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Forty Years of Hydrometeorological Data from the Fernow Experimental Forest, West Virginia

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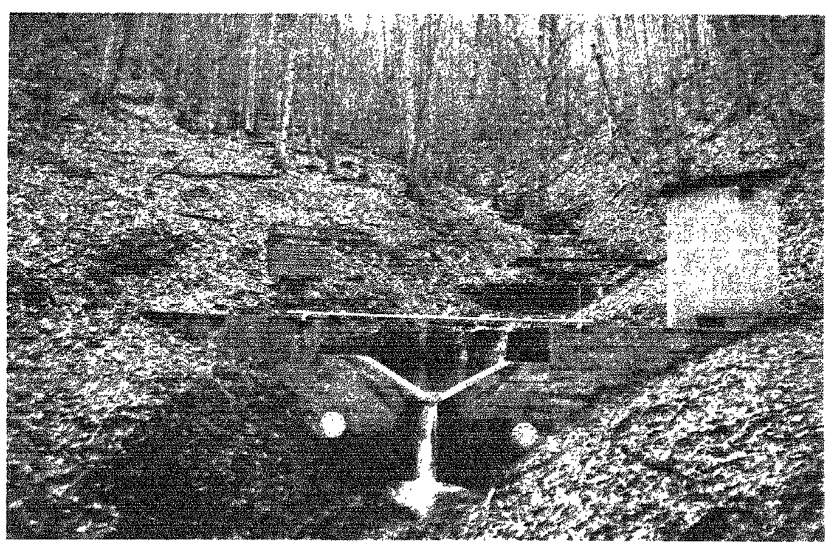
Watershed 1
1958



Watershed 1
1993

Abstract

Hydrometeorological data have been collected at the Fernow Experimental Forest in West Virginia since 1951. This publication summarizes these data, describes their collection, and provides other information that characterizes the Fernow. The value and utility of long-term data sets are discussed.

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Cover Photos: Watershed 1 following a commercial clearcut in 1957-58 and in 1993 after 35 years of regrowth.

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Introduction

With heightened concern about long-term changes in the earth's atmosphere and climate has come an increased appreciation of the value of reliable long-term data. From the 1930's through the 1950's, the USDA Forest Service established a number of experimental forests around the country. Although these forests were established with a variety of objectives, those which have survived to the present are proving to be of great value because of the long data records which have accrued. The Fernow Experimental Forest in West Virginia is one such experimental forest. This publication summarizes some of the hydrometeorological data collected on the Fernow Experimental Forest during the last 40 years. This publication does not provide exhaustive analyses of these data; rather the objective is to characterize the physical and chemical environment of the Fernow Experimental Forest, and to provide readers with summaries of important data sets. More specific information and detailed analyses are provided in other publications listed in Godwin et al. (1993).

History

The Fernow Experimental Forest was established on May 28, 1934. Named in honor of Bernard E. Fernow, a well-known German-born forester who pioneered scientific forestry in the United States, it initially comprised 1,473 hectares (ha) and was expanded to 1,902 ha in 1974. The Fernow is a field laboratory for two research projects: one is concerned with the protection of water resources in central Appalachian forests; the other is studying the growth and culture of central Appalachian hardwoods. Both projects are headquartered at the Northeastern Forest Experiment Station's Timber and Watershed Laboratory at Parsons, West Virginia.

Research on forest hydrology began on the Fernow in 1951 when five watersheds ranging from 15 to 39 ha were instrumented to measure precipitation and streamflow. For the first 6 years, the watersheds were calibrated to determine "natural" streamflow patterns and relationships. In 1957-58, four cutting practices ranging from commercial clearcutting to a light selection cut were initiated on four of the watersheds (Reinhart et al. 1963; Hornbeck and Reinhart 1964). Later research examined water yield, erosion, and water quality in response to other forest management practices (Patric and Reinhart 1971; Aubertin and Patric 1974; Patric and Aubertin 1977; Helvey et al. 1989; Kochenderfer et al. 1990; Edwards et al. 1991a). In addition, studies of rainfall interception, solar radiation, soil-moisture dynamics, stormflow response, and streamflow modeling have been completed (Patric and Caruso 1979; Edwards and Helvey 1985; Helvey and Patric 1987). Precipitation and streamflow have been measured almost continuously on the five original watersheds since 1951 (Table 1), and four other watersheds have since been instrumented.

Description of Fernow Experimental Forest

The Fernow Experimental Forest is located in the Allegheny Mountain section of the unglaciated Allegheny Plateau (latitude 39° 05' N, longitude 79° 41' W). The topography is rugged, with elevations ranging from 533 to 1,112 m, and slopes of 10 to 60 percent. Slopes of 20 to 30 percent are common. The original Fernow Experimental Forest boundaries encompassed almost the entire Elklick Run drainage, approximately 6.2 km long and as much as 3.7 km wide (Fig. 1).

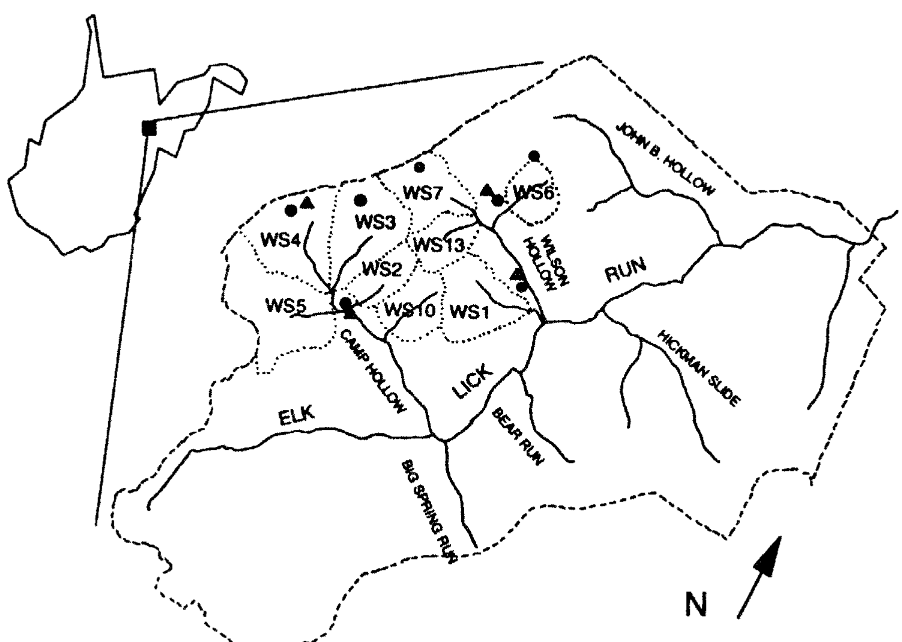


Figure 1.--Major streams and experimental watersheds (WS 1-7,10,13) on the Fernow Experimental Forest. Recording rain gages are indicated by a triangle and standard rain gages by a circle.

Table 1.--Description and summary of treatments on Fernow watersheds

Watershed	Treatment	Treatment date	Area	Aspect
			ha	
1	Installation	5/51	30.11	NE
	Clearcut to 6 inches d.b.h. except culls	5/57-6/58		
	Aerial application of Dimilin	5/86, 5/92		
2	Installation	5/51	15.50	S
	17-inch diameter limit cut	6/58-8/58		
	Repeat treatment (Compartment 2A)	7/72, 8/87		
	Repeat treatment (Compartment 2B)	7/77		
	Lime application to riparian zone (3 tons/acre)	11/90, 11/92		
3	Installation	5/51	34.27	S
	Intensive selection cut, including culls in trees > 5 inches d.b.h.	10/58-2/59		
	Repeat treatment	9/63-10/63		
	0.4-acre patch cuttings (total 5.6 acres), cut to 5 inches d.b.h., stems sprayed with herbicide	7/68-8/68		
	Clearcut to 1 inch d.b.h., all but buffer strip	7/69-5/70		
	Clearcut buffer strip (7.4 acres), clear stream channel and riparian zone	11/72		
	Aerial application of ammonium sulfate 3 times/year	1/89 to present		
4	Installation	5/51	38.73	ESE
	Control (no treatment)			
5	Installation	5/51	36.41	NNE
	Extensive selection cut, including culls in trees > 11 inches d.b.h.	8/58-11/58		
	Repeat treatment (Compartment 5A)	2/68-6/68, 1/78-6/78, 10/87		
	Repeat treatment (Compartment 5B)	5/83		
6	Installation	11/56	22.34	S
	Lower 27.5-acre clearcut	3/64-10/64		
	Maintained barren with herbicides	5/65-10/69		
	Upper 27.5-acre clearcut	10/67-2/68		
	Maintained barren with herbicides	5/68-10/69		
	Planted Norway spruce	3/73-4/73		
	Treatment of hardwood stems: aerial application of herbicide	8/75, 9/80		
7	Installation	11/56	24.23	E
	Upper 30-acre clearcut	11/63-3/64		
	Maintained barren with herbicides	5/64-10/69		
	Lower 30-acre clearcut	10/66-3/67		
	Maintained barren with herbicides	5/67-10/69		
10	Installation	11/84	15.20	S
	Control (no treatment)			
13	Installation			
	Control (no treatment)	11/88	14.23	NNE

The soils on the Fernow are predominantly loams and silt loams of the Calvin and Berks/Muskingam series (Typic Dystrochrepts), Belmont series (Typic Hapuludalfs), and Meckesville series (Typic Fragiudults). Soils are derived from acidic sandstones and shales of the Hampshire formation on the western half of the forest and from sandstones, shales, and limestone of the Mauch Chunk and limestone of the Greenbrier group on the eastern half of the forest. The gaged watersheds are located on shale or sandstone bedrock. Average soil depth is about 1 m (Losche and Beverage 1967).

The land that became the Fernow Experimental Forest was cut heavily between 1905 and 1910, as was much of West Virginia. Most trees less than 5 cm d.b.h. and species such as sugar maple (*Acer saccharum* Marsh.), beech (*Fagus grandifolia* Ehrh.), birch (*Betula lenta* L.) and hickory (*Carya* spp.) were considered unmerchantable at the time of logging. Logs were skidded with horses and hauled to the Elk Lick Company's mills on a railroad that paralleled the main tributary of Elklick Run. When cutting began again in the early 1950's, most of the trees harvested were residual stems from the early loggings. American chestnut (*Castanea dentata* (Marsh.) Borkh.) was a major forest component until it was killed by the chestnut blight (*Endothia parasitica*) in the 1920's.

Timber stands on the watersheds before treatments began were 40 to 50 years old, with many scattered older residuals. Vegetation on the watersheds fit into Core's (1966) mixed hardwood forests floristic province. Common tree species on the better sites included yellow-poplar (*Liriodendron tulipifera* L.), sugar maple, black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), and red oak (*Quercus rubra* L.). Dominant tree species on the poorer sites included various species of oak (*Quercus* spp.), hickory (*Carya* spp.), sourwood (*Oxydendrum arboreum* (L.) DC.), and sassafras (*Sassafras albidum* (Nutt.) Nees.). Sawtimber volumes averaged 129 m^3 ha^{-1} (13,000 board feet per acre) (Weitzman 1949).

