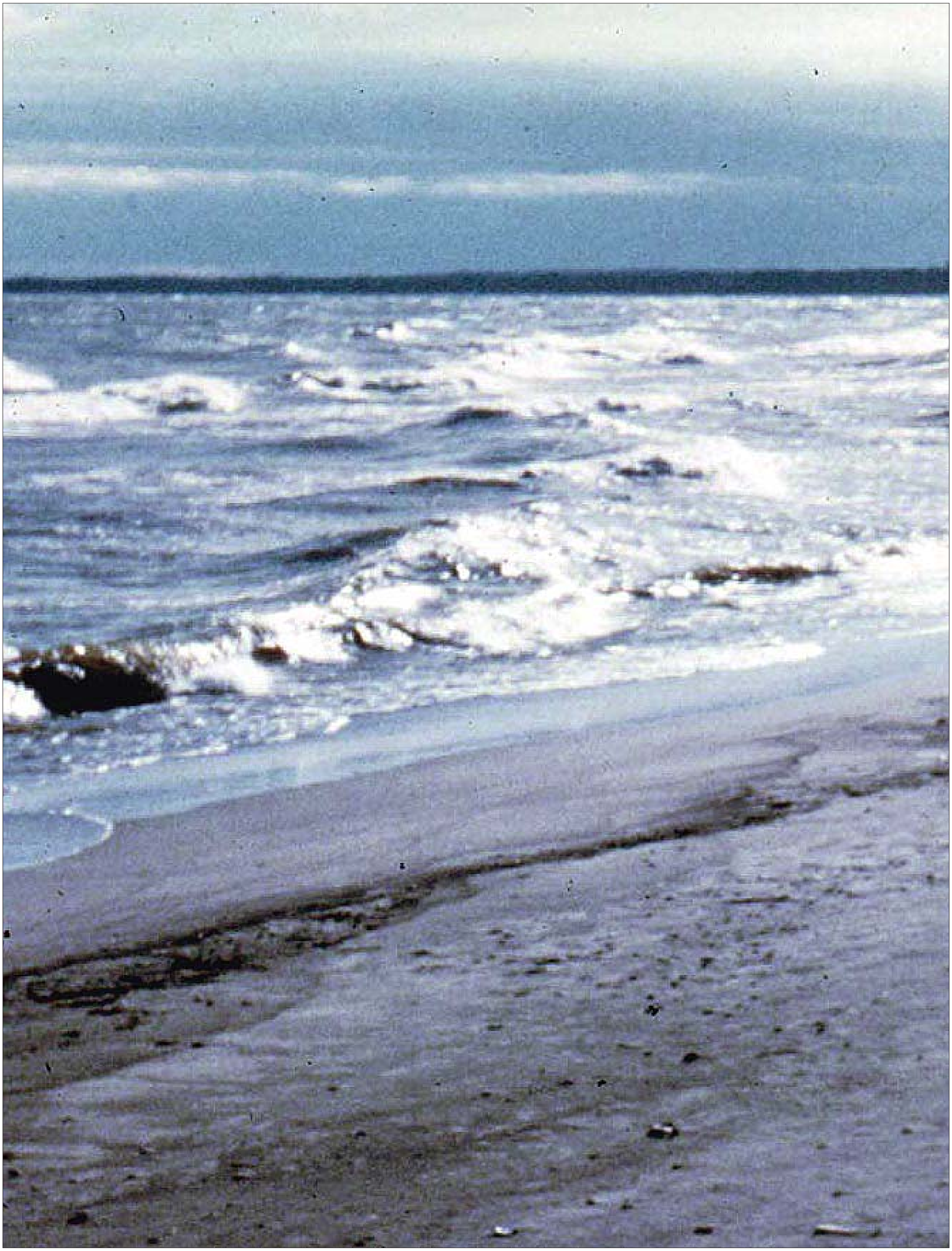


Waves from a northwest storm attack the barrier beach at Old Woman Creek (Charles E. Herdendorf).

Chapter 4. Climatology

Past Climate Trends

During the Pleistocene epoch, 1.6 million to 10,000 years before the present (YBP), at least four major glaciers advanced over the Great Lakes. Ice more than 2 km thick slowly proceeded across the landscape, scouring the surface, filling valleys, and leveling hills. The last glacier (Wisconsin) reached as far south as Cincinnati (18,000 YBP) before it began to recede (Forsyth 1961). The air temperatures ahead of the glacier were probably 10°C cooler than at present (Figure 4.1) as spruce forests extended into Florida and Texas (Terasmae 1961). As the glacier receded to the northeast, reaching present-day Niagara Falls about 12,500 YBP, a relatively dry tundra climate dominated northern Ohio in its wake (Beltzner 1976). As the temperature slowly warmed and moisture increased, conifer forests became more prevalent as shown by spruce pollen frequencies in excess of 50% (Shane 1994).

By 10,000 YBP the ice sheet had retreated north of the modern Great Lakes and air temperatures in northern Ohio had risen to only 3-4°C lower than at present (Phillips 1989). Gradually at first, then more rapidly, spruce and other conifers were replaced by oak and other deciduous trees. The first evidence of human occupation in the watershed is from this period as nomadic Palaeo-Indians hunted in Old Woman Creek valley (Shane 1981). Lake Erie's water level was about 20-25 m lower than present leaving the central basin partially dry (Herdendorf and Bailey 1989) and the estuary, if one existed, was some 50 km farther to the northeast.

The climate continued to warm after 10,000 YBP with air temperatures in the Great Lakes region taking a dramatic jump of 4-5°C within a millennium (Figure 4.2). Pollen studies show that spruce was entirely replaced by hardwood trees (Cushing 1965, Shane 1994), as boreal forests and tundra gave way to deciduous woodlands and prairie grasslands. A warmer climate also favored a more diverse fauna, including the propagation of game animals along the valleys of north central Ohio, as Early Archaic Indians established hunting camps on the bluffs near Old Woman Creek around 8,000 YBP (Shane 1992, Abel 1994).

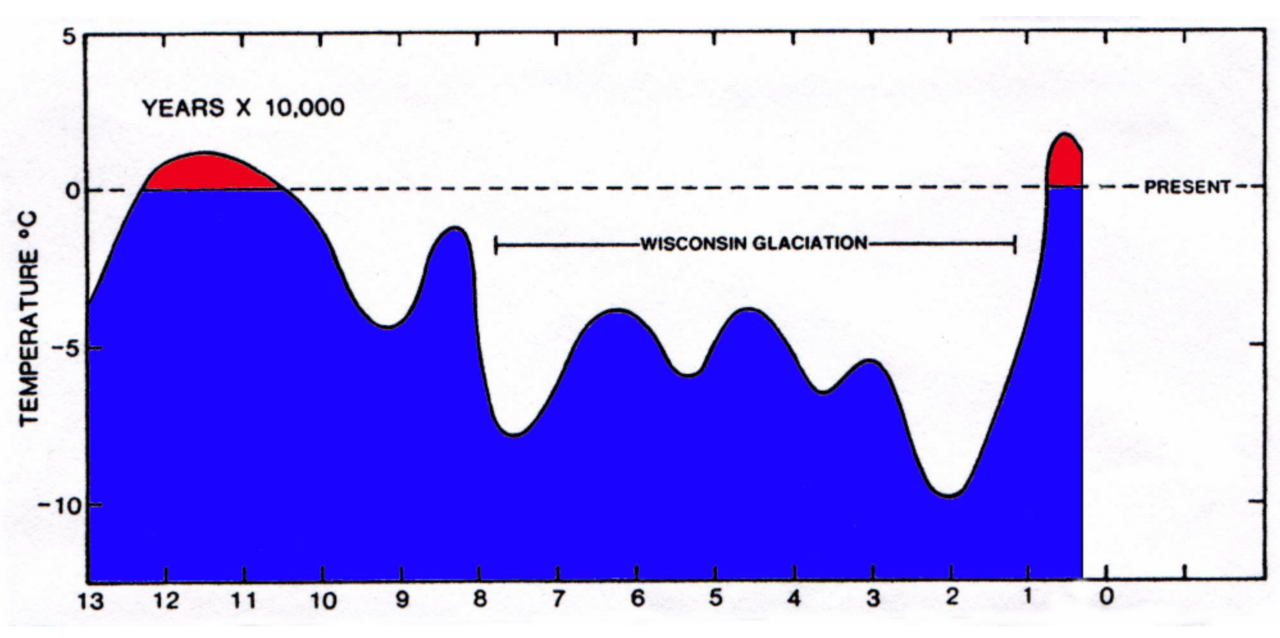


Figure 4.1. Trends in mean air temperature in the Great Lakes Basin during the Wisconsinan glacial period: 100,000 to 10,000 YBP (from Terasmae 1961, Phillips 1989).

