental sites tend to be highly ranked, with Konza being ranked first. Jornada and Okefenokee are also highly ranked. With respect to the lowest monthly mean on record, both Cedar Creek and Northern Lakes sites have recorded lower temperatures than Niwot Ridge and the Jornada high elevation desert site has recorded a lower value than Okefenokee. If the number of months with mean temperatures above 0 deg. C is taken as an index of the potential growing season, the sites might be said to fall into two groups (Table 13.6). One group of sites (including Okefenokee, North Inlet, Coweeta, Andrews, Jornada, and Konza) display a growing season that potentially lasts the entire year. The other sites exhibit some part of the year when it unlikely that plant growth would occur. If a monthly mean temperature above 15 deg. C indicates some upper restriction on plant growth (Table 13.6), then vegetation at Okefenokee and North Inlet, Jornada and, to a lesser extent, Konza, Illinois, and Coweeta, might suffer from exceeding this threshold.

Since the proximity to the ocean has arisen as a factor in a number of the above rankings, it is appropriate to perform a more formal analysis on this factor. The index of continentality k (Conrad and Pollak, 1962:296-300) is computed as:

$$k = \frac{1.7 * \text{Annual temp range}}{\sin(\text{angle of latitude} + 10 \text{ degrees})} - 14$$

For comparison, k is near 100 for inland Verkhoyansk (67.5 deg. N, 133.4 deg. E) in Siberia, Soviet Union and near 0 for coastal Thorshavn (62.1 deg. N, 6.7 deg E) in

Norway. Four of the LTER sites (Table 13.7), Cedar Creek, Northern Lakes, Konza, and Illinois, rank highly on this scale but do not come close to Verkhoyansk in continentality. Likewise, although the value indicating the maritimity of the Andrews site is low, it is not close to the values found near the Norweigian coast. L.W. Swift (pers. comm., 1987) has pointed out that the equation for the index of continentality is very sensitive to latitude, a factor which was originally included in the index in an attempt to normalize for the general correlation existing between annual range of temperature and geographic latitude.

A wide range of precipitation values is found in Table 13.8. Predominant vegetation reflects annual precipitation totals (Table 13.9) in that the forest sites have the most and the grassland and desert sites have least. However, the high latitude continental sites of Northern Lakes and Cedar Creek, both of which have large numbers of trees, rank low in total precipitation. Similar rankings appear for the precipitation total in the wettest and the driest (Table 13.9) years on record. Note, however, that Konza moves up in ranking for the high precipitation year as well as down in the ranking for the driest year, increasing the range shown in Table 13.10. The Northern Lakes, grassland, and Jornada sites all have notably dry years. The range of precipitation between the wettest and driest year on record (Table 13.10) is an index of precipitation variability. This index suggests that Andrews has the most variable intra-annual precipitation followed by Konza, Coweeta, and Niwot. An entirely different impression, and perhaps more meaningful one, in terms of bioclimates, is given when the range is normalized by the average annual total preciptation (Table 13.10). This shows the grassland and desert sites to have the most variable annual precipiation while Andrews and the southeastern sites have the least variable annual preciptation. The precipitation value of the wettest month (Table 13.11) tends to rank the sites in a similar way to the ranking by total precipitation. However, the precipitation of the driest month (Table 13.11) identifies the southeastern sites as ones having a useful amount of precipitation even in the driest month. Contrastingly, the other high precipitation site, Andrews, ranks along with the grassland and desert sites as being low on this index. The range between precipitation totals for the driest and wettest month of the year (Table 13.11) shows Andrews to have the greatest intra-annual variation by far.

Note from Table 13.8 that the months when maximum and minimal precipitation occur are also highly variable between the sites. Andrews shows a winter maximum of precipitation while the other sites receive their maxima in the summer months except for the Colorado stations and Coweeta where a spring maximum is more usual. Winter minima are found in most sites except for Andrews (summer), Coweeta and Niwot (fall) and North Inlet (late spring). For comparison, a principal components analysis on monthly precipitation, made on data averaged over various record periods, suggests three general groups of sites (Conley, 1986). These are 1) Andrews, Coweeta, and Niwot Ridge with greater winter or early spring precipitation; 2) Illinois, CPER, Konza, Cedar Creek and N. Lakes with predominantly summer precipitation; and 3) North Inlet and Jornada where precipitation peaks late in the summer and continues through autumn.