Description of Hydrometeorologic Network

Since 1951, stream discharge has been measured on Watersheds 1-5 with 120° sharp-crested V-notch weirs equipped with FW-1 water level recorders (Fig. 2). After 6 years of calibration, Watershed 4 was chosen to be maintained as an untreated reference or control watershed. Most of the gaged streams are classified as second-order streams. The experimental watersheds and their treatments are described in Table 1. Currently, nine watersheds are monitored on the Fernow. An additional six gaged watersheds are located nearby on the Monongahela National Forest. However, data records from the latter watersheds are not as complete as those for the Fernow watersheds and are not discussed here.

Stream-water grab samples have been collected from Watersheds 1-5 on a weekly or biweekly basis since 1960. Electrical conductivity and pH are determined for all samples. Calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), sulfate (SO_4), nitrate (NO_3), chloride (Cl), ammonia (NH_3), and alkalinity have been analyzed for most samples since March 1971. Analyses of water chemistry on weekly grab samples began on Watersheds 6 and 7 in January 1960, on Watershed 10 in December 1983, and on Watershed 13 in May 1984.

The precipitation monitoring network on the Fernow consists of seven 20-cm-diameter standard rain gages and four weighing-type recording rain gages (Fig. 1), all located in the center of a forest opening large enough to provide an unobstructed zenith angle of 45° from the gage opening. Precipitation catch is measured weekly, usually on Tuesdays; strip charts on the recording rain gages are changed at that time. Total weekly precipitation collected by each standard gage is prorated into daily amounts using daily percentages from the nearest recording rain gage. Average daily watershed precipitation is computed by the Thiessen weighting method (U.S. Department of Agriculture 1962).

Chemical analyses of routine grab samples and precipitation were performed at the Timber and Watershed Laboratory at Parsons; pH was determined with color indicators until 1968, and with potentiometric methods thereafter. A Leeds and Northup meter was used from 1968 to 1975, a Corning Model

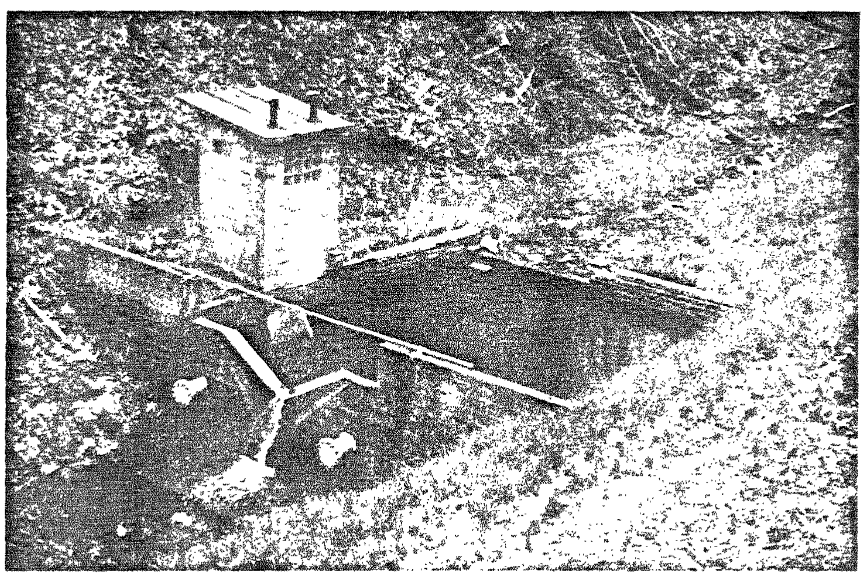


Figure 2.--A 120° V-notch weir equipped with a water-level recorder to measure streamflow from an experimental watershed (Watershed 5).

10 meter from 1975 to 1983, and a Fisher 815 MP meter since.[1] Cation concentrations were determined by atomic absorption. Anion concentrations were determined by the Hach method (Hach Chemical Co. 1977) until 1981, and by ion chromatography since.

Air temperature and relative humidity are monitored continuously at the Camp Hollow weather station with a hygrothermograph. Weekly maximum and minimum temperatures also are recorded with maximum/minimum thermometers. Air temperature and relative humidity have been monitored at this site since 1951. Wet-deposition collectors and bulk (wet+dry) collectors located in Camp Hollow and on Watershed 4 are part of the routine monitoring program on the Fernow.

Maximum and minimum stream temperatures are recorded weekly on Watersheds 3, 4, and 10 with standard maximum/minimum thermometers placed in the streams. When flow is low so that the thermometer is exposed to the air, no measurement is recorded. Stream temperature is monitored continuously on watersheds 3 and 4 with a USGS Minimonitor (Fig. 3); see Kochenderfer and Edwards (1990) for a complete description. The Minimonitor also records in situ pH and electrical conductivity. Meteorological information has been recorded since 1958 at the Timber and Watershed Laboratory at the Nursery Bottom site (approximately 3 km north of the Fernow). Although this site is lower in elevation than much of the Fernow (506 m compared to 625 to 867 m for the experimental watersheds), the completeness and detail of the data set warrant its inclusion here. Precipitation is measured daily in a standard rain gage and continuously with a recording rain gage. Maximum and minimum air temperatures are recorded daily from thermometers, and a hygrothermograph records temperature and relative humidity continuously. Evaporation during the growing season and windspeed have been monitored since September 1964, with a standard U.S. Weather Bureau evaporation pan and 3-cup anemometer, respectively.

The Nursery Bottom site is part of the National Dry Deposition Network (NDDN) and the National Atmospheric Deposition Program (NADP), providing data on air quality and precipitation chemistry. The Nursery Bottom NADP site was established in July 1978 (one of the first two sites in the United States). The NDDN site was established in January 1989. Aerochem-Metrics Model 301 wet/dry collectors collect wet and dry fallout separately (Peden 1981). Sulfur dioxide, particulate sulfate, particulate nitrate, and nitric acid are measured at the NDDN site with a 3-surface filter pack (U.S. Environmental Protection Agency 1990). Ozone is measured with a Thermo Electron Model 49 ozone analyzer (Edwards et al. 1991b). Supporting variables measured at the NDDN site include windspeed, wind direction, temperature, relative humidity, and solar radiation.

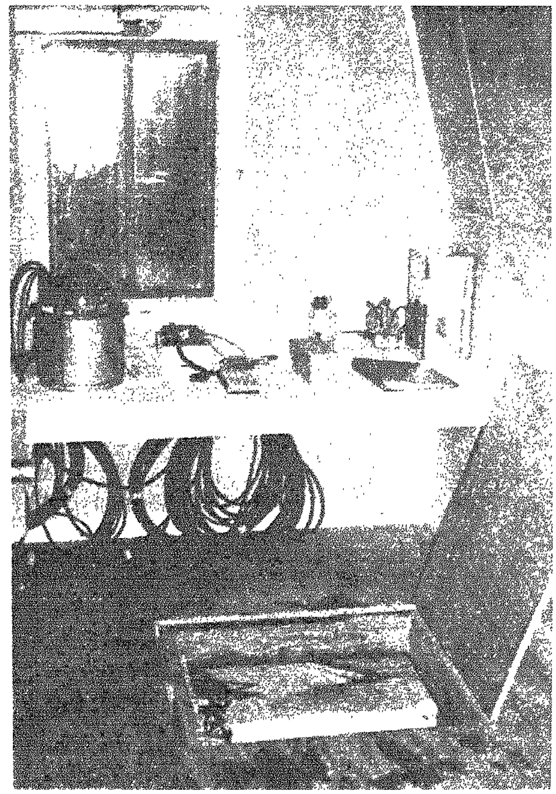


Figure 3.--Electrochemical continuous monitoring instrument (Minimonitor) and Omnidata Easy Logger data logger in a water-monitoring shelter. The trapdoor provides access to the shelter cellar where conductivity, pH, and temperature probes are located.

Unless otherwise indicated, data are summarized on a water-year basis. The Fernow water year begins on May 1 when the soil is fully recharged with moisture. Thus, the 1951 water year began on May 1, 1951, and ended on April 30, 1952. Data collected through the 1990 water year are included here.

Data Summaries

Precipitation

Total annual precipitation is shown in Table 2. Average annual precipitation across all watersheds was 1,450 mm, with expected variability in rainfall among them. Watershed 7 received the least precipitation on average, and Watershed 1 received the most; the average difference between the precipitation reaching the two watersheds was about 80 mm. Both are east-facing slopes, so the difference does not appear to be related to aspect.

[1] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U. S. Department of Agriculture or the Forest Service of any produce or service to the exclusion of others that may be suitable.

Table 2.--Annual precipitation for Fernow watersheds, in mm

Year	WS1	WS2	WS3	WS4	WS5	WS6	WS7
1951	1532	1479	1490	1472	1490		
1952	1295	1284	1282	1272	1282		
1953	1360	1333	1344	1353	1318		
1954	1697	1682	1688	1664	1677		
1955	1532	1497	1503	1479	1501		
1956	1782	1750	1751	1725	1732		
1957	1418	1380	1407	1384	1370	1313	1357
1958	1603	1589	1583	1572	1617	1537	1550
1959	1475	1466	1484	1465	1489	1412	1427
1960	1578	1542	1558	1539	1530	1535	1535
1961	1425	1426	1453	1459	1428	1377	1402
1962	1546	1518	1531	1525	1500	1503	1516
1963	1470	1467	1475	1476	1490	1407	1416
1964	1395	1387	1380	1394	1423	1351	1316
1965	1140	1114	1108	1096	1103	1111	1057
1966	1303	1278	1280	1273	1271	1322	1231
1967	1335	1303	1284	1288	1309	1258	1215
1968	1344	1311	1300	1298	1300	1252	1217
1969	1437	1357	1365	1383	1357	1378	1332
1970	1396	1345	1344	1357	1362	1301	1281
1971	1611	1539	1561	1545	1553	1519	1481
1972	1675	1646	1675	1657	1689	1584	1556
1973	1686	1835	1659	1642	1645	1551	1553
1974	1624	1586	1641	1604	1605	1588	1551
1975	1345	1304	1317	1230	1253	1259	1243
1976	1284	1254	1253	1257	1265	1213	1170
1977	1455	1400	1405	1385	1412	1348	1330
1978	1684	1624	1637	1613	1610	1619	1625
1979	1493	1462	1472	1456	1466	1434	1449
1980	1438	1412	1440	1385	1396	1365	1395
1981	1674	1658	1687	1630	1647	1568	1585
1982	1523	1465	1578	1447	1448	1468	1517
1983	1607	1569	1579	1512	1544	1528	1527
1984	1554	1510	1517	1470	1518	1485	1486
1985	1782	1735	1749	1757	1769	1738	1742
1986	1484	1406	1403	1377	1415	1400	1387
1987	1246	1205	1211	1175	1186	1178	1190
1988	1513	1454	1457	1426	1455	1447	1435
1989	1617	1573	1581	1567	1597	1547	1539
1990	1699	1633	1635	1608	1663	1619	1583
Mean	1501	1464	1476	1457	1467	1427	1418
Std. dev.	150	148	154	148	154	142	152
Mean [a]	1496	1457	1471	1451	1461	1427	1417
Std. dev.[a]	146	142	150	145	151	142	152

[a]Calculated using data from 1957 to 1990 only.

Annual precipitation for the last 40 years for Watershed 4 is shown in Figure 4. There is no evidence of an increase or decrease in annual precipitation over the last 40 years, but the year-to-year variability is great enough that any such trend could be masked. Note the low precipitation in water years 1965 and 1987, and the high precipitation in water years 1956 and 1985. Yearly streamflow is highly correlated with yearly precipitation.

