# Low lake levels in northern Wisconsin and the relative roles of precipitation and evaporation

by John Lenters, Associate Professor, University of Nebraska – Lincoln

## Lake level trends

In recent years, the lakes of northern Wisconsin have undergone a pronounced drop in water level. An example of this is shown in Figure 1, which graphs the water level of Sparkling Lake (in Vilas County) from 1984-2007. Over this time period, the lake level typically varied over a range of about 24 inches with high lake levels in the mid 1980s and 1990s and low levels at other times. On top of this variation is a long-term trend toward lower water levels, with an average downward trend of about 6.3 inches per decade (see the straight, black line in Figure 1).

Much of this downward trend began after 1997, when lake levels dropped by 42 inches down to their current record low level in 2007. This dramatic 10-year drop is probably what stands out most in the eyes of northern Wisconsin residents. A natural question to ask is, why? Have we simply been receiving less rain? Less runoff from snow? More evaporation from the lakes? There are many possible contributing factors, and we will examine two of them in this article (precipitation and evaporation).

Although Sparkling Lake is just one lake of thousands in the Northwoods, lakes often respond very similarly to variations in climate. This is again illustrated in Figure 1, which shows the water levels of Lake Superior side-by-side with those of Sparkling Lake. It can be seen from this figure that Sparkling Lake and Lake Superior behave very similarly, despite their vast difference in size (Sparkling lake's surface area is 0.25 square miles compared to Lake Superior's 31,000 square miles). So although our discussion will focus on Sparkling Lake, it is important to know that this lake is fairly representative of a much broader region.

## The lake water budget

In order to understand the cause of lake level variations, one must calculate the "water budget" of a lake. Similar to balancing your checkbook, a water budget does an accounting of all the inputs and outputs of water to a lake. Any imbalance results in a change in lake level.

Sparkling Lake is a seepage lake on sandy soil (which means precipitation and groundwater are the primary sources of water for the lake), so there is no need to account for inputs or outputs of water from overland runoff or streams. Factors that influence Sparkling Lake's water level include precipitation over the lake (P), lake evaporation (E), and the net flow of groundwater into or out of the lake (G). If we represent Sparkling Lake's water budget in terms of an equation it would look like this: $L = P - E + G$. L is the change in lake level over the given time period (usually a month, year, etc.) and is measured using staff gauges.

Although groundwater inputs and outputs to Sparkling Lake are important, they are difficult to measure and are not routinely monitored. Therefore, we will focus our attention on P, E, and L, each of which has been measured since at least 1989 as part of the North Temperate Lakes Long-term Ecological Research (LTER) Program at the University of Wisconsin-Madison.

## Influence of precipitation

Figure 2 shows the annual average precipitation measured at Minocqua Dam for the water years 1985-2007. A "water year" is the 12-month period from October to the following September, with the calendar year referring to the latter 9 months, January-September. The 23 year average precipitation at this location is around 32 inches.

Also shown in Figure 2 is the annual change in water level for Sparkling Lake, which is typically measured in late September. In most cases, years that have above-average precipitation are accompanied by an increase in lake level (i.e., a positive L in the water budget equation). This occurs, for example, in 1991, 1996, and 2002. Similarly, drops in lake level occur during years in which the precipitation rate is below average (e.g., 1987, 1998, 2005, and 2007). The recent decline in lake levels (Figure 1) is at least partially explained by the fact that precipitation rates have been below normal for each of the past 5 years (Figure 2). It is interesting to note that the two driest years of the record (1987 and 1998) both occurred in conjunction with an El Niño event. These periodic warming events in the eastern Pacific Ocean are usually accompanied by warm, dry winters in the Upper Midwest. The El Niño winters of 1986/87 and 1997/98 were good examples of this.

One can conclude from this initial analysis that year-to-year variations in lake level are strongly controlled by the amount of precipitation that falls during that year. In fact, Figure 2 reveals that the effects of precipitation on lake level are actually amplified (by about 60%). This reflects the influence of the larger watershed surrounding Sparkling Lake, since high precipitation leads to increased inputs of groundwater to the lake, thereby enhancing the effect of precipitation on lake level.

In addition to the year-to-year variations in precipitation, there is an overall downward trend in annual precipitation from about 34.2 inches at the beginning of the record to 29.5 inches at the end (the black line in Figure 2). Sparkling Lake has undergone a similar downward trend in its annual change in water level. At the beginning of the 23-year period, Sparkling Lake water levels were roughly in balance (i.e., L = 0). By the end of the record, however, the annual change in water level had become negative, dropping to a value of L = -3.7 inches. This is similar to the 4.7 inch drop in annual precipitation. One can conclude, therefore, that the observed changes in water level for Sparkling Lake, including the recent low-water period, can be almost entirely explained by changes in precipitation.