WATER BALANCE

The water balance of the rooting zone of the soil is vitally important to the growth of vegetation and water availability or nonavailability has often been associated with the nature of the vegetation found in any particular location. The month by month variation of water budget parameters is given for each of the sites in the preceeding chapters. The annual values of water balance components (Table 13.12) differentiate the climate of the LTER sites.

Once more the LTER sites show a wide range in annual values. Precipitation ranges from 231 mm at Jornada and 309 mm at Central Plains to 2290 mm at Andrews. Potential evapotranspiration (PET) ranges from 306 mm at Niwot to 976 mm at Okefenokee. Thornthwaite (1948) used PET as an index of thermal efficiency because it is an expression of daylength as well as of temperature. He believed it to be useful in bioclimatology because it was an index of plant growth in terms of the water needed for growth. Actual evapotranspiration (AET) varies from 231 mm at Jornada and 299 mm at Central Plains to 952 mm at Okefenokee. Several workers have noted a close relationship between AET values and values of biomass production (Chang, 1968). Soil moisture deficit ranges from 0 at Coweeta to 306 mm at Central Plains and 566 mm at Jornada. Although a small deficit is shown for Okefenokee, this occurs because the water budget calculations for this site were made for a land surface and not a water surface. Soil moisture surplus (Table 13.14), an index of expected runoff, varies from 0 mm at Jornada and 10 mm at CPER to 1738 at Andrews. As mentioned in chapter 7, monthly calculations of the water balance can mask facts that are important to the ecosystem in particular cases. One example is the fact that, even at Jornada there can be significant runoff during and after heavy storms. In another case, at the Andrews site despite the high soil moisture surplus indicated in the calculations, extremely high percolation rates and deep regolith preclude overland flow or surface runoff in the location. Also at Andrews, despite the small soil water deficit shown, the plants experience a profound soil moisture deficit nearly every year (McKee, pers. comm., 1987).

Ranking the LTER sites by PET (Table 13.13) shows a tendency for an association between PET values and latitude. Niwot is an exception due to its altitude. The ordering for AET (Table 13.13) is similar because most sites, except for CPER and Jornada, come close to having enough soil moisture to meet their PET needs. Soil moisture deficit values (Table 13.14) at Jornada and CPER are notably greater than at the rest of the sites. Likewise, Andrews and Coweeta are outstanding in having high values of soil moisture surplus (Table 13.14). Jornada and the grassland sites have low or zero soil water surpluses.

Sites with similar bioclimates may be grouped using the water balance components of the moisture index and the PET value (Mather, 1985) (Table 13.15 and Fig. 13.2). Okefenokee and North Inlet form one group, Andrews and Coweeta comprise another, a third includes Northern Lakes, Cedar Creek, Illinois, and Konza. A fourth group is formed by the dry sites of Jornada and Central Plains, while Niwot stands by itself. This is generally consistent with the Fig. 13.1 display, which is based on annual temperature and precipitation.

CLIMATIC CLASSIFICATION

Exercises in climatic classification are useful not only because of the end result, some descriptive term for the climate, but also for the insights gained while making the classification. This is certainly the case when the LTER sites are classified according to some of the most popular bioclimatically oriented climatic classifications.

Applying the Köppen classification (as defined by McKnight, 1984 and Oliver, 1973) (Table 13.16) some interesting climatic categories emerge. These categories can vary according to which version of the Köppen system is used. In the McKnight (1984) version, D climates are defined as those having 4 to 8 months with average temperatures greater than 10 deg. C. In this case, low temperatures and the summer dryness at Andrews yield an unusual Köppen class of Dsb. It is also interesting to find Coweeta and Konza in the D category. Oliver (1974) quotes a version based on the Köppen classification as modified by Geiger and Pohl, in which D climates are defined as those having the temperature of the coldest month being less than -3.0 deg. C. In this case, which is employed in Table 13.16, the Andrews, Coweeta, and Konza sites all fall into the C class. This discrepancy indicates that all three sites are near climatic boundaries. The variable relief at Andrews and Coweeta probably causes the boundaries to be crossed at different locations within those sites. Both arid sites, Jornada and CPER, are classified as cold.