Monthly precipitation for Watershed 4 for the last 40 years was distributed relatively evenly across the year and averaged 122 mm per month (Table 3). On average, spring and summer months (March through August) were those with the greatest precipitation. Data from the Nursery Bottom site show that snowfall averaged 1,370 mm per year (Fig. 5), most of which fell in January and February. Water content of the snow was not recorded, but assuming an average water

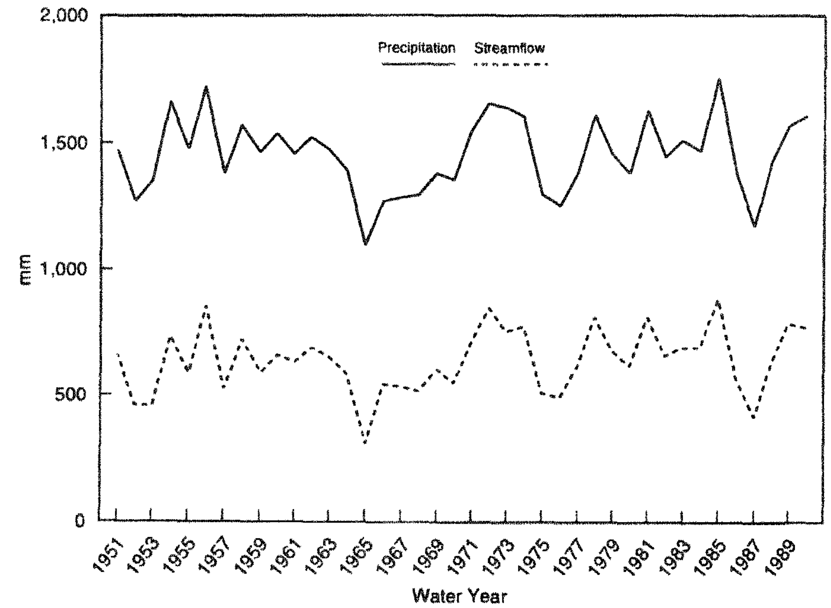


Figure 4.--Annual precipitation and streamflow for Watershed 4 during water years 1951-90.

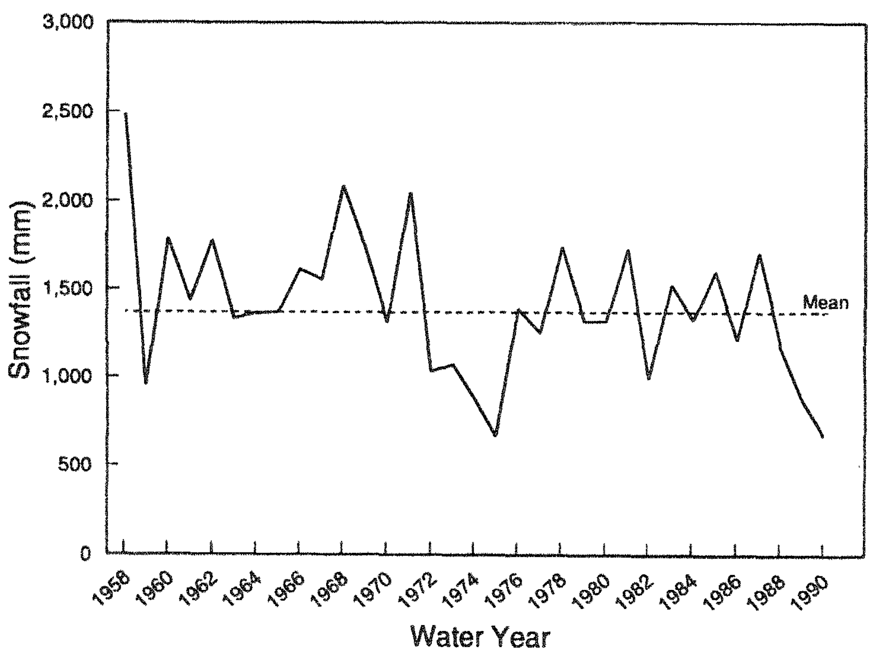


Figure 5.--Annual snowfall at Nursery Bottom site for water years 1958-90.

Table 3.--Monthly precipitation for Watershed 4, in mm

Water year	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	Total
1951	136	273	78	50	78	53	123	179	219	3	120	12	1472
1952	149	104	92	60	9	36	73	106	168	107	152	127	1271
1953	167	109	166	180	4	36	54	115	134	78	165	84	1330
1954	90	90	158	272	59	275	68	140	94	146	185	85	1664
1955	85	135	118	227	43	98	92	65	130	203	182	100	1479
1956	220	171	118	170	98	72	68	175	168	195	76	124	1725
1957	97	209	88	37	62	141	57	167	118	118	116	172	1384
1958	138	171	296	215	76	42	92	47	155	90	115	136	1572
1959	121	75	183	120	36	168	136	144	141	133	103	105	1465
1960	163	133	122	110	142	78	86	107	85	148	179	188	1539
1961	114	163	141	88	68	92	79	148	124	133	174	135	1459
1962	107	166	101	54	124	142	136	142	74	114	271	92	1525
1963	104	187	127	164	99	13	152	81	109	136	122	181	1476
1964	56	198	84	88	115	26	89	126	184	74	167	188	1394
1965	36	92	86	92	74	94	36	55	120	144	55	212	1096
1966	80	58	125	80	154	71	94	91	43	115	247	114	1273
1967	211	91	167	92	84	97	90	126	79	55	133	64	1288
1968	209	56	97	132	88	87	139	114	92	73	107	105	1298
1969	67	90	142	145	157	60	85	203	78	73	116	168	1383
1970	60	112	188	120	110	56	86	206	147	122	110	40	1357
1971	137	67	108	144	183	66	110	68	183	176	121	183	1545
1972	145	213	139	94	68	158	181	209	74	107	65	203	1657
1973	126	157	99	161	171	127	101	177	157	122	119	125	1642
1974	174	210	94	140	117	55	97	146	145	115	161	152	1604
1975	159	133	83	209	82	69	62	125	107	101	114	55	1300
1976	69	127	121	52	173	20	56	105	73	52	115	109	1256
1977	70	145	170	172	100	115	134	96	180	45	77	81	1385
1978	137	156	246	114	47	61	86	208	226	138	77	118	1615
1979	133	105	117	153	132	161	98	78	83	61	165	171	1457
1980	134	134	160	189	78	77	121	72	49	120	93	160	1388
1981	185	283	95	67	193	110	55	126	127	108	183	101	1632
1982	128	201	113	158	133	75	116	100	66	59	126	175	1450
1983	202	118	84	166	67	111	134	126	63	129	160	164	1523
1984	160	110	196	216	81	142	128	118	109	59	140	66	1471
1985	187	145	241	90	19	158	333	86	90	174	92	141	1757
1986	93	155	188	110	90	91	184	88	108	62	52	155	1375
1987	62	181	43	88	149	47	102	117	89	88	102	105	1173
1988	157	48	104	98	201	61	115	80	140	152	178	93	1426
1989	170	267	145	145	100	129	106	92	123	108	72	130	1587
1990	209	115	180	105	115	113	52	195	129	89	167	138	1607
Mean	130	144	137	129	103	97	105	124	120	109	132	129	1458
Std. dev.	48	57	52	54	44	52	50	44	44	41	48	42	149

content of 10 to 12 percent, snowfall contributed approximately 14 percent of the annual precipitation. Snow cover is intermittent throughout the winter, with snowpacks lasting only a few days to less than 2 weeks. Rain-on- snow events are common. Because the experimental watersheds are slightly higher in elevation than the Nursery Bottom site, they receive more snow and retain snowfall longer.

The 20 largest precipitation events (storms) from 1951 to 1991 are listed in Table 4. Storms are separated by 6-hour or longer periods that are free of precipitation. The single largest daily rainfall occurred on November 4, 1985, when 143 mm of rain fell due to Hurricane Juan. Hurricanes influence precipitation on the Fernow despite its inland and upland location. Most of the large storms occurred during the growing season (May 1 to October 31), and many of these occurred in late September and October. The Nursery Bottom site consistently receives slightly less precipitation each year than the Fernow, but long-term trends are similar

Table 4.--Twenty largest storm events recorded at Nursery Bottom weather station, in descending order

Rank	Amount	Duration	Date		Type
	mm	*Hours*			
1	154	42	11/2-6/85	Hurricane Juan	Rain
2	121	49	8/15-17/75		Rain
3	119	87	6/20-24/72		Rain
4	114	14	10/15/54	Hurricane Hazel	Rain
4	114	49	3/5-7/67		Rain then snow
6	97	49	12/8-10/72		Rain
7	93	67	9/27-30/64		Rain
8	92	42	5/23-24/68		Rain
8	92	25	6/5-6/81		Rain
10	91	33	10/19-22/85		Rain
11	90	53	5/31-6/2/74		Rain
12	89	22	9/13/88		Rain
12	89	16	7/8-9/85		Rain
14	88	88	3/19-22/63		Rain 1/2, snow 1/2
15	86	19	9/29-30/73		Rain
16	84	63	9/9-11/60	Hurricane Donna	Rain
16	84	68	4/2-7/87		Rain
18	83	38	7/2-4/78		Rain
18	83	26	2/9-10/57		Rain
20	81	58	10/7-9/76		Rain

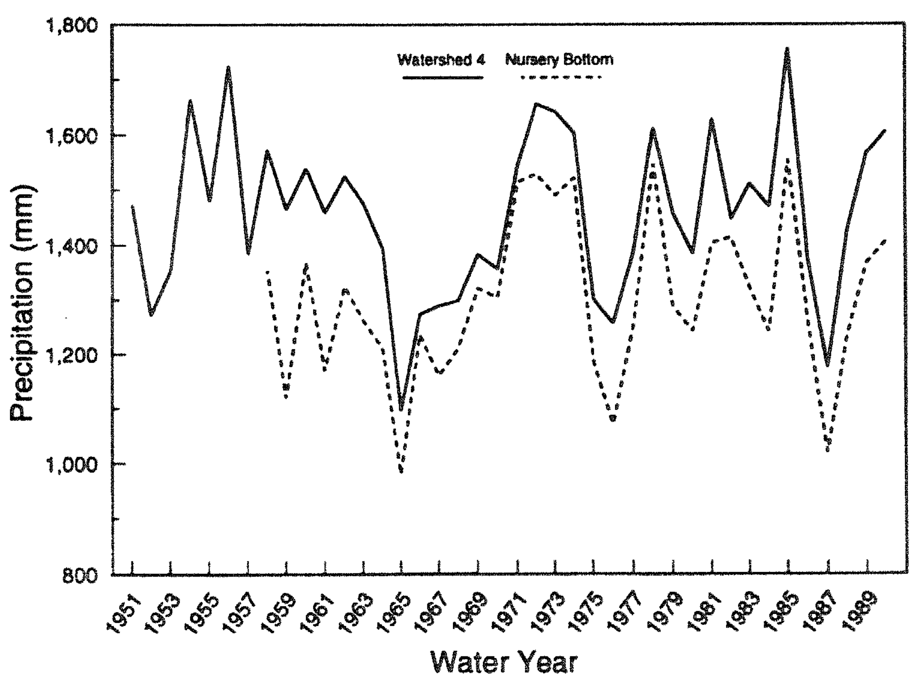


Figure 6.--Annual precipitation for Watershed 4 and the Nursery Bottom site during water years 1951-90.