## Climate change and evaporation

Northern Wisconsin, like other regions throughout the world, is getting warmer as a result of global climate change. The effects of this are beginning to be noticed in our lakes—from reduced ice cover, to warmer water temperatures, to earlier and reduced runoff from snowmelt. An example of this for Sparkling Lake is illustrated in Figure 3, which shows the average surface water temperature during the summertime (July-September) from 1989-2005. In addition to the year-to-year variability, there is a pronounced upward trend in water temperature of about 2.8°F per decade. Given the fact that warm water tends to evaporate more readily than cold water, it is natural to wonder whether these temperature changes are leading to higher evaporation rates in the Northwoods.

Figure 3 shows the summertime evaporation (July-September) for Sparkling Lake from 1989-2005. Values range from a low of 10.6 inches in 1994 to 16.1 inches in 2005, with an average value of 13.8 inches. In fact, there is a distinct trend toward higher evaporation rates since 1994, with six of the last eight summers showing above-normal evaporation. This may be related, in part, to the general trend toward warmer water temperatures.

Warm summers tend to be associated with above-average evaporation (e.g., 1991, 1998, 2002, and 2005). Conversely, cold summers (e.g., 1992, 1996, 2000) tend to have below-normal evaporation rates. Given the likelihood that lake temperatures will continue to increase in the coming years, it is more likely than not that lake evaporation will continue to rise as well. In fact, the increase may be even greater than what is shown here, given the ongoing lengthening of the ice-free season.

## Summary

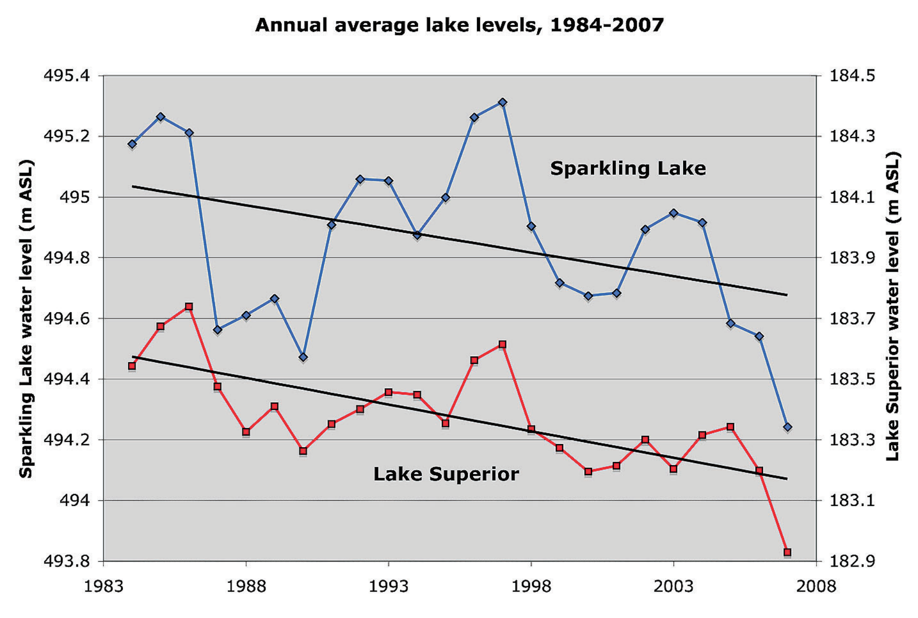
Variations in lake level in northern Wisconsin are primarily caused by changes in precipitation. The recent trend toward lower water levels is largely the result of a downward trend in annual precipitation of about 0.2 inches per year. Although this may seem small, when each year's precipitation deficit is added up over a 23-year period, this leads to a 53-inch drop in accumulated water input to the lakes. On top of this, northern Wisconsin lakes are getting warmer, and summertime evaporation has been increasing since 1994. This can only exacerbate the ongoing trend toward drier conditions. Unless we see a reversal in one or both of these trends in the coming years, we can expect low lake levels to be the "norm" for quite some time.