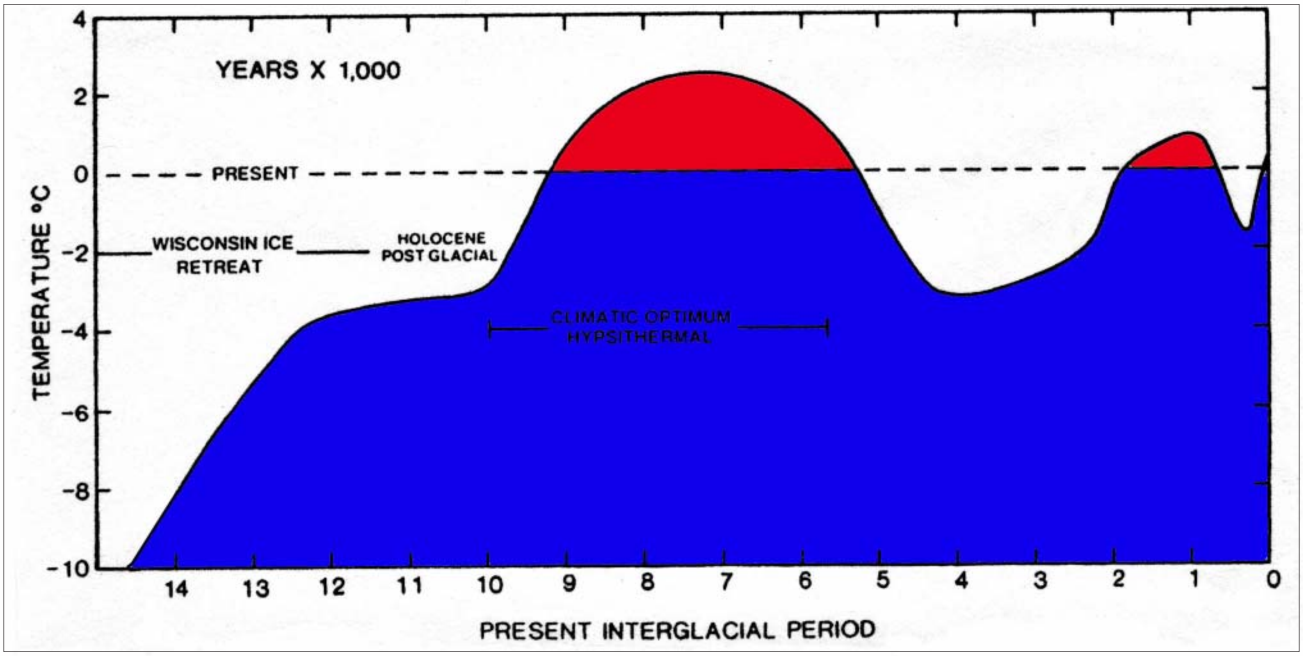


Figure 4.2. Trends in mean air temperature in the Great Lakes Basin during the present interglacial period: 14,000 to 0 YBP (from Terasmae 1961, Phillips 1989).

As the ice moved farther north, the prevailing winds shifted from off the ice front to more westerly and dryer air masses, as warmer weather spread across the region (Webb and Bryson 1972). Between 8,000 to 6,000 YBP the region was quite mild, perhaps 2-3°C warmer than at present, initiating a phase known as the Climatic Optimum or Hypsithermal Interval (Phillips 1989). Pollen records indicate that subtropical plants grew as far north as Minnesota during this interval (Ross 1995). Following the onset of the warm phase, conditions became somewhat dryer (Figure 4.3) and drought-resistant (prairie) vegetation moved into the region from the southwest.

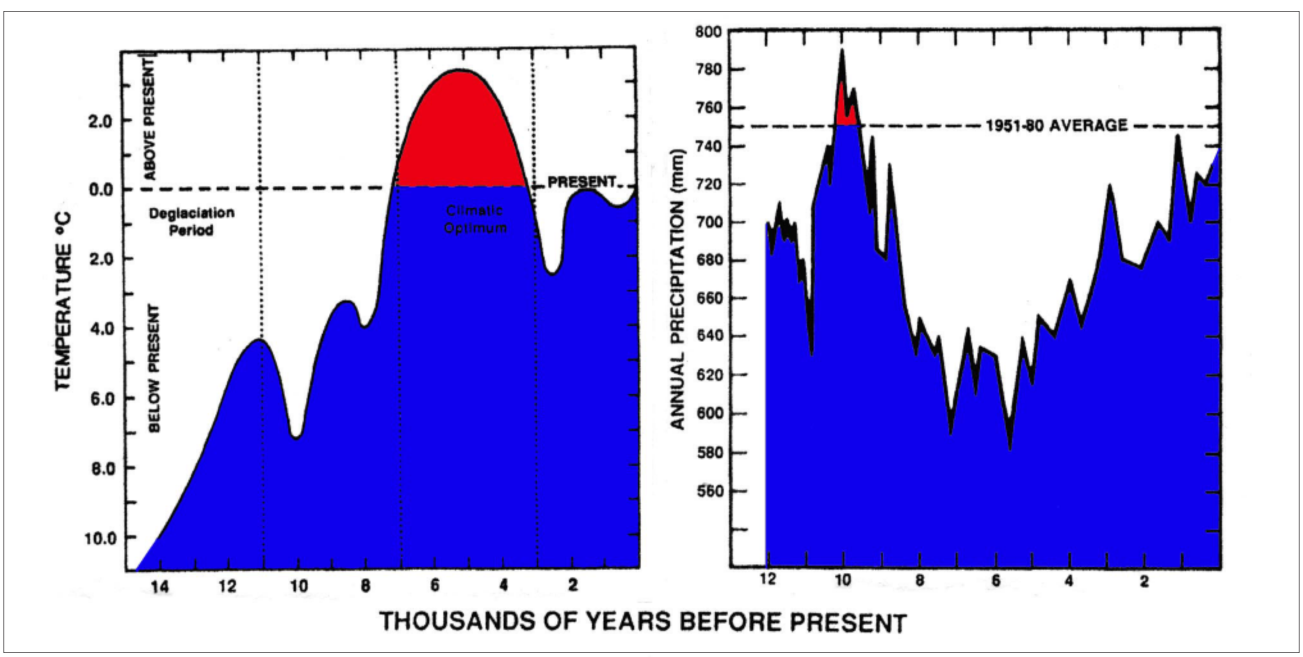


Figure 4.3. Postglacial trends in mean air temperature and precipitation in the Great Lakes Basin: 14,000 to 0 YBP (from Terasmae 1961, Webb 1981, Phillips 1989).

Starting about 5,500 YBP there was another rapid change in climate as the mean temperature dropped nearly 5°C in 1,500 years. This cooler period, known as Neoglaciation (Flint 1971), was accompanied by the growth of polar glaciers and a return of conifer trees to north central Ohio (Reeder and Eisner 1994). Historical evidence points to a cool, but warming period from about 3,000 to 1,500 years BP. Woodland Indian cultures flourished during this period, establishing agrarian villages on promontories in northern Ohio, including a bluff overlooking Old Woman Creek estuary (Shane 1981). By this time Lake Erie had risen to a level that flooded the valley of Old Woman Creek, forming an estuary near its present location, as shown by pollen records for aquatic and wetland plants (Reeder and Eisner 1994).

Beginning around 1,200 YBP, a 500-year mild phase (Medieval Period, AD 800 to 1,300) ensued (Figure 4.4) with temperatures 1°C warmer than present (Phillips 1989). The Whittlesey (Erie) Indians inhabited northern Ohio during the mild phase, constructing small, fortified villages on high banks of streams that empty into Lake Erie (Brose 1976, Otto 1980). Swain (1984) speculated that near the end of the Medieval mild climate, the first European settlement in the region may have taken place when a Norse expedition traversed the length of the Great Lakes (ca. 1362), leaving an inscription on the controversial Kensington Runestone in northeastern Minnesota.

In the later part of the 14th century (700 YBP), the climate swung back toward progressively colder, wetter conditions (Figure 4.4). Another Neoglaciation episode occurred from AD 1430 to 1850 that is sometimes called the "Little Ice Age" (Ross 1995). At this time the glaciers in northern Canada made a modest advance and Ohio became considerably colder. Presumably in response to adverse climatic conditions and hostilities among Indian groups, most of the State was without inhabitants from the 15th to 18th centuries, except for small settlements of Whittlesey Indians along the Lake Erie shore and Fort Ancient Indian villages in the Ohio River valley, where these water bodies moderated the climate (Otto 1979, 1980).

European settlement of the Great Lakes region began in appreciable numbers by the middle of the 18th century. Summers were still cool during the first half of the 19th century, in particular 1816 has been called the "year without a summer" because frosts occurred each month (volcanic ash from the eruption of Mount Tambora on the island of Sumbawa in Indonesia appears to be associated with this climatic event). Following the cold episode, until about 1940, temperatures warmed somewhat, followed by another period of lower temperatures (Figure 4.5). In recent years there has been another warming trend which may be related, in part, to the "greenhouse effect"–the warming of the Earth's atmosphere because of its transparency to incoming sunlight and its opacity to heat radiated from Earth. Opacity, hence heat, is increased by added amounts of carbon dioxide, water vapor, methane, and dust in the atmosphere.

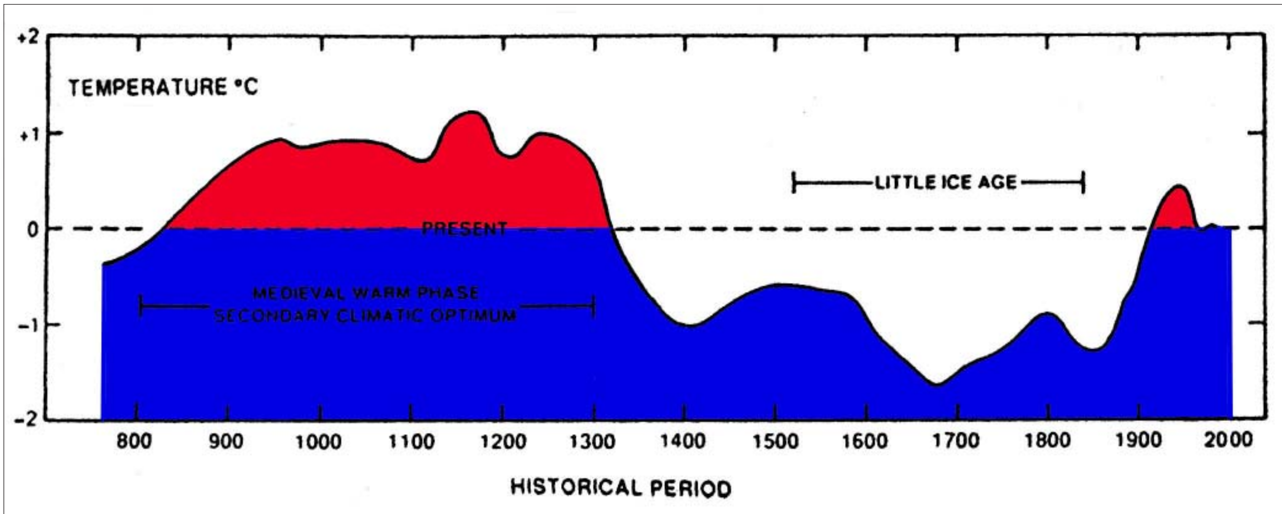


Figure 4.4. Historic trends in mean air temperature in the Great Lakes Basin: 1,200 to 0 YBP (from Phillips 1989).