The remarkable point arising from the application of Thornthwaite's 1955 classification (Thornthwaite and Mather, 1955) (Table 13.17) is that most of the sites show little or no soil water deficits and that all, except Niwot and Northern Lakes fall into the Mesothermal category. It must be remembered, however, that some sites, such as Andrews, due to particular circumstances may have vegetation that suffers from short-term drought despite what these calculations indicate. One of the interesting findings is that several stations are near margins between climatic types. This is true for Andrews and Coweeta with respect to temperature. One interpretation of the classifications would be that Konza had a climate that might support trees if cultural factors, such as absence of fires, permitted this. Unlike some of the preceeding analyses, the Thornthwaite classification is able to distinguish the difference between the aridity at the Jornada and CPER sites.

The Köppen and Thornthwaite classifications were designed to highlight global contrasts. Within the global context, the LTER sites demonstrate a limited variation. Nevertheless, other analyses in this chapter point out an ample variety of climates in which to pursue Long-Term Ecological Research.

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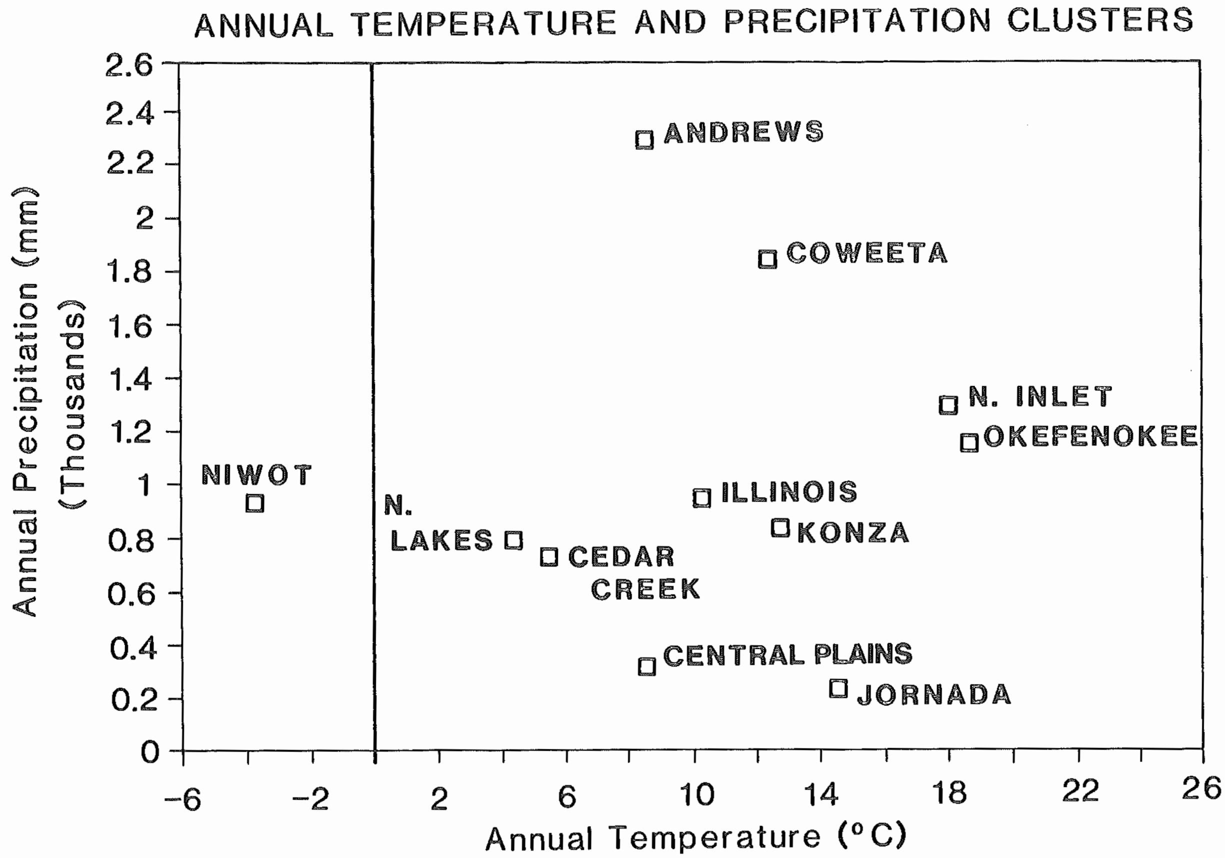