Table 5.--Annual streamflow from Fernow watersheds, in mm (T indicates treatment of watershed; see Table 1 for treatment details)

Water	Watershed								
year	1	2	3	4	5	6	7	10	13
1951	--	--	663	660	--	--	--	--	--
1952	426	492	457	461	596	--	--	--	--
1953	420	473	450	458	588	--	--	--	--
1954	655	776	712	736	917	--	--	--	--
1955	544	603	583	588	760	--	--	--	--
1956	811	900	855	856	1056	--	--	--	--
1957	539T	555	541	526	662	424	652	--	--
1958	801T	788T	711T	724	933T	579	860	--	--
1959	638	685	593	590	766	471	706	--	--
1960	699	734	690	660	832	538	843	-	--
1961	596	675	633	632	776	474	773	--	--
1962	697	767	698	691	829	590	862	--	--
1963	597	682	646T	651	843	497	777T	--	--
1964	552	647	596	583	762	520T	880T	--	--
1965	329	369	330	308	418	379T	532T	--	--
1966	517	609	582	544	693	574T	826T	--	--
1967	511	591	559	535	700	520T	909T	--	--
1968	499	568	543T	517	669T	650T	895T	--	--
1969	572	657	654T	603	746	746T	984T	--	--
1970	499	616	775T	549	698	624	899	--	--
1971	683T	772	798	713	901	758	1044	--	--
1972	776	934T	912T	849	1074	797	1195	--	--
1973	718	857	834	755	--	710T	1077	--	--
1974	742	884	851	776	--	771	1131	--	--
1975	490	571	557	509	--	517T	732	--	--
1976	466	543	508	491	--	506T	671	--	--
1977	600	690	673	617	--	655T	844	--	--
1978	766	910	840	813	--	865	1100	--	--
1979	658	--	712	678	--	673	927	--	--
1980	621	--	633	617	--	608T	818	--	--
1981	750	--	839	813	T	845	1049	--	--
1982	648	--	695	656	--	706	911	--	--
1983	693	--	731	690	--	695	945	--	--
1984	674	--	710	690	--	680	913	--	--
1985	950	--	915	885	--	886	1126	839	--
1986	589T	--	598	565	--	554	782	572	--
1987	403	--	435	415	--	358	564	376	--
1988	567	771T	622	626	T	512T	821	610	--
1989	732	898	779T	788	--	691T	995	725	987
1990	729	861T	728T	770	--	587	935	730	975
Mean	619	696	666	640	772	614	882	642	981
Std. dev.	128	144	133	128	151	132	155	147	6

(Fig. 6). An analysis of years 1982-89 revealed no statistically significant differences in rainfall between the Nursery Bottom and the Fernow.[2]

[2] Gilliam, F. S.; Adams, M. B. Precipitation chemistry in the West Virginia Appalachians: temporal and spatial variation. Manuscript in preparation.

Streamflow

Annual streamflow for the Fernow watersheds is summarized in Table 5. Differences in average streamflow are apparent among watersheds, but these differences reflect experimental treatments as well as inherent variability. Watershed treatments and treatment effects on streamflow are described in Kochenderfer et al. (1990). The reference watershed (Watershed 4) was used in analyses of streamflow and for other similar analyses. Because Watershed 4 has not been cut since about 1910 (except for salvage of dead American chestnut in the 1940's), it provides the best estimate of streamflow for undisturbed conditions on the Fernow. Annual streamflow on Watershed 4 averaged 640 mm, ranging from 330 mm in 1965 to 915 mm in 1985.

Streamflow can be highly variable during the year but on average was greatest during late winter and early spring and least during early autumn (September-October)(Table 6). Note that there are several years with months for which no streamflow was recorded, and that there was virtually no streamflow of 7 months in 1965.

Table 6.--Monthly streamflow from Watershed 4, in mm

Water year	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	Total
1951	70	109	21	1	1	0	8	96	165	27	79	85	660
1952	75	6	1	0	0	0	0	15	100	81	94	87	461
1953	86	4	31	46	0	0	0	7	78	45	114	47	458
1954	35	4	8	66	4	105	40	101	41	141	142	48	736
1955	32	16	9	42	1	1	9	33	66	180	138	64	588
1956	117	72	39	62	3	4	14	120	135	146	58	84	856
1957	29	41	6	0	0	1	2	78	55	53	114	147	526
1958	83	56	110	106	4	1	15	27	112	60	75	77	724
1959	55	9	5	3	0	7	43	107	113	39	118	91	590
1960	83	31	5	8	14	2	26	28	47	152	140	124	660
1961	66	63	12	7	0	1	7	55	101	88	140	90	632
1962	23	67	3	0	0	11	94	46	81	44	275	47	691
1963	59	53	29	23	14	0	26	44	112	29	142	121	651
1964	26	51	3	1	1	0	4	64	114	62	127	132	583
1965	11	1	1	0	0	0	0	1	17	105	52	119	308
1966	60	9	1	0	2	10	18	57	37	54	230	65	544
1967	124	10	17	3	1	12	25	70	65	44	120	44	535
1968	102	14	1	5	1	1	47	75	68	44	89	70	517
1969	38	2	3	13	21	7	37	112	91	76	75	128	603
1970	18	5	19	6	5	2	25	120	119	120	82	28	549
1971	73	7	1	3	39	8	37	69	118	117	116	126	713
1972	77	85	54	5	0	28	125	167	42	67	60	138	849
1973	61	57	2	23	21	40	70	122	123	73	83	80	755
1974	54	119	4	3	27	7	42	97	112	100	108	103	776
1975	77	35	6	40	3	2	14	49	91	90	66	36	509
1976	18	10	7	1	4	97	41	51	11	103	87	61	491
1977	32	8	27	46	5	41	63	91	84	14	151	56	617
1978	84	29	88	18	3	1	14	144	147	140	72	73	813
1979	64	11	9	29	29	93	58	53	40	58	121	114	678
1980	71	67	14	67	5	3	51	50	21	95	79	94	617
1981	99	140	10	3	41	25	33	83	98	96	120	66	813
1982	40	87	14	15	30	27	64	77	26	76	77	124	656
1983	111	20	4	3	2	7	65	89	29	101	129	130	690
1984	51	5	57	90	5	36	73	94	30	110	84	54	690
1985	64	68	73	6	0	13	228	58	48	144	100	84	885
1986	37	18	58	7	5	14	115	60	58	44	49	100	565
1987	23	29	3	0	2	2	22	76	62	61	75	59	415
1988	102	6	1	0	14	5	57	52	101	98	128	62	626
1989	111	123	29	22	20	56	67	44	121	63	46	86	788
1990	110	15	52	6	5	26	23	132	101	75	124	100	770
Mean	64	39	19	19	8	17	43	73	80	83	107	86	640
Std. dev.	31	38	23	26	11	27	42	37	37	38	33	31	128

Peak stormflows for Watershed 4 are shown in Table 7. Not surprisingly, peak flows are somewhat correlated with the largest storm events; however, during the growing season (as in the August 1975 and June 1972 storms), large storms do not always result in the greatest stormflow due to evapotranspirational demand and soil-moisture depletion. Fourteen of the 20 highest flows were recorded during the dormant season when evaporative demand is low.

Annual precipitation less runoff (streamflow), expressed as PPT-RO, is shown for Watersheds 1-7 in Table 8. PPT-RO provides one means of estimating evapotranspiration and leakage. Potential evapotranspiration was estimated as 559 mm yr^{-1} by Patric and Goswami (1968) and as 614 mm yr^{-1} by Troendle and Phillips (1970). We can infer that there is some loss due to deep seepage or leakage around the weir cutoff walls. However, leakage has varied little over the years. Patric (1973) reported that one end of the cutoff wall on Watershed 6 is known to be seated in colluvium. The same is believed true for Watersheds 4 and 1.

Precipitation Chemistry

Annual and seasonal precipitation-weighted mean concentrations of Ca, Mg, K, Na, NH_4, NO_3, Cl, and SO_4 in precipitation are shown in Table 9. During 1978-91, mean annual precipitation pH ranged from 4.12 to 4.31 (Fig. 7), with a seasonal mean as low as 3.99 during the summer of 1983. These pH values were among the lowest in the United States (NADP 1991). An examination of Figure 7 reveals no apparent trends in pH of precipitation during the last 20 years, and large year-to-year variability. Summer precipitation generally was more acidic than that of other seasons. Concentrations of sulfate and nitrate also were among the highest reported for the United States (NADP 1991). Concentrations of sulfate and nitrate ions in precipitation were highest in summer and lowest in winter.

Table 7.--Watershed 4 streamflow peaks, in mm

Rank	Date	Peak flow	
1	11/4/85	161	Juan
2	10/15/54	114	Hazel
3	6/6/81	109	
4	2/10/57	98	
5	5/24/68	83	
6	3/5/63	74	
7	3/6/67	72	
8	12/22/70	70	
9	5/28/56	67	
10	8/11/84	63	
10	4/30/66	63	
12	1/22/59	61	
13	3/21/62	59	
14	3/19/63	58	
15	7/9/85	54	
15	1/29/70	54	
17	4/28/58	53	
18	11/28/85	51	
19	3/5/64	49	
19	8/16/75	49	

Stream Chemistry

Mean annual stream pH for Watershed 4 has remained relatively constant at about 6.0 (Fig. 8). The relatively large changes in pH from 1960 to 1968 probably reflect the

Table 8.--Annual precipitation minus annual streamflow (PPT-RO) for Fernow watersheds, in mm

Water year	WS1	WS2	WS3	WS4	WS5	WS6	WS7
1951	--	--	827	812	--	--	--
1952	869	792	825	810	686	--	--
1953	940	860	894	895	730	--	--
1954	1042	906	976	928	760	--	--
1955	988	894	920	891	741	--	--
1956	971	850	896	869	676	--	--
1957	879	825	866	858	708	889	705
1958	802	801	872	848	684	958	690
1959	837	781	891	875	723	941	721
1960	897	808	868	879	698	997	692
1961	829	751	820	827	652	903	629
1962	849	751	833	834	671	913	654
1963	873	785	829	825	647	910	639
1964	843	740	784	811	661	831	436
1965	811	745	778	788	685	732	525
1966	786	669	698	729	578	748	405
1967	824	712	725	753	609	738	306
1968	845	743	757	781	631	602	322
1969	865	700	711	780	611	632	348
1970	897	729	569	808	664	677	382
1971	928	767	763	832	652	761	437
1972	899	712	763	808	615	787	361
1973	968	778	825	887	--	841	476
1974	882	702	790	828	--	817	420
1975	855	733	760	721	--	742	511
1976	818	711	745	766	--	707	499
1977	855	710	732	768	--	693	486
1978	918	714	797	800	--	754	525
1979	835	--	760	778	--	761	522
1980	817	--	807	768	--	757	577
1981	924	--	837	817	--	723	536
1982	875	--	882	791	--	762	606
1983	914	--	848	822	--	833	582
1984	880	--	807	780	--	805	573
1985	832	--	834	872	--	852	616
1986	895	--	805	812	--	846	605
1987	843	--	776	760	--	820	626
1988	946	683	835	800	--	935	614
1989	885	675	802	779	--	928	544
1990	970	772	907	838	--	1032	648
Mean	881	760	810	816	670	813	536
Std. dev.	56	61	71	46	46	102	114