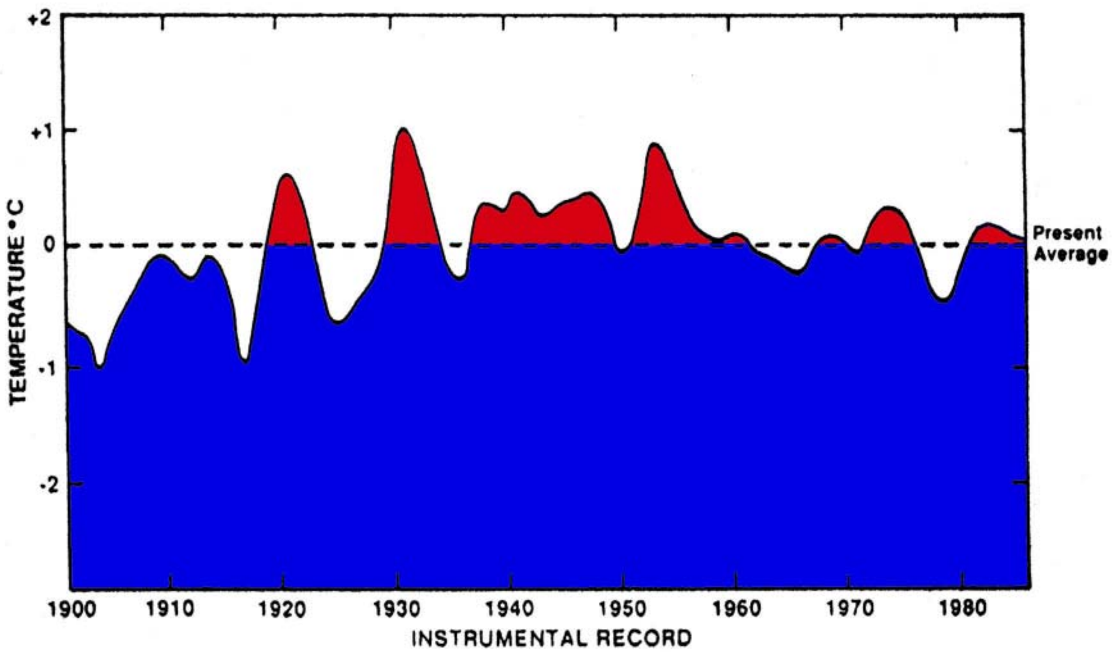


Figure 4.5. Historic trends in mean air temperature in the Great Lakes Basin during the period of instrumental record: 100 to 20 YBP (from Phillips 1989).

MODERN CLIMATE

The climate of north central Ohio is classified as "temperate – humid continental – long summer" (Fisher 1989), signifying a middle latitude location (35°-45°) in the interior of a large land mass well removed from oceanic influences with ample rainfall, warm to hot summers, and cold winters. These climatic characteristics are expressed in four distinct seasons, large seasonal temperature ranges, frequent precipitation, and sudden changeability with the rapid passage of different weather systems through the area. While the prevailing winds are from the southwest, one or two weather disturbances affect the Old Woman Creek watershed each week, bringing changes in wind direction, overcast skies, and often precipitation. The settled weather associated with high-pressure systems is thus interrupted every few days by disturbances such as fronts or low-pressure areas which can bring warm subtropical air from the south or cold Arctic air from the north (Schmidlin 1996).

Thus, the climate of the watershed is marked by large fluctuations in temperature and precipitation. Because of the proximity to the lake, winds from the northerly quadrants tend to lower daily temperatures in the summer, while raising them in the winter. The growing season at the Reserve averages 198 days (frostless days). Summers are moderately warm and humid with about 16 days where the temperature exceeds 32°C (90°F). Winters are generally cold and cloudy, however, the tempering effect of the lake limits subzero (F°) temperatures on the average to only 3 out of 5 years. As is typical for continental climates, precipitation is highly variable on a yearly basis, but in the watershed it is generally abundant and evenly distributed with autumn being the driest season. Average annual precipitation is approximately 89 cm (35 in). Winds average 10 km/hr (7 knots) in the summer and 14 km/hr (10 knots) in the winter. Although the prevailing winds are southwesterly, the southern coast of Lake Erie has a history of severe storms from the northeast and northwest that have caused extensive damage to and recession of the shoreline (Carter and Guy 1980). Average monthly weather conditions for Erie county, Ohio are tabulated in Table 4.1. Monthly average precipitation and maximum/minimum average daily air temperatures for Sandusky, Ohio (18 km WNW of the Reserve) are given in Table 4.2.

TABLE 4.1. AVERAGE WEATHER CONDITIONS FOR ERIE COUNTY, OHIO

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DAYS												
Sunny	10	10	12	14	17	18	21	20	18	17	10	9
Rainy	5	5	6	7	7	6	5	5	5	5	4	5
Thunderstorm	0	0	1	2	5	7	7	5	3	1	0	0
Snowy (> 2.5 cm)	3	2	2	0	0	0	0	0	0	0	1	2
Hot (> 32°C)	0	0	0	0	5	6	5	3	0	0	0	0
Cold (< 0°C)	27	23	20	-	0	0	0	0	0	-	13	23
WIND												
Speed (km/hr)	15	15	18	15	13	11	11	9	11	13	15	15
Direction (dominant)	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
Gusts (days)	4	4	5	5	3	3	2	1	2	3	4	5
LAKE												
Temperature (°C)	< 1	< 1	2	6	13	19	22	24	21	14	7	2
Ice thickness (cm)	20	30	10	0	0	0	0	0	0	0	0	5
SUNSHINE												
Percent (%) (of possible)	32	38	44	51	60	68	70	65	63	58	39	34
Clouds (% sky)	80	80	70	70	60	60	50	50	60	60	80	80
AIR TEMPERATURE	> Probability (%)											
-5°C	82	86	100	100	100	100	100	100	100	100	100	96
0°C	26	26	93	100	100	100	100	100	100	100	100	53
5°C	0	0	15	100	100	100	100	100	100	100	69	0
10°C	0	0	0	44	100	100	100	100	100	100	0	0
15°C	0	0	0	0	59	100	100	100	100	15	0	0
20°C	0	0	0	0	0	89	100	100	26	0	0	0
25°C	0	0	0	0	0	0	11	11	0	0	0	0

> = greater than
< = less than

Period of Record: 1859-1985

Data Sources: Alexander (1924), Miller (1971), Herdendorf et al. (1986a,b), Herdendorf (1987), Bolsenga and Herdendorf (1993)

TABLE 4.2. WEATHER DATA FOR SANDUSKY, OHIO

	Average Daily Air Temperature (°C) Minimum	Maximum		Precipitation (cm) Average	Snowfall
JAN	-6.1	1.1		6.1	18.3
FEB	-5.6	2.2		5.6	16.0
MAR	-1.1	7.2		7.3	14.7
APR	4.4	13.9		8.2	2.8
MAY	10.6	21.1		8.7	0.0
JUN	16.1	26.1		10.4	0.0
JUL	18.3	28.3		9.2	0.0
AUG	17.8	27.8		8.2	0.0
SEP	13.9	23.9		7.1	0.0
OCT	8.3	18.3		5.1	0.0
NOV	1.7	10.0		5.6	6.4
DEC	-3.9	3.3		5.2	15.5
YEAR MEAN	6.2	15.3	TOTAL	86.7	73.7

Period of Record: 1936-1965

Data Source: U.S. Weather Service, Sandusky, Ohio

Starting in 1983, meteorological observations have been recorded at the Old Woman Creek State Nature Preserve and National Estuarine Research Reserve (Figure 4.6). Parameters routinely monitored include: (1) air temperature, (2) precipitation, and (3) wind speed and direction. Summaries of these observations are presented in Tables 4.3 through 4.7. Starting in 1997, photosynthetically active radiation (PAR) measurements have been recorded at the Reserve. PAR measurements are discussed in the Solar Radiation section of this chapter. Complete meteorological records are available at the Ohio Center for Coastal Wetlands Study located within the Old Woman Creek State Nature Preserve and National Estuarine Research Reserve. A related daily observation is the open or closed condition of the Lake Erie barrier beach at the mouth of the estuary. Monthly summaries of barrier beach conditions for the period 1983 to 2000 are presented in the Estuary Hydrology section in Chapter 5.

Figure 4.6. Meteorological tower and weather station at Old Woman Creek SNP & NERR (Charles E. Herdendorf).

TABLE 4.3 MONTHLY AIR TEMPERATURE AT OLD WOMAN CREEK NERR 1989-2000

Maximum and Minimum (°C)

	1989		1990		1991		1992		1993		1994	
MONTH	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
JAN	—	—	13.89	-4.44	11.67	-12.78	12.78	-16.11	15.00	-7.78	9.44	-23.33
FEB	—	—	17.78	-13.89	17.78	-13.33	14.44	-11.67	12.22	-15.56	18.89	-13.89
MAR	—	—	25.00	-9.44	21.67	-17.39	18.89	-7.22	15.00	-11.67	24.44	-3.89
APR	—	—	30.56	-3.89	31.11	-3.33	26.67	-2.78	27.22	1.11	30.56	-1.67
MAY	—	—	25.56	3.89	32.78	5.56	30.00	2.22	31.67	6.11	31.11	4.44
JUN	—	—	31.67	5.00	32.22	9.44	31.67	6.11	32.78	9.44	35.00	7.78
JUL	—	—	31.67	10.00	35.00	12.22	31.11	11.11	36.67	13.33	34.44	12.78
AUG	—	—	33.33	11.67	31.67	11.11	32.78	9.44	36.11	12.22	30.00	10.56
SEP	25.56	3.89	31.67	4.44	33.89	2.22	29.44	4.44	32.78	5.56	31.11	8.89
OCT	28.33	1.11	27.22	0.00	27.22	-1.11	25.00	0.00	28.33	0.56	26.67	2.78
NOV	21.11	-6.11	22.22	-3.33	20.00	-7.78	19.44	-3.33	18.89	-1.67	21.11	-2.78
DEC	7.78	-23.89	15.00	-12.78	17.22	-9.44	15.00	-7.78	15.00	-13.89	16.67	-6.67
MEAN	—	—	25.46	-1.06	26.02	-2.05	23.94	-1.30	25.14	-0.19	25.79	-0.42