Fig. 13.1. Annual temperature and precipitation clusters for LTER sites.

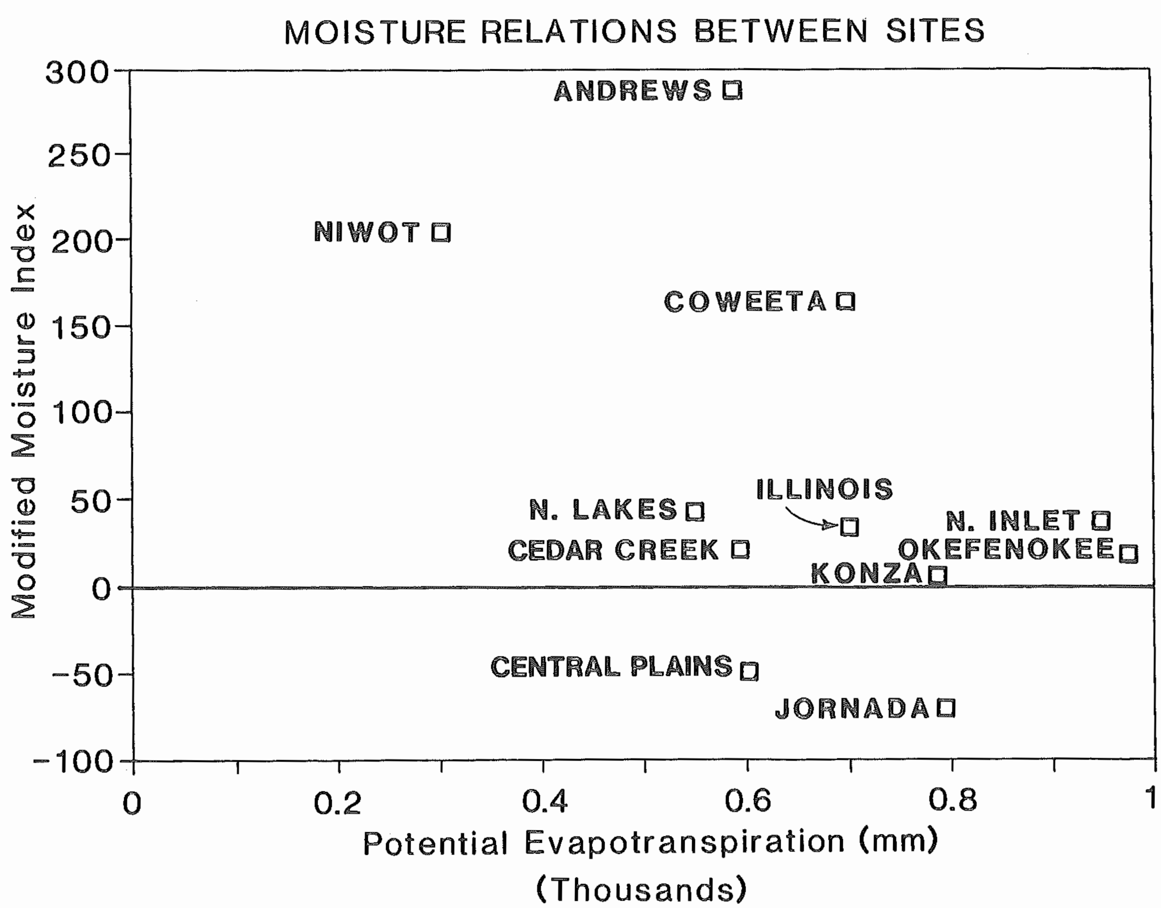

Fig. 13.2. Moisture relations between the LTER sites.