Table 9.--Precipitation chemistry (1978-91) for the Nursery Bottom NADP site (Precipitation-weighted means)[a]

Year	Ca	Mg	K	Na	NH_4	NO_3	Cl	SO_4	pH	Electrical conductivity
	----	----	----	----	mgL^{-1}	----	----	----		$uS\ cm^{-1}$
Annual[b]										
1978	0.15	0.020	0.028	0.205	0.18	1.32	0.13	2.99	4.26	24.8
1979	0.23	0.030	0.041	0.197	0.24	1.75	0.13	3.35	4.26	29.0
1980	0.29	0.032	0.044	0.150	0.24	2.04	0.21	3.56	4.16	34.3
1981	0.29	0.045	0.039	0.080	0.28	1.89	0.16	3.54	4.18	35.8
1982	0.15	0.024	0.024	0.048	0.20	1.30	0.10	2.64	4.31	27.1
1983	0.16	0.023	0.029	0.046	0.20	1.39	0.11	2.52	4.29	26.2
1984	0.15	0.026	0.025	0.051	0.19	1.37	0.11	2.46	4.31	25.6
1985	0.18	0.028	0.031	0.045	0.23	1.62	0.12	3.18	4.19	33.5
1986	0.23	0.031	0.029	0.063	0.29	2.06	0.16	3.96	4.12	39.5
1987	0.17	0.024	0.023	0.057	0.28	1.82	0.14	3.06	4.22	31.3
1988	0.18	0.022	0.021	0.051	0.17	1.61	0.12	2.95	4.25	28.6
1989	0.12	0.016	0.019	0.046	0.25	1.56	0.12	2.79	4.23	29.6
1990	0.12	0.017	0.017	0.046	0.22	1.42	0.13	2.49	4.28	27.2
1991	0.15	0.018	0.023	0.047	0.20	1.62	0.13	2.79	4.24	29.6
Winter[c]										
1979	0.14	0.014	0.028	0.144	0.07	1.06	1.13	1.89	4.41	17.7
1980	0.41	0.036	0.050	0.217	0.11	2.14	0.26	2.42	4.43	22.8
1981	0.51	0.036	0.062	0.066	0.25	2.16	0.28	2.88	4.34	30.5
1982	0.34	0.042	0.049	0.076	0.19	1.80	0.17	2.91	4.32	27.8
1983	0.16	0.024	0.033	0.062	0.11	1.39	0.17	1.20	4.60	15.2
1984	0.14	0.021	0.022	0.041	0.09	1.13	0.12	1.34	4.58	15.1
1985	0.14	0.027	0.030	0.074	0.09	1.31	0.14	1.61	4.49	18.5
1986	0.55	0.054	0.065	0.080	0.28	2.57	0.21	3.39	4.22	33.2
1987	0.23	0.025	0.025	0.053	0.25	1.94	0.15	2.00	4.37	23.3
1988	0.13	0.015	0.016	0.050	0.08	1.40	0.11	1.77	4.42	19.3
1989	0.11	0.013	0.013	0.056	0.09	1.29	0.13	1.81	4.41	19.5
1990	0.13	0.018	0.018	0.061	0.17	1.47	0.15	1.73	4.39	20.9
1991	0.08	0.010	0.013	0.040	0.09	1.08	0.11	1.59	4.43	18.9
Spring										
1979	0.27	0.040	0.077	0.171	0.36	1.85	0.15	3.64	4.28	28.2
1980	0.29	0.038	0.062	0.307	0.29	2.11	0.24	3.42	4.22	31.7
1981	0.24	0.037	0.041	0.090	0.41	2.14	0.17	3.65	4.13	38.1
1982	0.21	0.031	0.028	0.064	0.25	1.42	0.11	2.69	4.34	26.0
1983	0.13	0.016	0.030	0.043	0.14	0.89	0.09	1.51	4.57	15.5
1984	0.18	0.031	0.025	0.055	0.19	1.36	0.10	2.10	4.41	21.9
1985	0.14	0.022	0.023	0.052	0.30	1.63	0.12	3.04	4.21	32.6
1986	0.32	0.055	0.036	0.089	0.38	2.41	0.22	3.97	4.16	38.1
1987	0.21	0.030	0.027	0.048	0.34	2.22	0.13	3.49	4.15	35.2
1988	0.26	0.027	0.042	0.052	0.20	2.02	0.14	3.12	4.22	31.5
1989	0.17	0.021	0.025	0.048	0.26	1.89	0.11	2.95	4.19	31.4
1990	0.15	0.022	0.028	0.052	0.27	1.80	0.14	2.55	4.28	27.9
1991	0.23	0.027	0.036	0.067	0.24	1.68	0.15	2.41	4.36	24.5

Table 9.--(Continued)

Year	Ca	Mg	K	Na	NH_4	NO_3	Cl	SO_4	pH	Electrical conductivity
	------------------ mgL^{-1} ------------------									$uS\ cm^{-1}$
Summer										
1978	0.18	0.025	0.032	0.223	0.23	1.68	0.13	4.04	4.14	33.6
1979	0.24	0.036	0.036	0.145	0.28	1.92	0.12	4.49	4.11	39.1
1980	0.25	0.029	0.032	0.099	0.21	1.95	0.18	4.17	4.06	40.5
1981	0.26	0.052	0.028	0.087	0.26	1.89	0.14	4.41	4.05	45.0
1982	0.13	0.020	0.022	0.028	0.21	1.34	0.07	3.36	4.20	34.3
1983	0.26	0.037	0.038	0.052	0.43	2.20	0.12	5.11	3.99	50.0
1984	0.16	0.025	0.026	0.038	0.30	1.71	0.12	3.81	4.11	39.3
1985	0.20	0.032	0.039	0.032	0.30	2.09	0.14	4.36	4.05	44.5
1986	0.15	0.022	0.024	0.047	0.29	1.96	0.14	5.07	4.01	49.6
1987	0.17	0.022	0.022	0.056	0.28	1.92	0.14	4.37	4.07	43.5
1988	0.19	0.023	0.011	0.045	0.19	1.87	0.10	4.68	4.04	43.6
1989	0.12	0.019	0.023	0.045	0.32	1.70	0.12	3.53	4.14	36.9
1990	0.13	0.017	0.016	0.032	0.26	1.76	0.14	3.55	4.12	38.6
1991	0.16	0.017	0.025	0.022	0.29	2.15	0.12	4.93	4.00	49.5
Fall										
1978	0.16	0.023	0.028	0.139	0.26	1.68	0.14	3.41	4.19	29.7
1979	0.24	0.028	0.023	0.345	0.23	1.74	0.12	2.91	4.37	24.9
1980	0.21	0.022	0.026	0.035	0.24	1.66	0.16	3.00	4.23	29.5
1981	0.19	0.046	0.028	0.061	0.20	1.37	0.08	2.77	4.34	26.2
1982	0.09	0.016	0.013	0.049	0.16	1.03	0.09	1.81	4.43	20.7
1983	0.11	0.021	0.023	0.043	0.12	1.31	0.11	2.05	4.34	23.3
1984	0.11	0.023	0.020	0.060	0.09	1.02	0.10	1.55	4.48	16.8
1985	0.07	0.020	0.010	0.042	0.08	0.81	0.08	2.23	4.33	24.4
1986	0.09	0.013	0.017	0.054	0.20	1.49	0.12	2.70	4.24	29.2
1987	0.15	0.026	0.023	0.078	0.28	1.33	0.17	2.06	4.44	20.0
1988	0.12	0.017	0.012	0.050	0.18	1.13	0.09	2.38	4.37	21.8
1989	0.07	0.010	0.010	0.037	0.25	1.22	0.10	2.56	4.28	26.9
1990	0.10	0.015	0.013	0.049	0.23	1.15	0.12	2.29	4.36	24.0
1991	0.09	0.014	0.015	0.049	0.19	1.45	0.12	2.65	4.22	29.1

[a]Summary data provided by National Atmospheric Deposition Program (1992).
[b]Values represent calendar year means.
[c]Winter = December through February; Spring = March through May; Summer = June through August; Fall = September through November.

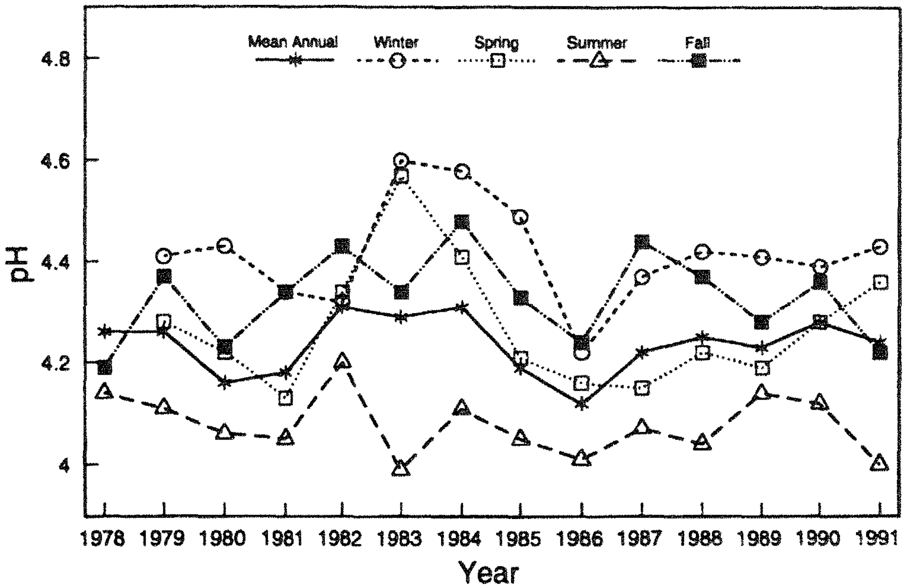


Figure 7.--Mean annual and seasonal precipitation pH (weighted by precipitation volume) for Nursery Bottom site during calendar years 1978-91.

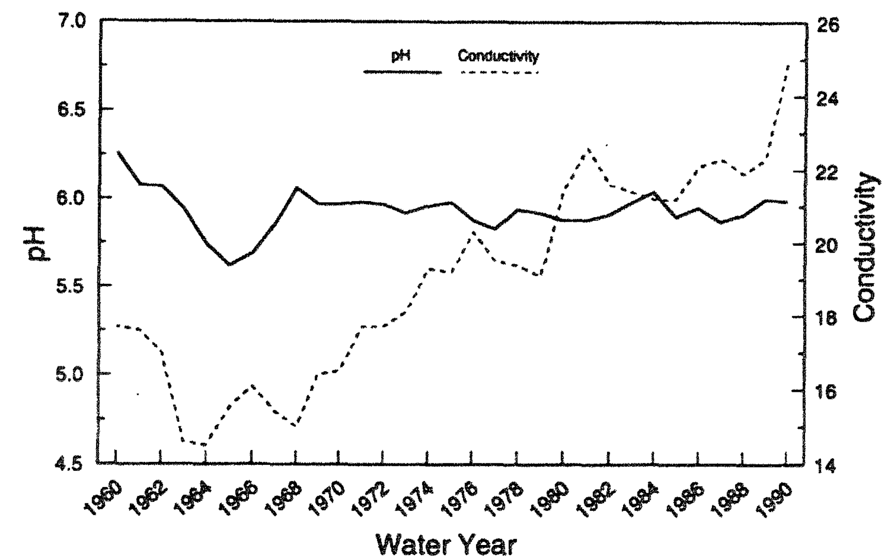


Figure 8.--pH and conductivity of streamwater from Watershed 4 during water years 1960-90.

inherent variability in the colorimetric methods used rather than large changes in pH. Helvey and Kochenderfer (1991) analyzed time trends in stream pH between 1968 and 1982 but reported inconclusive results because of instrument changes in 1975 that coincided with a drop in annual pH. The authors concluded that any changes over time were small if they existed at all. By contrast, electrical conductivity increased steadily over the same period (Fig. 8, Edwards and Helvey 1991). Ca and NO_3 concentrations also increased (Table 10) and were primarily responsible for the increase in conductivity (Edwards and Helvey 1991). Other constituents changed randomly over time or as a result of instrument changes (e.g., NH_4). There was relatively little variation in mean monthly chemistry (Table 11).