	1995		1996		1997		1998		1999		2000	
MONTH	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
JAN	19.44	-11.67	—	—	18.89	-13.89	17.49	-6.95	19.00	-19.36	16.38	-20.56
FEB	12.22	-14.44	—	—	20.85	-12.26	17.46	-6.67	22.72	-9.01	24.12	-13.87
MAR	26.11	-6.11	—	—	22.58	-7.42	28.01	-8.72	23.81	-15.74	26.91	-6.03
APR	28.89	-2.78	—	—	24.62	-5.37	23.76	-0.99	26.56	-2.15	25.01	-2.10
MAY	31.11	8.89	—	—	24.88	1.72	32.29	8.53	31.59	2.24	31.21	4.36
JUN	35.56	13.33	—	—	33.97	6.73	34.67	8.22	34.34	7.64	32.44	6.80
JUL	37.78	13.89	—	—	33.79	11.59	33.98	13.27	36.06	12.80	30.31	9.52
AUG	—	—	35.00	14.44	32.17	11.87	31.63	11.08	32.02	12.46	31.79	9.59
SEP	—	—	—	—	30.07	5.81	33.65	9.12	32.49	6.00	30.31	4.16
OCT	—	—	—	—	29.33	-0.77	28.57	1.06	26.73	0.90	28.03	1.52
NOV	—	—	23.33	-2.78	12.05	-6.58	22.23	-2.23	25.20	-3.39	22.45	-11.42
DEC	—	—	17.78	-6.11	11.61	-10.85	21.83	-13.27	17.48	-12.47	10.00	-18.20
MEAN	—	—	—	—	24.57	-1.62	27.13	1.04	27.33	-1.67	25.75	-3.02

TABLE 4.4. MONTHLY PRECIPITATION AT OLD WOMAN CREEK NERR 1983-2000

Monthly Total (cm)

MONTH	1983	1984	1985	1986	1988	1989	1990	1991	1992
JAN	—	—	—	—	—	4.80	3.56	4.50	4.70
FEB	—	—	—	—	—	1.73	9.35	4.57	3.94
MAR	—	—	—	—	—	4.98	2.44	3.07	5.28
APR	—	8.46	3.51	8.74	3.86	6.86	7.52	7.29	8.38
MAY	—	11.23	10.90	9.40	1.96	12.83	10.08	6.96	6.65
JUN	—	5.26	5.13	7.80	1.42	6.71	5.79	1.37	5.72
JUL	—	7.62	7.04	9.04	6.91	7.65	9.19	3.00	24.46
AUG	—	7.26	9.55	5.66	10.21	3.53	6.76	4.29	12.98
SEP	—	6.65	2.34	12.32	2.79	8.13	14.76	3.91	13.03
OCT	—	9.27	8.33	7.67	7.16	8.76	7.87	8.43	3.76
NOV	—	7.21	15.06	4.55	8.74	7.14	4.24	5.84	4.10
DEC	6.65	5.72	—	—	4.80	2.67	15.95	4.17	7.67
TOTAL	—	—	—	—	—	75.79	97.51	57.40	100.67

MONTH	1993	1994	1995	1996	1997	1998	1999	2000	MEAN
JAN	8.31	4.72	8.79	3.51	4.80	—	6.35	2.46	5.14
FEB	4.04	1.37	2.57	3.61	11.00	—	3.18	2.54	4.35
MAR	7.80	2.54	4.42	5.82	11.96	—	3.96	0.81	4.83
APR	8.56	9.78	11.25	10.52	—	—	10.87	5.36	7.93
MAY	2.79	3.86	10.59	6.50	25.12	2.03	3.28	11.71	8.44
JUN	10.31	9.53	11.46	10.72	14.99	11.86	12.07	12.29	8.28
JUL	2.79	4.57	8.00	10.82	—	—	7.72	6.48	8.24
AUG	2.44	10.49	11.07	0.08	—	6.93	4.04	6.43	6.78
SEP	10.03	3.45	3.56	24.18	—	3.73	5.87	6.12	7.79
OCT	5.61	1.45	9.14	7.49	—	3.89	6.99	3.94	6.65
NOV	9.98	5.72	6.93	5.51	—	3.05	6.68	1.24	7.07
DEC	4.06	7.57	1.88	8.61	—	3.56	5.51	4.04	5.92
TOTAL	76.72	65.05	89.66	97.37	—	—	76.52	63.42	81.42

Note: Weather station inoperable in 1987

TABLE 4.5. MONTHLY RAINSTORMS AT OLD WOMAN CREEK NERR 1983-2000

Number of Storms (>2.0 cm) and Storm Precipitation (cm)

MONTH	1983	1984	1985	1986	1988	1989	1990	1991	1992
JAN	—	—	1	—	—	1	0	0	1
Precip	—	—	2.01	—	—	2.41	0	0	2.29
FEB	—	1	—	—	—	0	2	1	0
Precip	—	2.67	—	—	—	0	6.60	2.54	0
MAR	—	1	2	—	—	0	0	0	0
Precip	—	4.06	6.30	—	—	0	0	0	0
APR	—	2	0	1	1	1	1	1	2
Precip	—	5.38	0	4.22	2.21	2.31	3.66	2.90	5.11
MAY	—	1	2	3	0	2	1	1	1
Precip	—	3.48	6.53	7.98	0	4.93	3.48	4.32	2.84
JUN	—	1	0	1	0	2	0	0	1
Precip	—	3.30	0	5.44	0	4.22	0	0	3.71
JUL	—	2	0	1	2	1	2	0	4
Precip	—	5.26	0	4.06	4.42	3.56	6.78	0	18.34
AUG	—	2	1	0	2	0	1	0	3
Precip	—	5.18	3.35	0	5.97	0	3.63	0	7.62
SEP	—	0	0	2	1	2	3	0	3
Precip	—	0	0	7.62	2.36	4.88	10.31	0	10.41
OCT	—	1	2	2	1	2	1	1	0
Precip	—	5.38	6.10	5.21	5.13	7.19	2.46	3.45	0
NOV	1	1	2	0	2	1	0	1	3
Precip	2.16	2.18	7.09	0	5.23	3.33	0	2.79	12.47
DEC	1	0	1	1	1	0	3	1	1
Precip	2.41	0	2.84	2.29	3.10	0	10.72	2.08	5.51
TOTAL						12	14	6	19
Precip						32.83	47.64	18.08	68.30
STORMS (percent of total monthly rainfall)						43.3%	48.8%	31.5%	61.7%

Note: Weather station inoperable in 1987

TABLE 4.5. MONTHLY RAINSTORMS AT OLD WOMAN CREEK NERR 1983-2000 (cont'd)

Number of Storms (>2.0 cm) and Storm Precipitation (cm)

MONTH	1993	1994	1995	1996	1997	1998	1999	2000	MEAN
JAN	1	1	2	0	0	—	1	0	0.7
Precip	4.57	2.08	6.81	0	0	—	3.35	0	2.94
FEB	0	0	0	1	1	—	0	0	0.5
Precip	0	0	0	2.79	7.90	—	0	0	3.75
MAR	3	0	1	0	2	—	1	0	0.8
Precip	6.53	0	2.90	0	5.28	—	2.00	0	2.71
APR	1	2	2	1	1	2	2	1	1.3
Precip	4.83	8.15	4.52	3.76	5.41	5.72	3.76	3.08	4.90
MAY	0	1	3	1	5	0	1	3	1.6
Precip	0	2.00	8.00	3.33	20.07	0	2.57	9.65	2.85
JUN	2	3	3	3	3	3	2	2	1.6
Precip	7.82	7.57	10.82	8.33	12.07	8.76	9.30	6.12	3.36
JUL	0	0	1	2	1	0	2	1	1.2
Precip	0	0	5.18	7.59	4.83	0	7.42	3.02	3.71
AUG	0	3	2	0	—	1	0	1	1.1
Precip	0	9.17	8.69	0	—	5.72	0	5.23	3.41
SEP	1	0	0	5	—	1	1	1	1.3
Precip	3.84	0	0	21.49	—	2.87	4.27	3.86	3.60
OCT	1	0	2	1	—	0	1	1	1.1
Precip	2.31	0	7.09	3.91	—	0	2.57	3.23	3.38
NOV	3	1	1	1	—	1	1	0	1.2
Precip	8.38	2.44	2.72	2.74	—	2.06	2.06	0	2.92
DEC	1	2	0	2	—	1	1	0	1.1
Precip	2.36	4.70	0	5.92	—	2.64	2.03	2.16	2.87
TOTAL	13	13	17	17			13	10	14
Precip	40.64	32.11	56.73	59.86			39.33	36.35	40.40
STORMS (percent of total monthly rainfall)	53.0%	55.5%	63.3%	61.5%	—	—	51.4%	57.3%	49.6%

TABLE 4.6. MONTHLY AVERAGE WIND SPEED AND DIRECTION AT OLD WOMAN CREEK NERR 1997-2000

MONTH	WS 1997	WD 1997	WS 1998	WD 1998	WS 1999	WD 1999	WS 2000	WD 2000	WS MEAN	WD MEAN
JAN	3.5	220°	8.5	190°	2.8	194°	2.9	208°	4.4	203°
FEB	8.0	204°	8.4	136°	2.7	190°	2.4	213°	5.4	186°
MAR	12.0	175°	3.3	192°	2.9	183°	2.8	174°	5.2	181°
APR	9.0	193°	3.1	122°	3.3	149°	2.6	151°	4.0	154°
MAY	10.7	194°	2.0	144°	2.3	141°	2.2	177°	4.3	132°
JUN	7.4	145°	1.7	186°	1.7	151°	2.0	180°	3.2	166°
JUL	6.4	171°	1.7	192°	1.5	198°	1.6	164°	2.8	181°
AUG	6.0	154°	1.5	161°	1.8	163°	1.6	186°	2.5	166°
SEP	6.4	189°	1.8	211°	1.8	183°	2.1	159°	3.0	186°
OCT	6.8	200°	1.9	205°	2.3	200°	1.7	178°	3.2	196°
NOV	8.7	190°	2.8	207°	2.7	231°	2.4	193°	4.2	205°
DEC	9.4	224°	2.6	216°	2.6	206°	2.5	207°	4.3	213°
MEAN	7.9	188°	3.3	180°	2.4	182°	2.2	182°	3.9	181°