Table 13.1

Values of the Thawing Degree Days, Precipitation and their ratio for the growing season (all months with > 0 deg C).

Station	Thawing Degree Days	Precip	Ratio Temp/ Precip
Andrews	3136.30	2291.00	1.37
Cedar Creek	3116.80	599.00	5.20
Central Plains	3336.10	294.00	11.35
Coweeta	4569.40	1847.00	2.47
Illinois	4123.20	825.00	5.00
Jornada	5327.20	233.00	22.86
Konza	4756.70	790.00	6.02
Niwot	714.30	222.00	3.22
N. Inlet	6602.10	1299.00	5.08
N. Lakes	2753.00	626.00	4.40
Okefenokee	6862.30	1154.00	5.95

Table 13.2

Sites Ranked by Different Combinations of the Components of the Thawing Degree Day/Precip Ratio.

Ranked by Thawing Degree Day/Precip Ratio value

Station	Thawing Degree Days	Precip	Ratio Temp/ Precip
Andrews	3136.30	2291.00	1.37
Coweeta	4569.40	1847.00	2.47
Niwot	714.30	222.00	3.22
N. Lakes	2753.00	626.00	4.40
Illinois	4123.20	825.00	5.00
N. Inlet	6602.10	1299.00	5.08
Cedar Creek	3116.80	599.00	5.20
Okefenokee	6862.30	1154.00	5.95
Konza	4756.70	790.00	6.02
Central Plains	3336.10	294.00	11.35
Jornada	5327.20	233.00	22.86

Ranked by Thawing Degree Days

Station	Thawing Degree Days	Precip	Ratio Temp/ Precip
Okefenokee	6862.30	1154.00	5.95
N. Inlet	6602.10	1299.00	5.08
Jornada	5327.20	233.00	22.86
Konza	4756.70	790.00	6.02
Coweeta	4569.40	1847.00	2.47
Illinois	4123.20	825.00	5.00
Central Plains	3336.10	294.00	11.35
Andrews	3136.30	2291.00	1.37
Cedar Creek	3116.80	599.00	5.20
N. Lakes	2753.00	626.00	4.40
Niwot	714.30	222.00	3.22

Ranked by Growing season precipitation

Station	Thawing Degree Days	Precip	Ratio Temp/ Precip
Andrews	3136.30	2291.00	1.37
Coweeta	4569.40	1847.00	2.47
N. Inlet	6602.10	1299.00	5.08
Okefenokee	6862.30	1154.00	5.95
Illinois	4123.20	825.00	5.00
Konza	4756.70	790.00	6.02
N. Lakes	2753.00	626.00	4.40
Cedar Creek	3116.80	599.00	5.20
Central Plains	3336.10	294.00	11.35
Jornada	5327.20	233.00	22.86
Niwot	714.30	222.00	3.22

Table 13.3

Comparison of Site Temperature Values (Degrees C.)

	Annual		
Station	Mean Temp	St. Dev. of Ann Mean	Mean Range*
Andrews	8.60	0.70	18.00
Cedar Creek	5.50	0.66	34.64
Central Plains	8.68	1.26	24.65
Coweeta	12.48	0.47	19.78
Illinois	10.36	0.67	29.70
Jornada	14.58	0.68	22.20
Konza	12.80	0.70	29.30
Niwot	-3.71	0.64	21.38
N. Inlet	18.06		18.50
N. Lakes	4.40	0.70	32.34
Okefenokee	18.75	0.68	17.13

* Range for each year is the warmest monthly mean minus coldest.

Table 13.4

Ranking of Sites by Annual Mean Temperatures (Degrees C.)