## *Captions for figures*

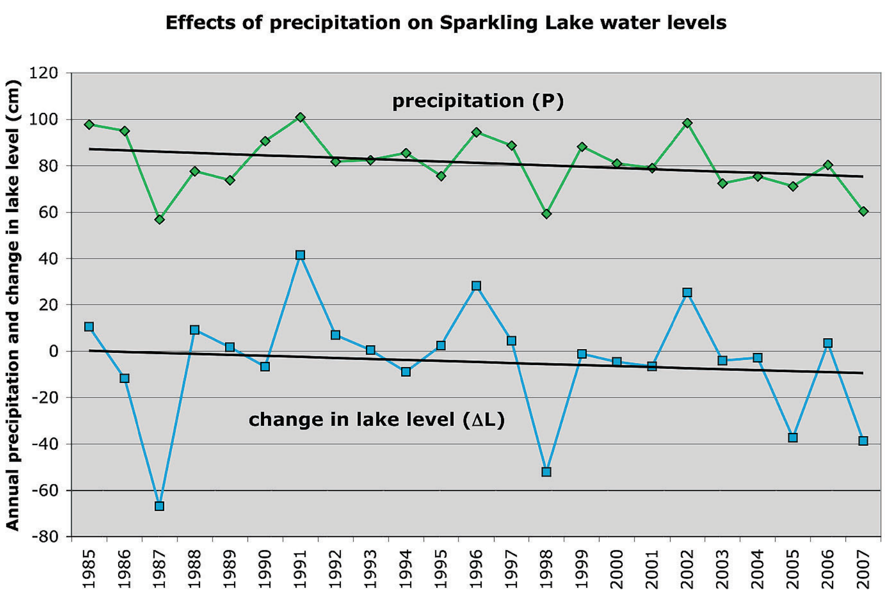
Figure 1. Annual average water levels of Sparkling Lake (Vilas County, WI) and Lake Superior in meters above sea level (ASL) for 1984-2007. Black lines indicate the long-term trend. Data courtesy of the North Temperate Lakes LTER Program and National Ocean Service.

Figure 2. Annual water-year (Oct-Sep) precipitation for Minocqua, WI (in cm) and change in water level for Sparkling Lake (in cm) for 1985-2007. Data courtesy of the North Temperate Lakes LTER Program.

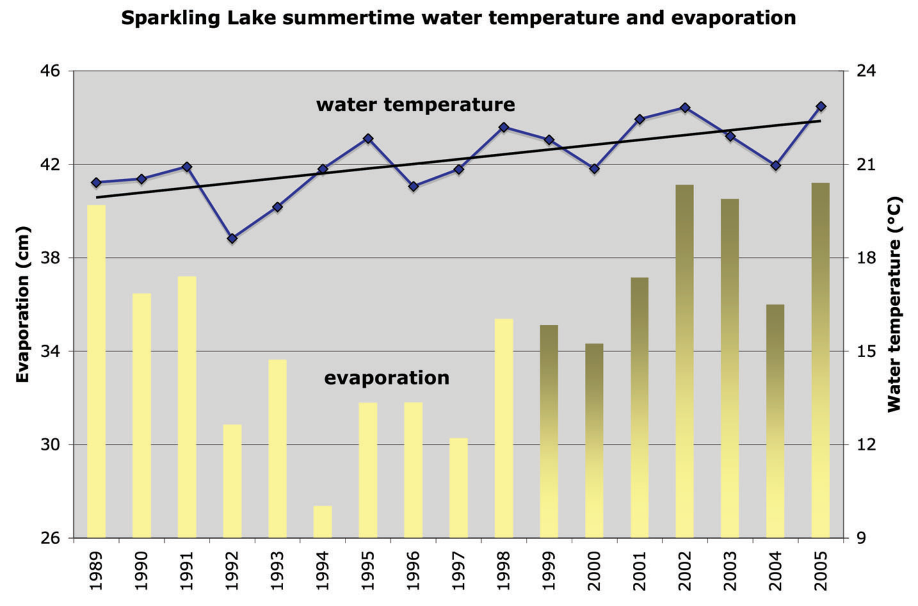
Figure 3. July-September average surface water temperature (in °C) and evaporation rate (in cm) for Sparkling Lake, 1989-2005. Shaded years (1999-2005) represent preliminary estimates. Data courtesy of the North Temperate Lakes LTER Program.



Annual average lake levels, 1984-2007
Sparkling Lake
Lake Superior
Sparkling Lake water level (m ASL)
Lake Superior water level (m ASL)
495.4
495.2
495
494.8
494.6
494.4
494.2
494
493.8
184.5
184.3
184.1
183.9
183.7
183.5
183.3
183.1
182.9
1983
1988
1993
1998
2003
2008



Effects of precipitation on Sparkling Lake water levels
precipitation (P)
change in lake level (ΔL)
Annual precipitation and change in lake level (cm)
120
100
80
60
40
20
0
-20
-40
-60
-80
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007


Sparkling Lake summertime water temperature and evaporation
water temperature
evaporation
Evaporation (cm)
Water temperature (°C)
46
42
38
34
30
26
24
21
18
15
12
9
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005