Wind Speed (WS) reported in m/sec

Wind Direction (WD) reported in true degrees (°) from which the wind emanated

TABLE 4.7. MONTHLY MAXIMUM AND MINIMUM WIND SPEED AT OLD WOMAN CREEK NERR 1997-2000

MONTH	MAX 1997	MIN 1997	MAX 1998	MIN 1998	MAX 1999	MIN 1999	MAX 2000	MIN 2000	MAX MEAN	MIN MEAN
JAN	6.5	1.7	18.3	2.8	5.8	0.2	5.7	1.5	9.1	1.6
FEB	17.6	0.7	29.4	1.3	5.3	0.7	4.7	0.7	14.3	0.9
MAR	22.7	6.5	8.1	1.0	5.2	1.3	5.6	1.1	10.4	2.5
APR	20.6	4.3	7.8	1.2	6.9	1.2	6.2	1.0	10.4	1.9
MAY	21.8	5.6	4.8	0.9	6.4	1.0	4.8	1.2	9.5	2.2
JUN	26.7	3.5	3.5	1.0	3.1	1.0	4.4	1.0	9.4	1.6
JUL	14.3	3.8	3.1	0.8	2.8	0.7	3.2	0.7	5.9	1.5
AUG	16.0	1.8	3.3	0.7	4.2	0.8	3.0	0.8	6.6	1.0
SEP	16.9	2.5	4.2	0.9	4.7	1.0	5.5	0.8	7.8	1.3
OCT	14.7	2.3	3.0	0.9	4.5	0.5	4.6	0.5	6.7	1.1
NOV	17.4	1.9	6.0	0.6	6.3	0.8	5.3	0.9	8.8	1.1
DEC	18.6	3.3	4.2	1.2	4.9	1.0	5.3	0.8	8.3	1.6
MEAN	17.8	3.2	8.0	1.1	5.0	0.9	4.9	0.9	9.0	1.5

Wind Speed (WS) reported in m/sec

LAKE EFFECT

Lake Erie has a modifying effect on the weather in the Old Woman Creek watershed and particularly on the weather in the Reserve. Winds off the lake tend to lower the air temperatures on summer days and raise them on winter days. The daily variation in air temperature becomes greater with increasing distance from the lake and the average annual precipitation increases slightly. Compared with the lakeshore, the southernmost part of the watershed has an average daily maximum 0.8°C higher, an average daily minimum 2.2°C lower, and average annual precipitation that is about 2.7 cm greater (Miller 1971). The insert below and Table 4.8 show that the frost period (interval between the first freezing date in the fall and the last freezing date in the spring) increases as the distance from the lake increases. This yields a longer growing season in the vicinity of the estuary than in the southern part of the watershed. The frost-free period for communities in the vicinity of the watershed range from 154 to 198 days.

	Growing Season
Huron (on Lake Erie)	198 days
Berlin Heights (6 km south of Lake Erie)	168 days
Norwalk (17 km south of Lake Erie)	154 days

Because water has a higher specific heat (capacity to absorb thermal energy in relation to temperature change) than soil, Lake Erie changes temperature more slowly than the surface of the watershed, delaying the change of seasons along the shore. Lake Erie absorbs a great amount of heat in the spring and summer with a relatively small change in temperature and slowly releases that heat in the fall and winter. The heat capacity of water not only permits the lake and estuary to act as a buffer against wide fluctuations in the coastal environment, it narrows the range of temperatures to which an aquatic organism is subjected as compared to those organisms living on land. Lake temperatures rarely exceed 27°C, whereas air temperatures as high as 42°C have been recorded in the vicinity of the watershed.

As the lake and estuary water gradually warm in the spring, the land within about 5 km of the shore remains cooler than the more southerly portions of the watershed. After reaching a temperature of 24-27°C in August, the lake begins to cool slowly during autumn and early winter, tempering the first cold waves of winter and pushing back the first freeze by several weeks. Lake Erie also adds moisture to the air during the cooling period. Evaporation of lake water is greatest at this time because the water is much warmer than the air. The added moisture results in frequent cloudiness; sunny days usually occur less than 20% of the time in November (Herdendorf et al. 1986a,b). To a lesser extent than it occurs in northeastern Ohio, but still noteworthy, the moisture evaporated from Lake Erie by cold air masses results in "lake-effect" rain and snow in the watershed, particularly as the cold, moist air masses ascend over the Berea escarpment.

Lake Erie is large enough to induce lake-land breezes. During the day in summer, the lake is typically cooler than the surrounding shore, and a breeze blows onshore to replace rising air masses over the warmer land. The effect of these cooling breezes can extend 30 km inland (Burns 1985). At night the lake temperature remains fairly constant while the land quickly cools, and the direction of the breeze changes and blows off the land to replace air masses rising over the lake. This process causes downdrafts of air over the lake during the day which tend to disperse clouds in front of a shoreward moving lake breeze front, resulting in clear skies over the lake and shore for 30-50% of the days in summer (Eichenlaub 1979). Conversely, at night updrafts over the lake can lead to severe thunderstorms (Phillips and McCulloch 1972).

WIND

Southwesterly winds prevail over the watershed in all months of the years, a feature common to temperate regions of the northern hemisphere. In fall and winter, northwesterly winds can also occur frequently, reaching velocities of 65 to 80 km/hr during severe storms (Herdendorf 1987). In spring, winds from the northeast are common, with storms producing velocities of 50 to 65 km/hr. The U.S. Nuclear Regulatory Commission (Ohio Edison Company 1977) reported meteorological data from a tower located near Berlin Heights. For the period 1973 to 1975 the predominant wind direction at three levels on the tower (10 m, 55 m, and 150 m) was south southwest through west southwest (37% of the time). The frequency of calm wind was 1.2% (Figure 4.7) of the time at the 10-m level and 0.1% at the upper two levels.

Wind blowing over land generally has a lower velocity than wind blowing over open Lake Erie. This

TABLE 4.8. PROBABILITY OF FREEZING AIR TEMPERATURES IN OLD WOMAN CREEK WATERSHED

Spring Season

DISTANCE SOUTH OF LAKE ERIE	PROBABILITY LATER THAN	AIR TEMPERATURE -7°C	0°C	+2°C
0-5 km	50% (5 years in 10)	Mar 13	Apr 14	Apr 25
	10% (1 year in 10)	Mar 28	Apr 24	May 7
5-10 km	50% (5 years in 10)	Mar 25	Apr 27	May 14
	10% (1 year in 10)	Apr 9	May 18	Jun 2
> 10 km	50% (5 years in 10)	Mar 25	May 6	May 20
	10% (1 year in 10)	Apr 12	May 21	Jun 4

Fall Season

DISTANCE SOUTH OF LAKE ERIE	PROBABILITY EARLIER THAN	AIR TEMPERATURE -7°C	0°C	+2°C
0-5 km	50% (5 years in 10)	Nov 30	Oct 29	Oct 18
	10% (1 year in 10)	Nov 16	Oct 18	Oct 3
5-10 km	50% (5 years in 10)	Nov 28	Oct 13	Oct 5
	10% (1 year in 10)	Nov 16	Sep 29	Sep 20
> 10 km	50% (5 years in 10)	Nov 13	Oct 8	Sep 24
	10% (1 year in 10)	–	Sep 23	Sep 5

Fall to Spring Frost Period (Days)

DISTANCE SOUTH OF LAKE ERIE	PROBABILITY GREATER THAN	AIR TEMPERATURE -7°C	0°C	+2°C
0-5 km	25% (1 year in 4)	104	168	190
	1% (1 year in 100)	133	189	217
5-10 km	25% (1 year in 4)	118	197	222
	1% (1 year in 100)	145	232	239
> 10 km	25% (1 year at 4)	133	211	239
	1% (1 year in 100)	–	241	269

Data Source: U.S. Weather Service (Miller 1971) difference is caused by greater frictional drag over land. This difference is greatest in the cooler months when the temperature differential between air and water is greatest (Table 4.9). Richards and Phillips (1970) found that on average the air to lake ratio was 1:1.66 (i.e. a 10 km/hr wind over land would have a velocity of 16.6 km/hr over the lake). Winds measured at the Research Reserve, about 0.7 km south of the lakeshore, are shown on Figure 4.8.

Thunderstorms typically occur in the watershed on 30 to 40 days each year. Tornadoes within an 80-km radius of the Reserve, for the period 1953 to 1974, were reported 85 times for a mean frequency of 3.9 per year. The most devastating tornado to hit the area was in 1924, when extensive damage and loss of life occurred in Sandusky and Lorain, Ohio, communities within a 40-km radius of the Reserve.