Annual		Warmest Month		Coldest Month	
Station	Mean Temp	Station	Mean Temp	Station	Mean Temp
Okefenokee	18.75	Okefenokee	26.99	Okefenokee	9.86
N. Inlet	18.06	N. Inlet	26.94	N. Inlet	8.44
Jornada	14.58	Konza	26.60	Jornada	3.16
Konza	12.80	Jornada	26.33	Coweeta	1.87
Coweeta	12.48	Illinois	24.00	Andrews	-0.40
Illinois	10.36	Coweeta	21.65	Konza	-2.70
Central Plains	8.68	Central Plains	21.55	Central Plains	-3.10
Andrews	8.60	Cedar Creek	21.19	Illinois	-5.70
Cedar Creek	5.50	N. Lakes	19.29	N. Lakes	-13.05
N. Lakes	4.40	Andrews	18.60	Niwot	-13.15
Niwot	-3.71	Niwot	8.23	Cedar Creek	-13.45

Monthly Means

Station	Max In Record	Warmest Month	Std Dev	Min In Record	Coldest Month	Std Dev	With mean Temp > 0	With mean Temp > 15
Andrews	20.80	18.60	1.10	-3.10	-0.40	1.50	12	2
Cedar Creek	24.20	21.19	1.40	-19.50	-13.45	2.81	7	3
Central Plains	25.20	21.55	1.83	-8.85	-3.10	2.38	9	4
Coweeta	23.03	21.65	0.75	-3.02	1.87	1.84	12	5
Illinois	27.34	24.00	1.24	-12.23	-5.70	2.72	9	5
Jornada	28.63	26.33	1.08	-0.06	3.16	1.34	12	6
Konza	31.00	26.60	1.80	-9.70	-2.70	2.50	11	5
Niwot	10.48	8.23	0.88	-17.58	-13.15	1.35	4	0
N. Inlet		26.94			8.44		12	7
N. Lakes	22.30	19.29	1.08	-19.00	-13.05	2.25	7	3
Okefenokee	28.68	26.99	0.62	4.17	9.86	2.86	12	7

Table 13.5

Ranking of Sites by Extreme Monthly Means (Degrees C.) in 30 year Record.

Maximum Recorded		Minimum Recorded	
Station	Temp	Station	Temp
Konza	31.00	Okefenokee	4.17
Okefenokee	28.68	Jornada	-0.06
Jornada	28.63	Coweeta	-3.02
Illinois	27.34	Andrews	-3.10
Central Plains	25.20	Central Plains	-8.85
Cedar Creek	24.20	Konza	-9.70
Coweeta	23.03	Illinois	-12.23
N. Lakes	22.30	Niwot	-17.58
Andrews	20.80	N. Lakes	-19.00
Niwot	10.48	Cedar Creek	-19.50

Table 13.6

Ranking of Sites by Months with Mean Temperature Above Certain Thresholds (degrees C.)

Station	Months With mean Temp > 0	Station	Months With mean Temp > 15
Okefenokee	12	Okefenokee	7
N. Inlet	12	N. Inlet	7
Jornada	12	Jornada	6
Coweeta	12	Konza	5
Andrews	12	Illinois	5
Konza	11	Coweeta	5
Illinois	9	Central Plains	4
Central Plains	9	N. Lakes	3
N. Lakes	7	Cedar Creek	3
Cedar Creek	7	Andrews	2
Niwot	4	Niwot	0

Table 13.7

Ranking of Sites by the Index of Continentality.

Station	Mean Annual Range (Deg.C)	Latitude Degrees	Index of Contintent - ality
Cedar Creek	34.64	45.40	57
N. Lakes	32.34	46.00	52
Konza	29.30	39.10	52
Illinois	29.70	40.60	51
Jornada	22.20	32.50	42
Central Plains	24.65	40.80	40
Coweeta	19.78	35.00	33
Niwot	21.38	40.00	33
N. Inlet	18.50	33.50	32
Okefenokee	17.13	30.70	31
Andrews	18.00	44.20	24

Table 13.8

Comparison of Station Precipitation Values (mm).