Stream Temperature

Mean monthly stream temperatures for Watershed 4 (Table 12) were highest from July through September, also the

Table 10.--Annual average stream water concentrations for Watershed 4

Water year	Ca	Mg	K	Na	NH_4	NO_3	pH	SO_4	Electrical conductivity
	----------	----------	----------	----------	mgL^{-3}	----------	----------	----------	$uS\ cm^{-1}$
1969	1.14	0.490	0.582	0.562		0.42	5.97	3.53	16.4
1970	0.93	0.477	0.649	0.573	0.11	0.46	5.97	3.19	16.5
1971	1.16	0.443	0.606	0.439	0.15	0.65	5.98	3.38	17.7
1972	1.11	0.435	0.67	0.521	0.04	0.73	5.97	3.19	17.7
1973	1.20	0.470	0.689	0.521	0.000	1.12	5.92	3.42	18.1
1974	1.18	0.391	0.621	0.578	0.04	2.08	5.96	3.40	18.3
1975	1.18	0.451	0.620	0.546	0.05	3.34	5.98	3.09	19.2
1976	1.29	0.476	0.555	0.459	0.08	1.76	5.88	3.14	20.3
1977	1.08	0.505	0.232	0.445	0.12	2.13	5.83	4.91	19.5
1978	1.33	0.568	0.767	0.433	0.15	2.53	5.94	6.50	19.4
1979	1.30	0.496	0.694	0.398	0.18	2.74	5.92	5.50	19.0
1980	2.44	0.615	0.644	0.313	0.14	3.72	5.88	5.92	21.4
1981	1.89	0.782	0.798	0.569	0.13	5.02	5.88	3.56	22.6
1982	1.52	0.750	0.423	0.411	0.16	4.08	5.91	3.41	21.6
1983	1.45	0.754	0.588	0.432	0.10	3.78	5.99	3.98	21.4
1984	1.48	0.772	0.736	0.467	0.18	3.38	6.04	4.43	21.2
1985	1.47	0.764	0.726	0.450	0.16	3.24	5.90	4.50	21.2
1986	1.45	0.776	0.666	0.468	0.16	3.26	5.95	4.40	22.1
1987	1.43	0.724	0.688	0.476	0.10	3.05	5.87	4.38	22.3
1988	1.54	0.754	0.65	0.419	0.001	2.90	5.92	4.88	21.9
1989	1.67	0.759	0.69	0.395	0.001	3.36	6.00	4.54	22.3
1990	1.74	0.823	0.702	0.479	0.000	4.32	5.99	4.30	24.9

Table 11.--Watershed 4 stream chemistry, monthly means for water years 1970-90

Month	Ca	NO_3	SO_4	pH	Electrical conductivity
	----------	mgL^{-1}	----------		$uS\ cm^{-3}$
May	1.38	2.52	4.07	5.96	19.7
June	1.50	2.74	3.95	5.93	20.3
July	1.40	2.70	4.13	5.95	19.9
Aug.	1.43	2.21	3.93	5.95	20.5
Sept.	1.47	2.74	4.22	5.96	20.9
Oct.	1.43	2.52	4.40	5.96	20.8
Nov.	1.42	2.61	4.30	5.94	20.6
Dec.	1.34	2.66	4.52	5.88	20.4
Jan.	1.36	3.23	4.06	5.85	20.2
Feb.	1.36	3.36	3.93	5.81	20.5
March	1.39	3.54	3.96	5.83	20.1
April	1.58	3.10	3.85	5.92	20.4

months of lowest flow. Stream temperatures were lowest in January and February. Mean annual temperature varied only by several degrees from year to year. Stream temperatures also have been recorded on Watershed 10 (another untreated control catchment) since 1984. A comparison of stream temperatures for the two control watersheds during 1984-90 reveals few differences (Fig. 9). Fluctuations in stream temperature followed fluctuations in air temperature, suggesting that ground-water input is constant or relatively small.

Air Temperature

Mean monthly air temperatures ranged from -1° to 5°C in January to 25°C in July for both the Camp Hollow (Fig. 10) and Nursery Bottom sites (not shown). The record low temperature of -29.4°C was recorded on January 16, 1982, at Camp Hollow. The record high temperature of 37.2°C was recorded on July 16, 1988, also at Camp Hollow. Daily variation is greater in winter than in summer.

Solar Radiation

Solar radiation was measured for 12 years (1965-77) at the Nursery Bottom with a Kipp-Zonen pyranometer (Patric and Caruso 1979). Mean daily radiation peaked in June (Fig. 11) when the range of measured daily radiation also was greatest. Daily radiation values were lowest and least variable during December. On clear days (those with less than one hour of cloudiness after the usual morning fog), daily inputs of solar energy approached the upper limits expected at the site during solstice and equinox months. The authors concluded that: 1) 700 or more langleys (29.33 MJ m^{-2}) are probable for only 1 day in both May and June; 2) at

Table 12.--Mean monthly stream temperatures for Watershed 4, in °C

Water year	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	Mean
1959	12	13	17	17	16	10	9	7	6	5	4	10	11
1960	11	13	14	16	15	11	8	5	4	3	7	7	10
1961	10	12	13	15	17	12	8	5	4	4	4	7	9
1962	12	13	12	15	--	12	8	7	4	3	6	10	9
1963	11	12	14	15	13	11	8	7	3	3	6	7	9
1964	11	13	14	--	--	--	--	7	6	4	4	8	8
1965	13	14	16	15	--	--	--	4	3	3	5	7	9
1966	10	13	17	17	13	10	7	6	5	5	6	8	10
1967	9	13	14	15	12	11	6	5	3	4	5	8	9
1968	8	11	15	16	13	11	7	4	3	3	2	7	8
1969	10	13	16	15	13	12	7	4	2	3	3	7	9
1970	10	13	14	15	14	11	7	6	3	3	5	7	9
1971	9	12	16	15	15	13	9	7	6	3	6	8	10
1972	11	13	14	16	15	11	9	7	4	4	7	9	10
1973	10	13	16	16	16	13	9	8	7	6	7	8	11
1974	12	12	14	16	15	9	10	6	6	6	6	7	10
1975	11	13	16	17	14	12	10	7	4	5	7	8	10
1976	11	13	16	16	14	11	7	5	2	4	7	9	10
1977	11	13	16	16	16	11	9	7	3	2	4	8	10
1978	9	12	14	16	16	10	8	6	6	3	5	8	9
1979	11	12	14	15	13	11	8	6	4	2	5	8	9
1980	10	12	16	16	16	11	7	6	2	3	5	8	9
1981	10	13	16	16	14	9	7	4	3	4	5	7	9
1982	12	12	15	16	13	11	9	6	4	4	5	7	10
1983	9	12	16	17	19	12	9	7	4	4	6	8	10
1984	11	14	15	15	14	12	9	8	4	4	6	9	10
1985	12	13	14	17	17	13	12	4	3	6	4	9	10
1986	12	14	15	17	13	12	10	7	4	3	5	8	10
1987	11	14	17	18	15	9	8	7	4	4	5	9	10
1988	11	13	16	--	14	9	8	4	6	6	8	8	9
1989	11	14	17	17	16	12	10	8	5	7	7	9	11
1990	12	13	16	17	16	11	8	8	6	6	7	9	11
Mean	11	13	15	16	15	11	8	6	4	4	5	8	
Std. dev.	1.1	0.7	1.2	0.9	1.6	1.1	1.2	1.3	1.3	1.3	1.3	2.3	

least 100 langleys (41.90 MJ m^{-2}) are probable for every day in July and August; 3) radiation in excess of 300 langleys (12.57 MJ m^{-2}) is unlikely from November through January; and 4) 500 or more langleys (20.95 MJ m^{-2}) are likely for half of the days in June. Mature forests of the Fernow absorb 86 percent of the solar radiation during leafless, snowfree conditions, 80 percent during full-leaf conditions, and 68 percent when there is snow cover (Hornbeck 1970).

Windspeed/Direction

Windspeed and direction have been recorded at the NDDN site on the Nursery Bottom since 1988. (Windspeed has been recorded only since 1964 at the Nursery Bottom weather station; those data are not summarized here because the NDDN data provide greater information despite the shorter period of record.) Average wind strength for the 4 years of record was calculated as wind direction X speed X time, and expressed in km day^{-1}. Figures 12-13 display wind occurrences by octant for the growing and dormant seasons. During the growing season, the wind most often was from the WNW or the ESE. During the dormant season, it most often was from the WNW. Wind strength generally was greater during the dormant season (Fig. 13), particularly for winds from the WNW.

Evaporation

Evaporation data are summarized by month and water year in Table 13. As expected, evaporation was greatest during the summer months of June and July. Almost no measurements were collected in water year 1986, following a flood in November 1985 that destroyed the weather station. Evaporation, as measured by the Nursery Bottom evaporation pan, is approximately 45 percent of precipitation.

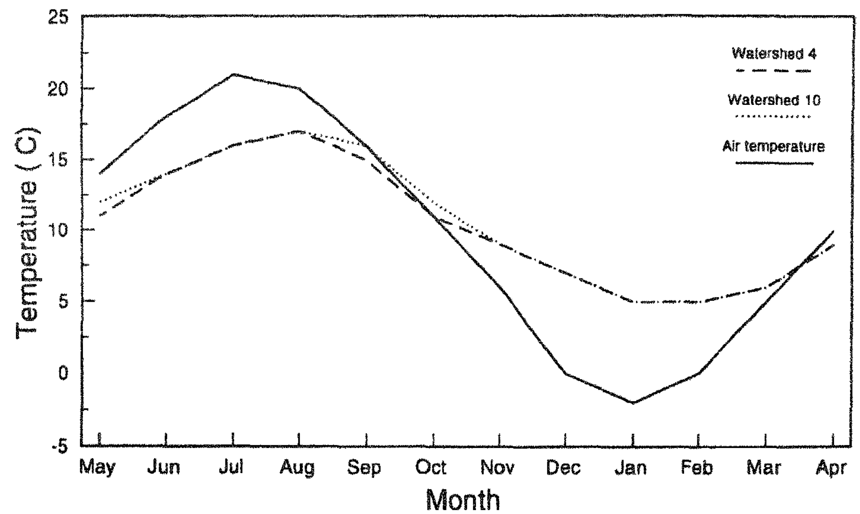


Figure 9.--Mean monthly stream temperature for Watersheds 4 and 10. Solid line is mean monthly air temperature averaged over water years 1984-90.