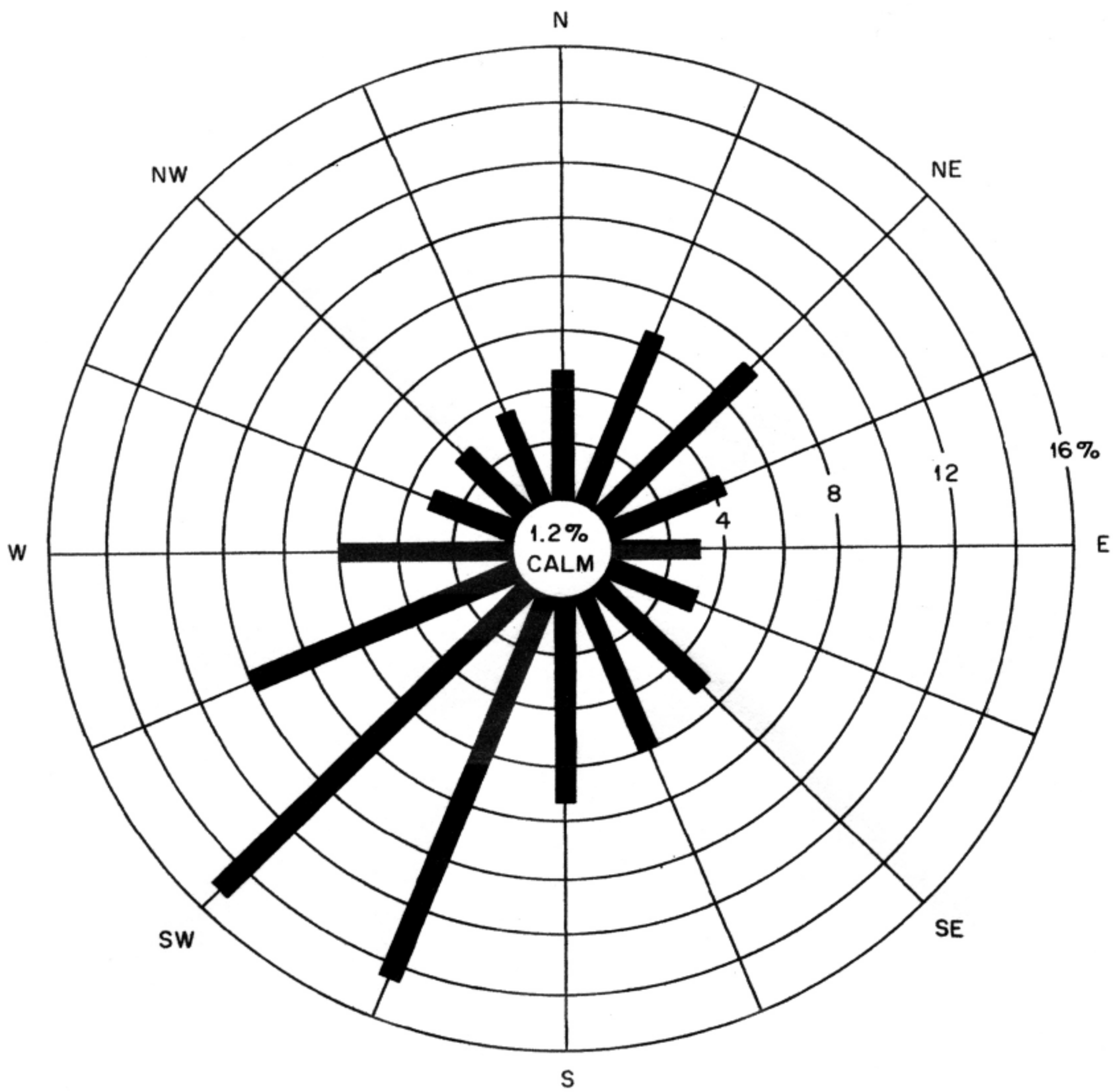
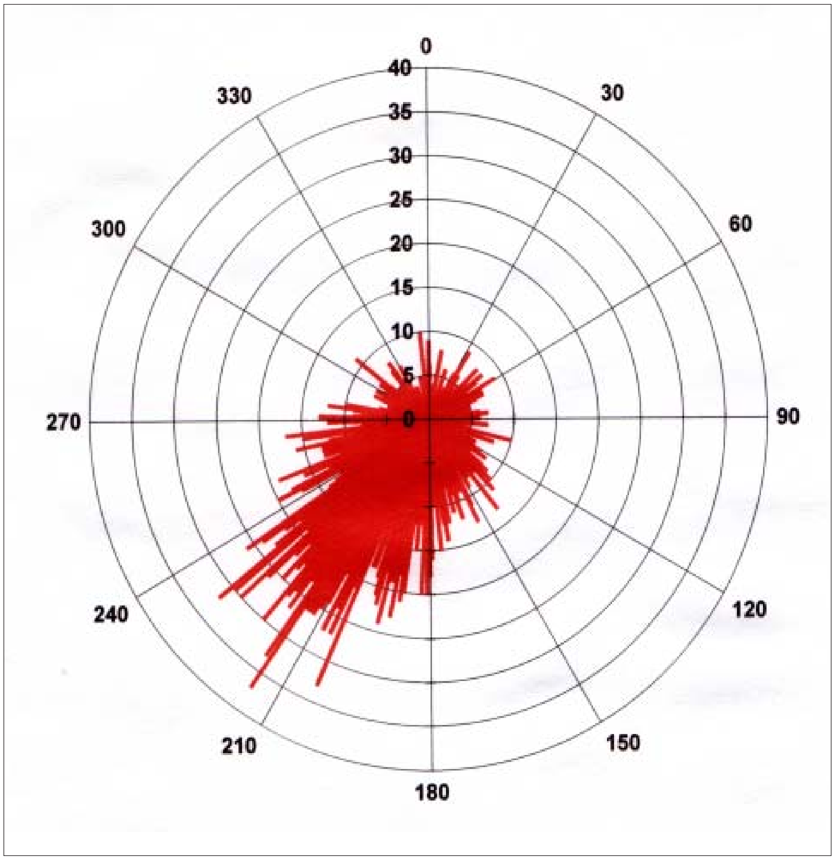


Figure 4.7. Wind rose at the 10-m level showing percentage of time for the major wind directions as recorded at the Berlin Heights, Ohio meteorological tower: 1973-1975 (from Ohio Edison Company 1977).



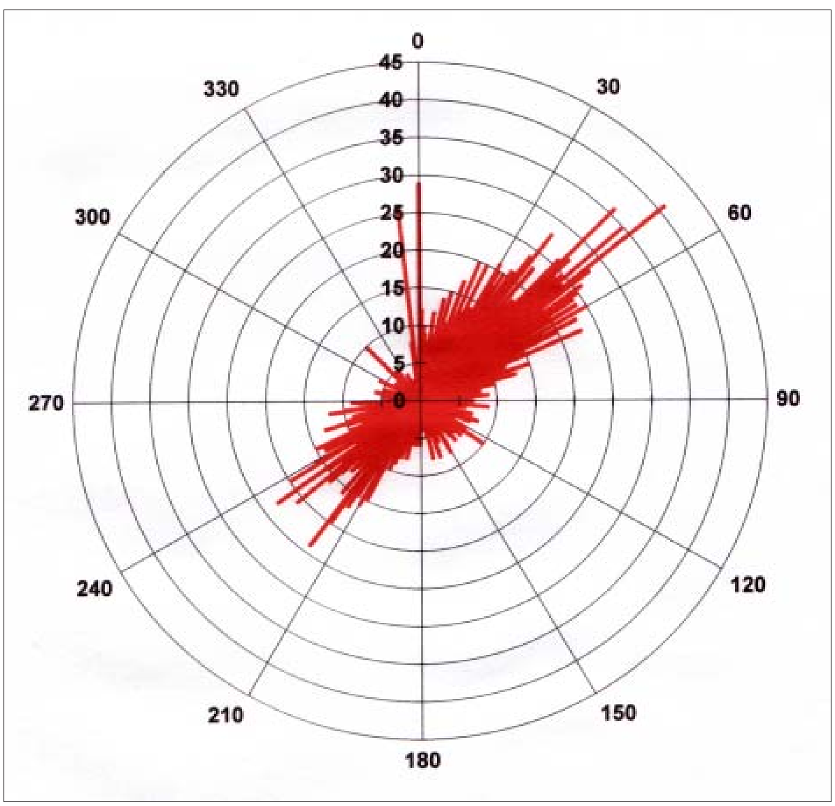


Figure 4.8. Monthly wind roses generated from measurements at Old Woman Creek Center showing dominant southwest wind patterns in the fall and the influence of northeast storms in the spring.

TABLE 4.9. RELATIONSHIP OF OVER LAND TO OVER LAKE PRECIPITATION AND WINDS FOR WESTERN LAKE ERIE

	Ratios Precipitation	Ratios Winds		Ratios Precipitation	Ratios Winds
JAN	1:1.02	1:1.96	JUL	1:0.88	1:1.16
FEB	1:0.88	1:1.94	AUG	1:1.00	1:1.39
MAR	1:0.97	1:1.88	SEP	1:1.95	1:1.78
APR	1:1.06	1:1.81	OCT	1:0.90	1:1.99
MAY	1:1.04	1:1.71	NOV	1:0.96	1:2.09
JUN	1:0.87	1:1.31	DEC	1:0.95	1:1.98
			MEAN	1:0.95	1:1.66

Data Sources: Richards and Phillips (1970), Bolsenga and Herdendorf (1993)

SOLAR RADIATION

The Old Woman Creek watershed experiences a maximum of about 15 hours of daylight in the summer and a minium of 9 hours in the winter (Herdendorf 1987). Because of the cloud-producing effect of the lake, December and January ordinarily have less than 40% of possible sunshine, while June and July average more than 70%. Table 4.10 gives the mean daily solar radiation received at the surface of Lake Erie. Photosynthetically active radiation (PAR) at the Reserve is measured in joules per second per square meter and in micromoles per second per square meter (400 to 700 nm waveband) with a Li-Cor quantum sensor (model LI-190SZ) . Figure 4.9 depicts the average daily PAR values recorded at the Reserve for 1997. The various units that are used to express solar radiation and conversion factors are presented in Table 4.11.