Station	Annual Total Precip	Wettest Year	Driest Year	Range between wet & dry years
Andrews	2289.2	3055	1503	1552
Cedar Creek	726.0	1037	327	710
Central Plains	309.0	588	108	480
Coweeta	1848.0	2315	1392	923
Illinois	944.6	1300	603	697
Jornada	231.4	413	91	322
Konza	834.9	1534	392	1142
Niwot	930.0	1427	541	886
N. Inlet	1300.0	no data	no data	no data
N. Lakes	791.5	1063	408	655
Okefenokee	1153.7	1507	772	735

Station	Mean Ppt in wettest month	Mean Ppt in driest month	Range between wet & dry months	Ppt in months with temp > 0	Month of Max Ppt	Month of Min Ppt
Andrews	407.3	11.6	395.7	2290	12	7
Cedar Creek	116.2	18.2	98.0	599	6	1
Central Plains	58.3	4.0	54.3	293	5	12
Coweeta	217.0	113.0	104.0	1848	3	10
Illinois	118.3	35.6	82.7	825	6	1
Jornada	49.8	4.5	45.3	413	8	4
Konza	134.2	21.2	113.0	814	6	1
Niwot	127.8	40.3	87.5	221	3	9
N. Inlet	173.2	64.0	109.2	1300	7	5
N. Lakes	124.4	22.0	102.4	626	6	2
Okefenokee	127.6	55.3	72.3	1154	8	11

Table 13.9

Ranking of Sites by Precipitation Values.

Station	Annual Total Precip	Station	Wettest Year	Station	Driest Year
Andrews	2289.20	Andrews	3055	Andrews	1503
Coweeta	1848.00	Coweeta	2315	Coweeta	1392
N. Inlet	1300.00	Konza	1534	Okefenokee	772
Okefenokee	1153.70	Okefenokee	1507	Illinois	603
Illinois	944.60	Niwot	1427	Niwot	541
Niwot	930.00	Illinois	1300	N. Lakes	408
Konza	834.90	N. Lakes	1063	Konza	392
N. Lakes	791.50	Cedar Creek	1037	Cedar Creek	327
Cedar Creek	726.00	Central Plains	588	Central Plains	108
Central Plains	309.00	Jornada	413	Jornada	91
Jornada	231.40				

Table 13.10

Ranking of Sites by Range of Precipitation Totals Between Wettest and Driest Year

Station	Range between wet & dry years	Station	Ratio of Range to Mean Annual Total
Andrews	1552	CPER	1.55
Konza	1142	Jornada	1.39
Coweeta	923	Konza	1.37
Niwot	886	Cedar Creek	0.98
Okefenokee	735	Niwot	0.95
Cedar Creek	710	N. Lakes	0.83
Illinois	697	Illinois	0.74
N. Lakes	655	Andrews	0.68
Central Plains	480	Okefenokee	0.64
Jornada	322	Coweeta	0.50

Table 13.11

Ranking of Sites by Mean Precipitation Total for Wettest and Driest Months.

Station	Mean Ppt in Wettest Month	Station	Mean Ppt in Driest Month	Station	Range Between Wet & Dry Months
Andrews	407.30	Coweeta	113.00	Andrews	395.70
Coweeta	217.00	N. Inlet	64.00	Konza	113.00
N. Inlet	173.20	Okefenokee	55.30	N. Inlet	109.20
Konza	134.20	Niwot	40.30	Coweeta	104.00
Niwot	127.80	Illinois	35.60	N. Lakes	102.40
Okefenokee	127.60	N. Lakes	22.00	Cedar Creek	98.00
N. Lakes	124.40	Konza	21.20	Niwot	87.50
Illinois	118.30	Cedar Creek	18.20	Illinois	82.70
Cedar Creek	116.20	Andrews	11.60	Okefenokee	72.30
Central Plains	58.30	Jornada	4.50	Central Plains	54.30
Jornada	49.80	Central Plains	4.00	Jornada	45.30

Table 13.12

Summary of Annual Water Balance Data.
(Annual totals in mm)

Station	Annual Precip	Potential ET	Actual ET	Soil Moisture Deficit	Soil Moisture Surplus
Andrews	2290	593	552	41	1738
Cedar Creek	726	597	586	11	140
Central Plains	309	605	299	306	10
Coweeta	1848	702	702	0	1145
Illinois	945	703	695	9	250
Jornada	231	797	231	566	0
Konza	835	790	736	54	98
Niwot	930	306	257	49	675
N. Inlet	1300	949	948	1	352
N. Lakes	792	554	548	6	244
Okefenokee	1154	976	952	24	202

Table 13.13

Ranking by Potential and Actual Evapotranspiration (mm).