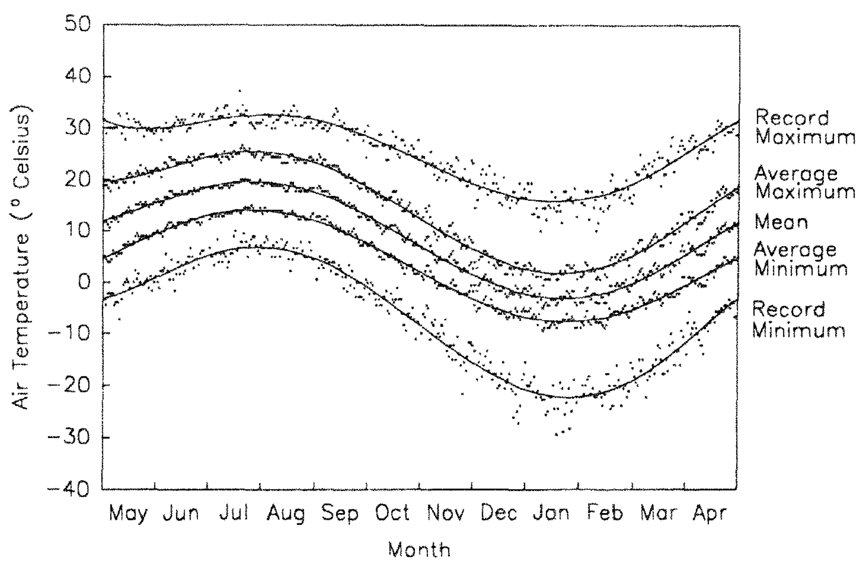


Figure 10.--Mean monthly, maximum, minimum, and record maximum and minimum air temperature at the Camp Hollow weather station during water years 1951-90.

Ozone/Air Quality

Edwards et al. (1991b) characterized concentrations of atmospheric ozone during consecutive drought and wet years (1988 and 1989, respectively) for the Nursery Bottom site. Overall, the frequency of high concentrations was greater during 1988. Diurnal ozone patterns are typical of low-elevation sites for this part of the United States, with peaks in afternoon and depressions at night (Fig. 14). Growing-season concentrations generally are greater than during the dormant season. Ozone levels are high in this region and can exceed the National Ambient Air Quality standard of 120 ppb (hourly). Four years of ozone data are shown in Figure 15. Note that water year 1991, which also was a drought year, had high concentrations of ozone during the summer, corroborating the conclusions of Edwards et al. (1991b). Maximum hourly ozone concentrations recorded for 1988, 1989, 1990, and 1991 were 156, 107, 102, and 99 ppb, respectively.

Data Availability

The Fernow Experimental Forest data in this report can be obtained from the USDA Forest Service, Timber and Watershed Laboratory, Parsons, WV 26287, Attn: Watershed Project Data Manager. Streamflow data are available as

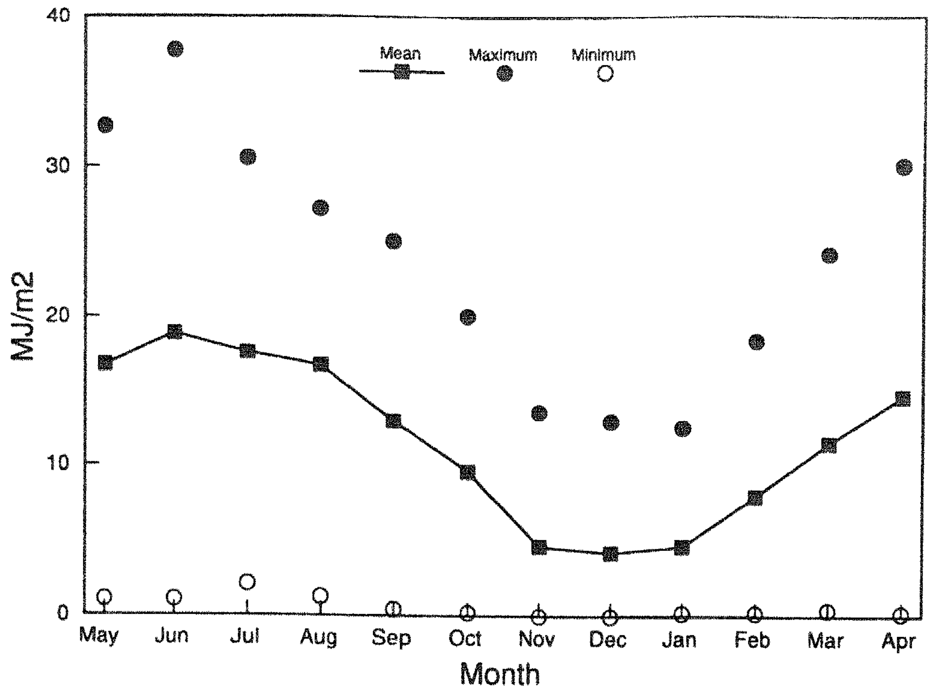


Figure 11.--Mean daily radiation at Nursery Bottom site, 1965-77. Adapted from Patric and Caruso (1979).

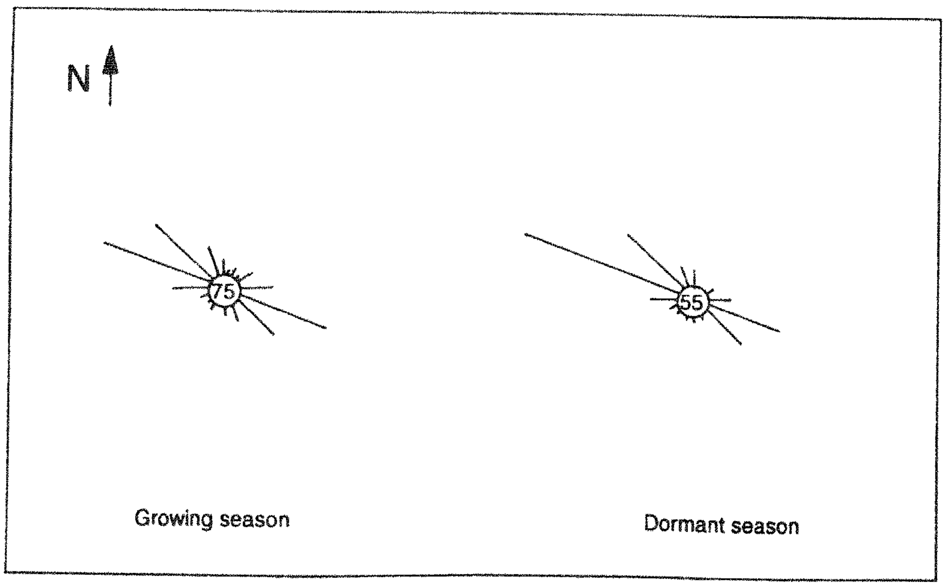


Figure 12.--Wind roses showing percent of occurrences for each of 16 quadrats during growing season (May-October), and dormant season (November through April). 0.6 mm = 1 percent. Numbers within circles indicate percent calm winds (<5 mph) rounded to nearest 5 percent.

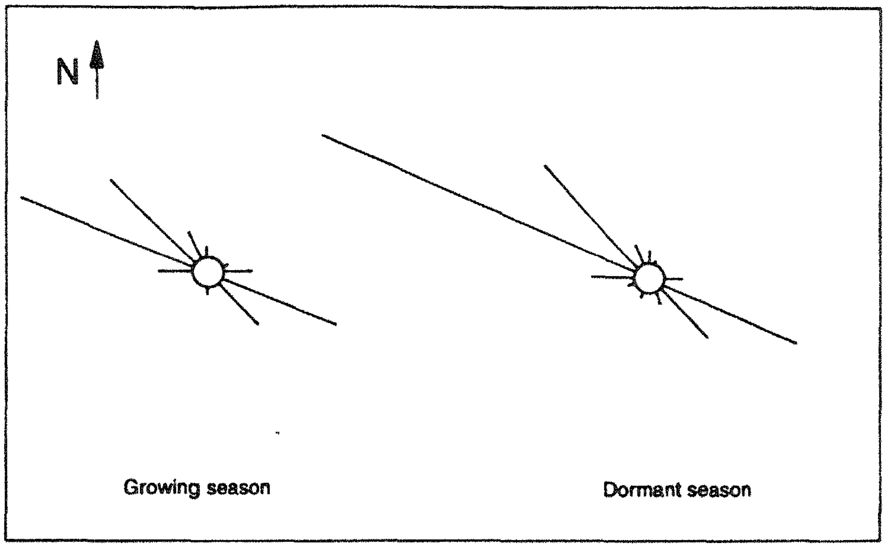


Figure 13.--Wind roses showing wind strength (km day^{-1}) for each of 16 quadrats during growing season (May through October) and dormant season (November through April). 0.6 mm = 1 km day^{-1}.

Table 13.--Mean daily evaporation (growing season, by month) and total evaporation from Nursery Bottom evaporation pan

Water year	MAY	JUN	JUL	AUG	SEP	OCT	Total
1965	4.77	5.09	5.12	4.40	3.75	2.64	790
1966	5.15	4.81	5.38	4.06	2.96	2.30	757
1967	3.17	5.21	3.78	3.31	2.86		553
1968	3.10	4.26	4.84	3.95	2.95	1.75	631
1969	4.25	4.28	4.54	4.04	3.31	2.32	678
1970	4.77	4.82	4.35	4.63	3.51	2.01	734
1971	3.63	4.40	4.62	4.29	2.90	1.86	665
1972	3.95	4.26	4.12	3.82	2.93	2.25	643
1973	3.16	5.00	4.68	3.64	3.76	2.48	692
1974	4.16	5.15	4.79	4.33	3.27	2.09	711
1975	4.07	4.90	4.56	4.45	3.14	2.20	694
1976	3.81	4.79	4.79	4.56	3.53	2.50	710
1977	4.61	4.09	4.76	4.01	2.75	1.96	660
1978	3.47	4.50	4.77	4.53	3.46	2.17	695
1979	4.04	4.58	3.88	3.56	2.86	1.84	626
1980	3.58	4.44	4.42	4.09	3.19	2.00	650
1981	3.33	4.11	4.23	3.88	2.56	1.95	574
1982	4.45	3.89	4.24	3.90	2.46	1.90	596
1983	3.52	4.13	4.60	4.28	2.84	1.82	648
1984	3.18	4.67	3.95	3.29	3.04	1.66	602
1985	4.05	4.00	4.88	3.04	3.29	2.03	647
1986	--	--	--	--	--	--	--
1987	4.96	5.05	5.60	5.42	2.79	2.39	793
1988	4.03	5.77	5.80	5.05	2.95	1.91	730
1989	3.00	3.89	4.29	3.41	2.72	1.90	588
1990	3.44	4.52	4.71	4.02	2.84	1.83	641
Mean	3.91	4.58	4.63	4.08	3.06	2.07	668
Std. Dev.	0.61	0.46	0.48	0.54	0.34	0.26	62

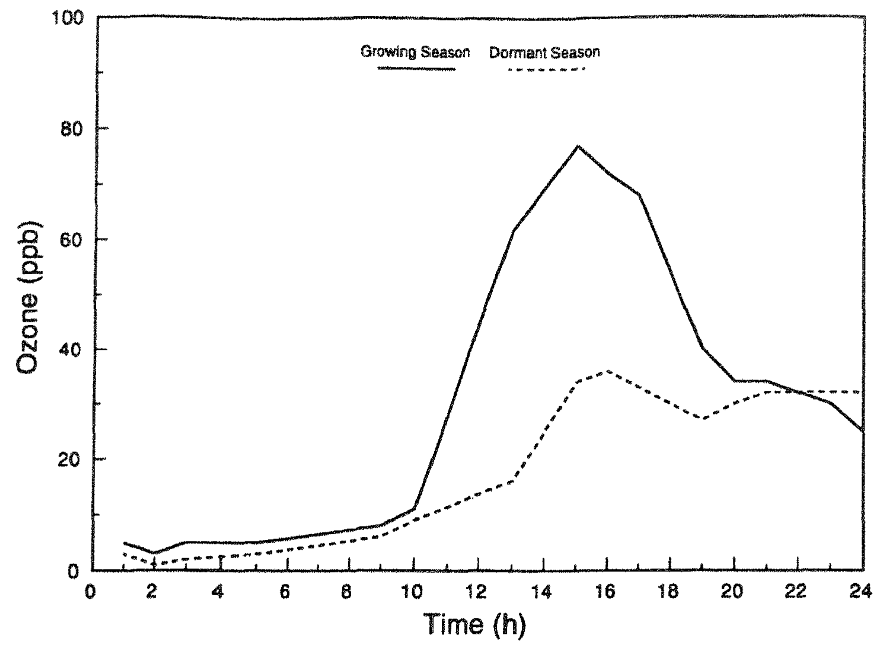


Figure 14.--Typical diurnal pattern of hourly ozone concentrations for growing season and dormant season. Adapted from Edwards et al. (1991).