TABLE 4.10. SOLAR RADIATION RECEIVED AT THE SURFACE OF WESTERN LAKE ERIE

	Sunlight (hours)	Solar Radiation (kcal day^{-1} m^{-2})	Radiant Energy Flux (joules s^{-1} m^{-2})	Irradiance (PAR) (μE s^{-1} m^{-2})	Irradiance (PAR) (photons)
JAN	9.4	1,100	136	567	3.5×10^{22}
FEB	10.5	1,900	211	894	5.4×10^{22}
MAR	11.9	2,900	284	1,202	7.2×10^{22}
APR	13.2	3,900	342	1,448	8.8×10^{22}
MAY	14.6	4,500	359	1,519	9.1×10^{22}
JUN	15.2	5,500	420	1,778	10.7×10^{22}
JUL	14.9	5,500	429	1,813	10.9×10^{22}
AUG	13.9	4,700	394	1,667	10.0×10^{22}
SEP	12.6	3,700	342	1,448	8.7×10^{22}
OCT	11.2	2,400	250	1,057	6.4×10^{22}
NOV	9.8	1,300	154	652	3.9×10^{22}
DEC	9.1	900	115	486	2.9×10^{22}

Data Source: U.S. Fish and Wildlife Service (Herdendorf 1987)

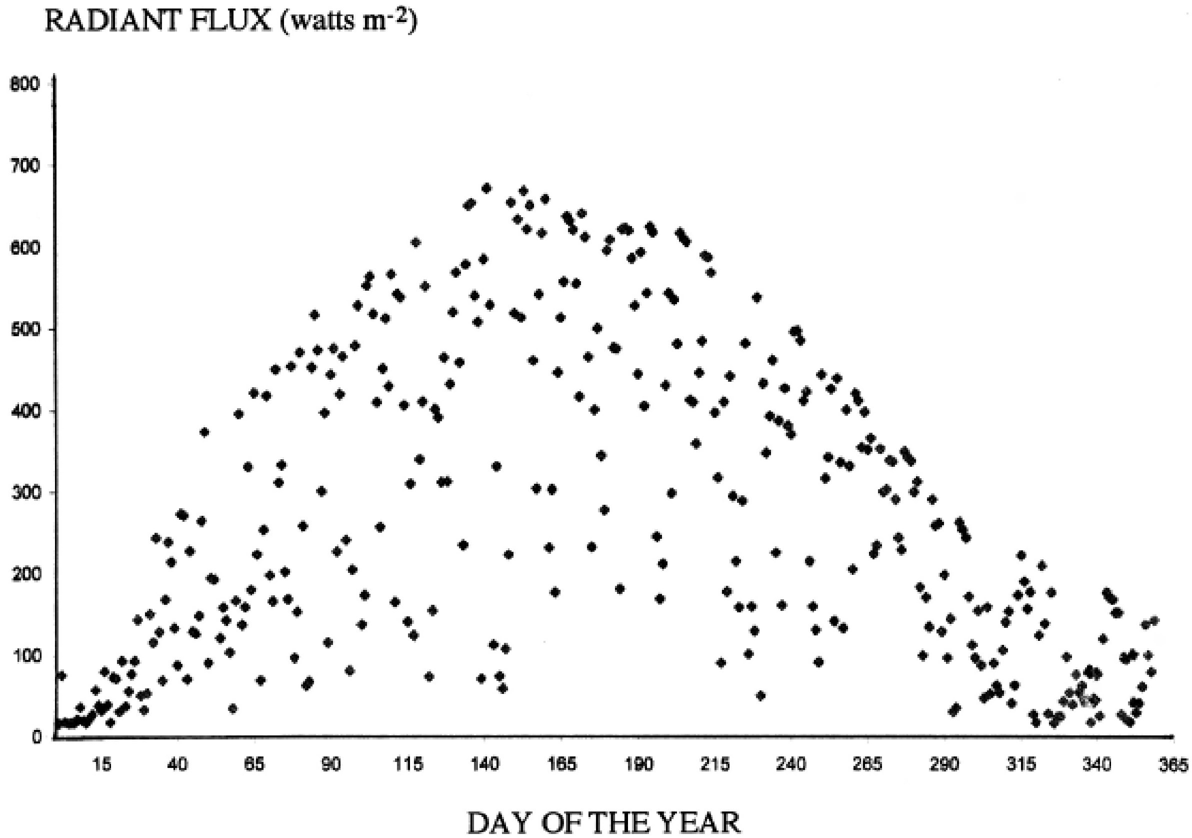


Figure 4.9. Mean daily solar radiation (PAR) measurements for 1997 at Old Woman Creek National Estuarine Research Reserve.

TABLE 4.11. CONVERSION FACTORS FOR SOLAR RADIATION MEASUREMENTS

1 foot candle = 1 lumen ft^{-2}

1 lux = 1 lumen m^{-2}

1 langley = 1 calorie m^{-2}

1 calorie = 4.19 joules

1 joule s^{-1} m^{-2} = 1 watt m^{-2}

1 joule = 4.3 µeinsteins (µE) [estimated mean value for visible light]

1 µmol s^{-1} m^{-2} = 1 µE s^{-1} m^{-2}

1000 µmol s^{-1} m^{-2} = 6.39 microamps

1 µE s^{-1} m^{-2} = 6.02×10^{17} photons (quanta) = 5.12×10^{-1} lux (estimate)

Full sun at zenith has an approximate PAR value of 2000 µmol s^{-1} m^{-2} or 2000 µE s^{-1} m^{-2}

Data Source: Herdendorf (1987)

ICE COVER

The shallow mean depth of Lake Erie and its associated small thermal reserve gives this Great Lake the most rapid response to changing atmospheric conditions. Ice cover extends over 90% of Lake Erie's surface most winters (Assel et al. 1983). Only during the last half of December and in April are there any persistent areas of open water. Ice cover usually develops in the western end of the lake in the last half of December. Likewise, Old Woman Creek estuary ices over at the same time or slightly earlier (Figure 4.10). During early March western Lake Erie usually has 40% to 60% coverage with ice and by the end of the month the estuary and adjacent Lake Erie are open water. Table 4.12 gives the normal and extremes of ice cover off the mouth of Old Woman Creek estuary for the period 1960 to 1979. Rafting of ice can cause considerable concentration and grounding of ice flows along the shoreline, which at times can form windrow several meters high.

TABLE 4.12. ICE COVER ON LAKE ERIE OFF OLD WOMAN CREEK ESTUARY (1960–1979)

Period	Maximum	Minimum	Normal Cover
December 16-31	0-10%	0-10%	0-10%
January 1-15	100%	0-10%	40-60%
January 16-31	100%	0-10%	0-10%
February 1-14	100%	0-10%	70-90%
February 15-28	100%	0-10%	70-90%
March 1-15	100%	0-10%	0-10%
March 16-31	40-60%	0-10%	0-10%
April 1-15	100%	0-10%	0-10%
April 16-30	0-10%	0-10%	0-10%

NOTE: (1) 0 to 10% (open water)—large area of freely navigable water in which some ice flows could be present; (2) 10 to 30% (very open pack)—pack ice in which water predominates over ice; (3) 40 to 60% (open pack)—pack ice with many leads and polynyas, where flows are generally not in contact with each other; (4) 70 to 90% (close pack)—pack ice in which the ice flows are mostly in contact; (5) 100% (consolidated pack)—pack ice in which the ice flows are frozen together

Data Source: NOAA, Great Lakes Environmental Research Laboratory (Assel et al. 1983)

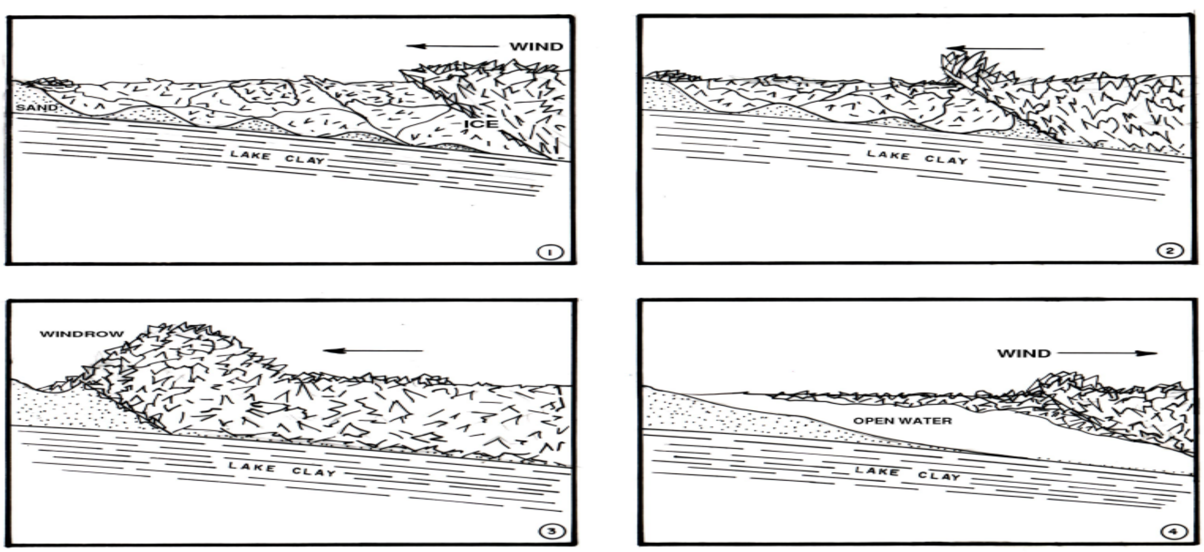


Figure 4.10. Sequence of events as ice moves onshore and offshore modifying the lake bottom at Old Woman Creek barrier bar (modified from Liebenthal and Herdendorf 1966).

How Weather Affects the Estuary

Storm events have a major impact on the water quality and quantity in Old Woman Creek estuary as well as the biota dwelling here. When heavy rain storms occur, turbid and chemically-laden waters flood the estuary from the watershed, frequently breaching the barrier beach and opening a connection with Lake Erie. Under these conditions the estuary is poorly able to assimilate watershed contaminants. When the barrier is open, lake biota can enter and reside in the estuary. However during periods with no severe storms, the barrier beach remains closed giving the estuary time to transform contaminants or settle them to the bottom. Estuary waters are further cleansed as they slowly percolate through the sands of the barrier beach. When the barrier is closed the biota in the estuary is distinctly different from that of Lake Erie. For example, during open periods the phytoplankton is dominated by small diatoms and flagellates, whereas when the barrier beach is closed, larger green algae, such as *Scenedesmus* spp., and some blue greens are dominant (Klarer 1999). This phenomenon is further discussed in the Ecology chapter of this profile.