Station	Potential ET	Station	Actual ET
Okefenokee	976	Okefenokee	952
N. Inlet	949	N. Inlet	948
Jornada	797	Konza	736
Konza	790	Coweeta	702
Illinois	703	Illinois	695
Coweeta	702	Cedar Creek	586
Central Plains	605	Andrews	552
Cedar Creek	597	N. Lakes	548
Andrews	593	Central Plains	299
N. Lakes	554	Niwot	257
Niwot	306	Jornada	231

Table 13.14

Ranking by Soil Moisture Surplus and Deficit (mm)

Station	Soil Moisture Surplus	Station	Soil Moisture Deficit
Andrews	1738	Jornada	566
Coweeta	1145	Central Plains	306
Niwot	675	Konza	54
N. Inlet	352	Niwot	49
Illinois	250	Andrews	41
N. Lakes	244	Okefenokee	24
Okefenokee	202	Cedar Creek	11
Cedar Creek	140	Illinois	9
Konza	98	N. Lakes	6
Central Plains	10	N. Inlet	1
Jornada	0	Coweeta	0

Table 13.15

Ranking by Modified Moisture Index.

Moisture index = humidity index - 0.6 aridity index
Humidity index = 100 (Soil moisture surplus/Potential ET)
Aridity index = 100 (Soil moist deficit/Potential ET)
Modified moisture index = 100((Surplus - Deficit) / PET)

Station	Potential ET	Soil Moisture Surplus	Soil Moisture Deficit	Moisture Index	Modified Moisture Index
Andrews	593	1738	41	289	286
Niwot	306	675	49	211	205
Coweeta	702	1145	0	163	163
N. Lakes	554	244	6	43	43
N. Inlet	949	352	1	37	37
Illinois	703	250	9	35	34
Cedar Creek	597	140	11	22	22
Okefenokee	976	202	24	19	18
Konza	790	98	54	8	6
Central Plains	605	10	306	-29	-49
Jornada	797	0	566	-43	-71

Table 13.16

Sites Classified According to Koppen's Classification
(as modified by Geiger and Pohl).

Station	Letter Class	Descriptive Name
Andrews	Csb	Humid Mid Latitude Summer Dry
Cedar Creek	Dfb	Humid Continental
CPER	BSk	Midlatitude Steppe
Coweeta	Cfb	Humid Continental
Illinois	Dfb	Humid Continental
Jornada	BWk	Mid Latitude Desert
Konza	Cfb	Humid Continental
Niwot	ET	Alpine Tundra
N. Inlet	Cfa	Humid Subtropical
N. Lakes	Dfb	Humid Continental
Okefenokee	Cfa	Humid Subtropical

Table 13.17

Sites Classified According to Thornthwaite's 1955 Classification

Station	Letter Class	Description
Andrews	A B'1 r b'3	Perhumid, Mesothermal,little water deficit
Cedar Creek	B1 B'1 r b'2	Humid, Mesothermal, little water deficit
CPER	D B'1 w2 b'2	Semiarid, Mesothermal, large winter water deficit
Coweeta	A B'1 r b'4	Perhumid, Mesothermal, little water deficit
Illinois	B1 B'1 r b'2	Humid, Mesothermal, little water deficit
Jornada	E B'2 d b'3	Arid, Mesothermal, little water surplus
Konza	C2 B'2 r b'4	Moist subhumid, Mesothermal, little water deficit
Niwot	A C'1 s c'1	Perhumid, Microthermal, mod summer water deficit
N. Inlet	B1 B'3 r b'4	Humid, Mesothermal, little water deficit
N. Lakes	B2 C'2 r b'1	Humid, Microthermal, little water deficit
Okefenokee	C2 B'3 r a'	Moist subhumid, Mesothermal, little water deficit

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