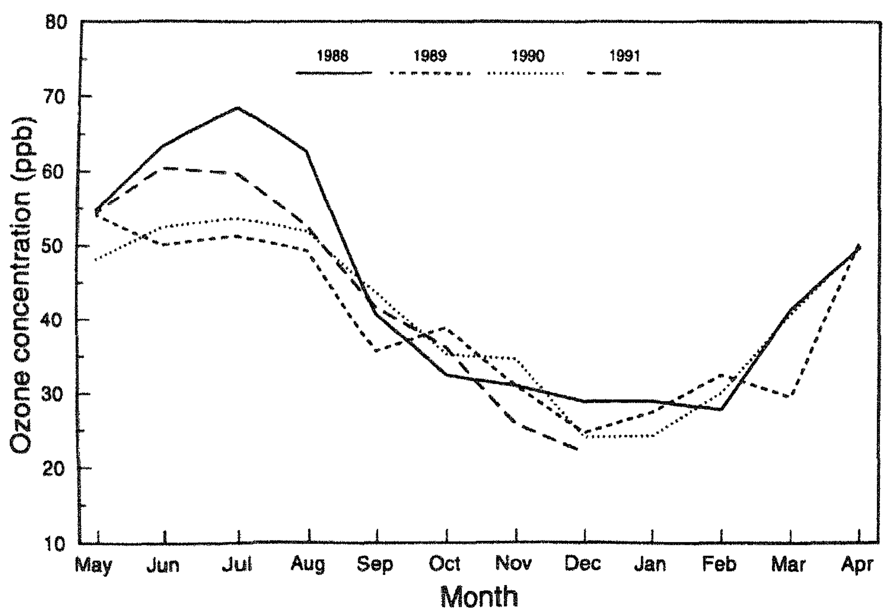


Figure 15.--Mean monthly 7-hour (0900-1559) ozone concentrations at the Nursery Bottom site for water years 1988-91.

mean daily csm, precipitation data as total daily watershed-weighted precipitation, and air-temperature data as daily maximum and minimum temperature in degrees Fahrenheit. Data on stream water and precipitation chemistry are available by collection date in the units discussed previously. All data are stored in ASCII-format flat files.

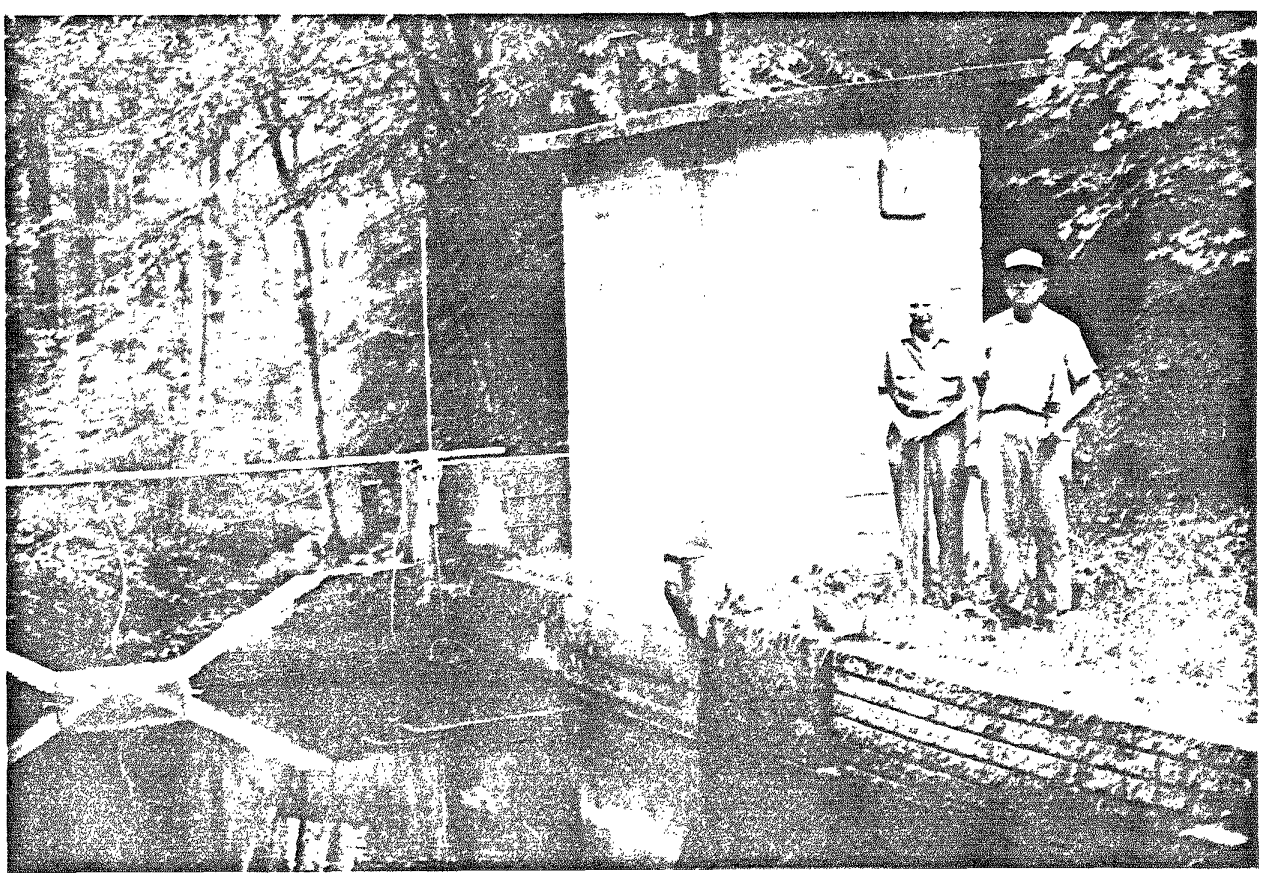
Air quality and meteorological data from the National Dry Deposition Network can be requested from the U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC 17711, Attn: NDDN Project Officer.

Conclusion

Long-term hydrometeorological monitoring requires a concerted effort and careful attention to detail by scientific and support staff, along with unwavering administrative support. Long-term data bases are necessary to reliably detect and quantify subtle environmental changes. Data collected by scientists on and near the Fernow Experimental Forest comprise probably the longest and most complete hydrometeorological record for the central Appalachians. As such, the Fernow represents a unique, irreplaceable resource that is increasing in value with time. In addition to hydrometeorological data, there are extensive data on stand and tree growth, as well as data that describe many other ecosystem parameters. Knowledge gleaned from such data has helped natural resource managers better manage forest ecosystems. The Northeastern Forest Experiment Station's support for long-term ecosystem research assures that the compilation of existing and new data sets will continue. Thus, the Fernow Experimental Forest is poised for use in long-term ecosystem studies and development of effective forest management strategies.

Acknowledgments

The collection, analysis, and quality of the data presented here are due largely to the dedicated efforts of many persons. Burley (Bud) Fridley and John Campbell (pictured below) were responsible for much of the day-to-day data collection for the watershed project during the last 40 years. Their diligence, attention to detail, and concern about the final product were outstanding. We also recognize the contributions of other current and past members of the field crew: Melvin Owens, Clifford Phillips, Douglas Owens, Frank Long, Cloyd Reinhart, Allen Hopkins, and James Phillips. Emmett Fox, John Pearce, and James Phillips performed chemical analyses on water samples, assisted by Jean Cassidy, Joan Mullenax, and Buck Grey. Data entry and analyses were performed by Anne Dennison, Linda Loughry, Layne Godwin, and Frederica Wood. The early vision and hard work of Sidney Weitzman, Arthur Eschner, Dick Trimble, and Ken Reinhart provided a sound basis for all of the succeeding years' work.



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Appendix

Dates of Equipment Use

Instrument	Date
pH	
Hellige	Before 3/11/68
Leeds and Northrup	7/7/65 to 10/6/75
Corning 10	10/6/75 to 9/27/83
Beckman Altex	9/27/82 to present
Fisher 815/915	9/27/83 to present
Conductivity	
Industrial Instruments Solu-Bridge	Before 1978
Beckman Solu-Bridge	1978 to 10/18/82
Markson Digital	April 1981 to 3/22/88
Radiometer CDM83	3/22/88 to present
Turbidity	
JTU Candle Turbidimeter	Before 1969
Hach 1860 Turbidimeter	1969 to 1971
H & F Turbidimeter	1971 to 7/14/80
Hach ration Turbidimeter	7/14/80 to present
Alkalinity	
Methyl Orange	Before 4/23/75
Buret Titration	4/23/75 to Nov. 1980
Fisher Automatic Titration	Nov. 1980 to 9/7/87
Radiometer Titralab	9/8/87 to present
Ammonia	
Hach NH3-N Method Using B & L Spectronic 100	3/10/81 to 4/5/88
Wescan Ammonia Analyzer	4/5/88 to present
Cations (except NH3-N)	
Perkin Elmer 390B AA	Before 10/10/80
Perkin Elmer 503 AA	10/10/80 to 9/1/92
ARL Spectraspan V DCP	9/1/92 to present
Anions	
Hach Ion Methods Using B & L Spectronic 20	Before 3/10/81
Dionex Model 10 IC	3/12/81 to 11/2/87
Dionex 4000i HPLC	11/2/87 to present

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Adams, Mary Beth; Kochenderfer, James N.; Wood, Frederica; Angradi, Ted R.; Edwards, Pamela. 1994. **Forty years of hydrometeorological data from the Fernow Experimental Forest, West Virginia.** Gen. Tech. Rep. NE-184. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 24 p.

Hydrometeorological data have been collected on the Fernow Experimental Forest in West Virginia since 1951. This publication summarizes these data, describes their collection, and provides other information that characterizes the Fernow. The value and utility of long-term data sets are discussed.

Keywords: hydrology, climate, watershed research, Fernow Experimental Forest, hydrometeorology