Lee et al. (1995) modeled the impacts of climate change on water levels in western Lake Erie resulting from a doubling of atmospheric carbon dioxide. With a changed climate Detroit River flow would decrease by 36% which would result in a drop in the long-term average annual water level of 1.5 m for Lake Erie (from an elevation of 174.3 to 172.8 m). A decline in water level of this magnitude would result in very significant decreases in water volume and surface area. Water volume for Lake Erie would fall 20%, and surface area decrease would result in the losses of wetlands, freshwater estuaries, and embayments. Estuaries, such as Old Woman Creek estuary, would only be inundated during lake storm events or when lake levels would rise above the long-term climate change levels. Some migration of coastal wetlands may be expected, but most of Lake Erie's coastal wetlands would not be able to migrate lakeward due to man-made dikes or natural barrier beaches.

Storm surges and associated seiche activity can significantly raise the water level along the lakeshore to a point where lake water intrudes into the estuary. This is particularly prevalent during northeast storm events. The degree of this influence can be seen by measurements of water levels and conductivity at both the estuary mouth and at the upper end of the estuary. Because Old Woman Creek water is considerably more mineralized than lake water, conductivity measurements can give signatures to these two distinct water masses.

Measurements of the water level at the mouth on July 5, 1995 revealed a bimodal pattern with a period of about 13 hours between the high water periods. Conductivity, correspondingly, showed marked decline when water levels increased (Figure 4.11). The rise in water level was the result of an influx of lake water caused by a wind tide. This influx of water resulted in a decrease in conductivity (lake water has a lower conductivity than creek or estuary water). Seiche activities on Lake Erie have a period of 12 to 14 hours (Herdendorf and Krieger 1989). A similar pattern of water level change was recorded at the upper end of the estuary (Figure 4.12).

Despite the change in water level, there was no corresponding change in conductivity at upper site. This suggests that the change in water level originated from the lake and not from a watershed storm (which would have caused a drop in conductivity at this site). These measurements demonstrate that the intrusion of lake water was largely confined to the lower reaches of the estuary. However, the intrusion pushed resident estuary water upstream which resulted in a rise in water level at the upper end of the estuary, but no marked change in conductivity.

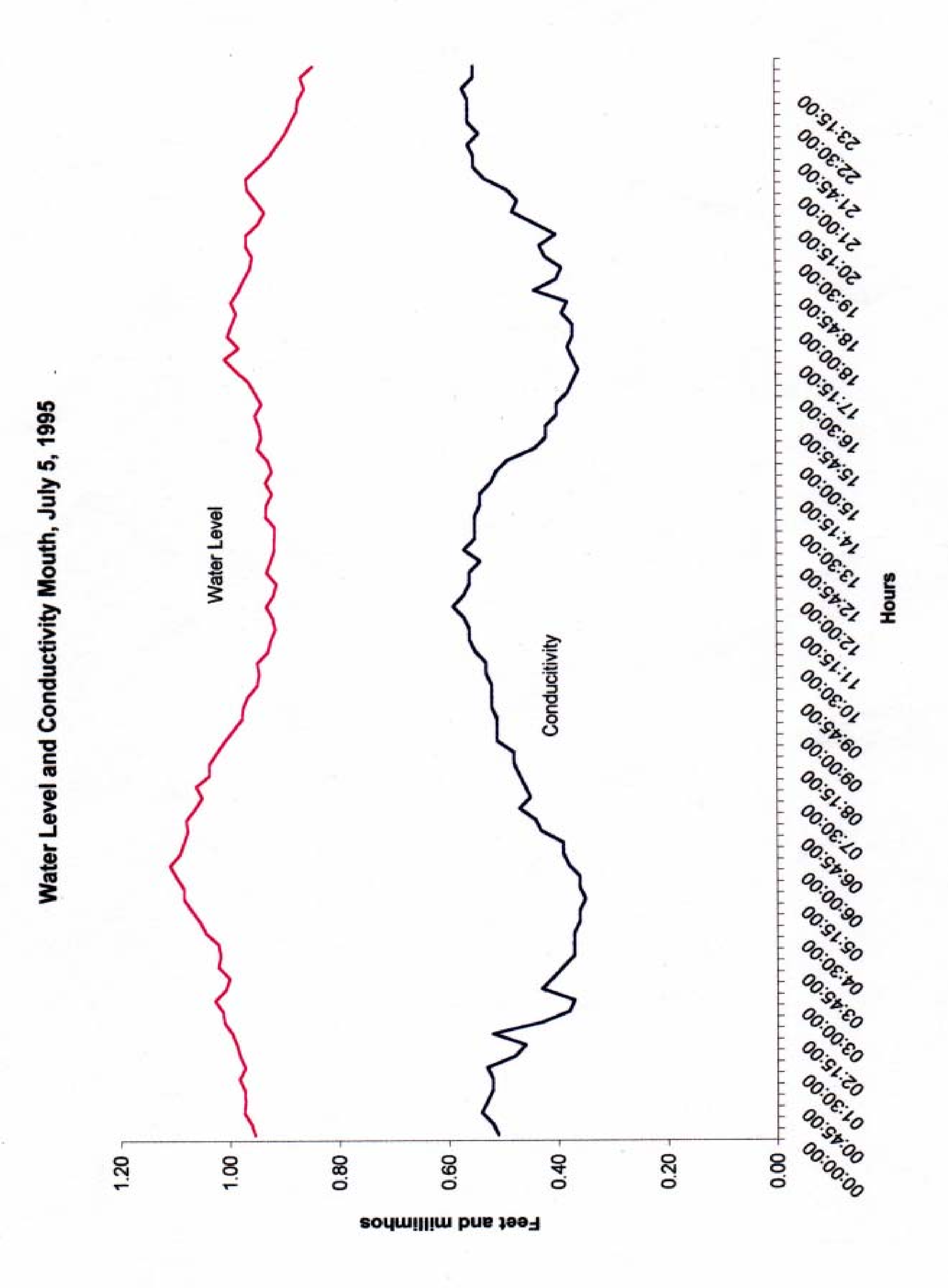


Figure 4.11. Measurements of water level (feet) and conductivity (millimhos) at estuary mouth on July 5, 1995.

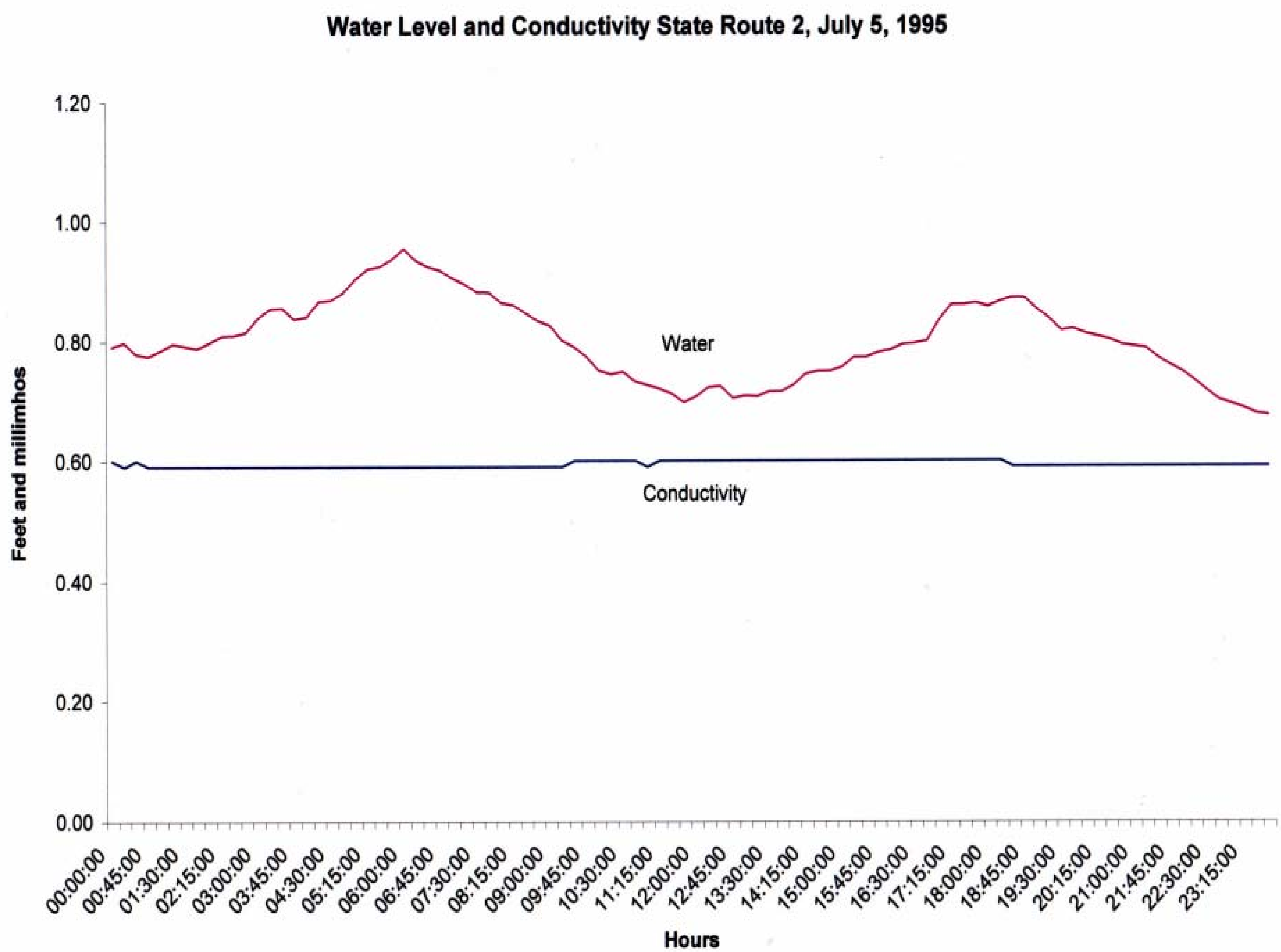


Figure 4.12. Measurements of water level (feet) and conductivity (millimhos) at upper end of estuary on July 5, 1995.