IS IT CLIMATE CHANGE? Exceptionally low water levels have been observed recently at a large number of lakes in northwestern and north central Wisconsin. As of June 2007, monthly precipitation totals in northwestern Wisconsin had been as much as two inches below normal in all but one of the preceding 12 months. Some lakes in Waushara County and elsewhere in the Central Sands region of the state were also drying up.

Below-normal seven-day average streamflows were recorded in most of the state in August 2007 except in southern and west-central portions of the state. The Palmer Drought Severity Index—a measurement of dryness based on recent precipitation and temperature—showed that northwestern and north-central Wisconsin were in severe to extreme drought during most of the summer, whereas most other parts of the state were in a mild to moderate drought following an unusually moist spring.

THE RISE AND FALL OF LAKES

Based on a presentation by Tim Asplund, Water Resources Specialist
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Much of this was due to a widespread drought that also affected most of Minnesota, Michigan, Iowa, Indiana and Ohio during the summer of 2007. But many people started wondering why lake water levels had dropped so low. Was climate change perhaps the cause, and if so, what does it mean for the future of Wisconsin's 15,000 lakes, 32,000 miles of perennial streams and other water resources?

WATER LEVELS GOING DOWN OR UP? There are few long-term lake level records in Wisconsin, but one of them is for Anvil Lake in Vilas County, near the Michigan border. This record shows there has been a steady long-term decline in the lake's water level since the 1930s, which suggests the cause may be more than a temporary drought. However, not too long ago, in the mid-1990s and again in 2002, high lake water levels were the norm around the state, and many lakeshore properties were flooded.

Another long-term record exists for Shell Lake in Washburn County, which shows—unlike Anvil Lake's record—a generally *upward* trend in water levels since the 1930s. This rise in water levels has been especially pronounced since 1970, despite a large decline caused by dry conditions since 2001. Unlike some other lakes in drought-stricken northern Wisconsin, Shell Lake is nowhere near its recorded lowest levels.

The long-term record for Devil's Lake in Sauk County also shows a general rise in seasonal water levels. And long-term groundwater level data from around the state likewise show an upward trend over the last 30 years.

A 2003 analysis of stream flow and well water records since 1970 throughout the state found a "step increase" in stream flow in 16 of 19 watersheds and a similar jump in water levels at 17 of 20 wells, including some in the northern parts of the state hardest hit by the drought. Is climate change involved in the rise in water levels in most areas, or is it instead behind the drought causing lake levels to decline? The answer: maybe both.

PROJECTED EFFECTS OF CLIMATE CHANGE By the end of this century, the projected changes in climate for the Great Lakes region include:

- An increase in average temperatures of 5-20 degrees Fahrenheit in summer and 5-12 degrees in winter. As a result, extreme heat will be more common, and the growing season will be several weeks longer. The length of time the land is snow covered and lakes and rivers are ice covered will be much shorter than it is today.

- Average daily precipitation will increase in winter and spring and decrease in summer and autumn. This means more rain in winter and during the spring planting season, and drier soils and more droughts during the summer growing season and fall harvest.

- The number of severe storms, floods and other extreme events could increase by 50 percent and perhaps even double in frequency.

For water resources in Wisconsin, such changes in climate mean:

- **Major changes in hydrology at the watershed scale.** Precipitation extremes will result in more floods as well as severe droughts that will dry up small streams and lakes. Less ice cover and snow cover will increase winter evaporation and reduce spring runoff.

- **Changes in aquatic species distributions.** For example, white bass will expand northward, coldwater species like trout will disappear from some southern streams, and nonnative species from warmer climates will invade our waters.

- **Reductions in the water quality of lakes, streams, rivers and wetlands.** For example, warmer temperatures will stimulate algal blooms, which can have a variety adverse ecological, aesthetic, and human and animal health effects.

HYDROLOGIC EFFECTS It is difficult to predict the effects of climate change on a particular watershed because its hydrologic cycle involves many interrelated components, including precipitation patterns, water temperature, evaporation rates, groundwater inputs and outputs, and the flow rates of surface waters.

Certain processes in the surface water balance are heavily influenced by rainfall intensity, so the projected increase in heavy rainfall raises several concerns. One is that the rate of percolation of water into the soil is limited. As rainfall intensity increases, soil moisture recharge tends to decrease, and runoff tends to increase.

Another is that evaporation rates will increase with warmer temperatures. In our present climate, rainfall increases during the summer months, which helps maintains soil moisture and reduces runoff. It also helps keep lake levels from declining. A seasonal shift to less rainfall in summer and more rainfall in winter and spring will affect each of these factors.

For example, less winter ice cover will increase evaporation from surface waters, warmer air temperatures increase evapotranspiration and water consumption by plants, less precipitation in summer will decrease soil moisture. This could cause lake levels to go down.

On the other hand, warmer, wetter winters will increase the recharge of groundwater and improve soil moisture; more carbon dioxide in atmosphere decreases evapotranspiration and increases the water-use efficiency of plants, which enhances both runoff and infiltration to groundwater; baseflow and groundwater levels increase over the long term. This could cause lake levels to go up.

However, a variety of other factors affect lake water levels, including the lake's location, its depth and area, variability in weather patterns, short-term droughts or wet periods, and the amount of water consumed for human uses.

LAKE HYDROLOGY Lakes are generally classified as being either a drainage lake or a seepage lake. A drainage lake is surface-water dominated—it gets and releases most of its water via a river or streams. Seepage lakes are generally groundwater dominated—they don't have a surface water source or outlet and rely groundwater for most of their water. Some seepage lakes receive little or no groundwater and depend primarily on precipitation for their water.

Lakes are also characterized by how water flows through them. These include:

- Recharge lakes, which don't receive but contribute to groundwater and depend on surface-water inflow or precipitation for all their water;
- Flow-through lakes, where water from surface and/or groundwater sources enters from the higher elevation side of the lake and exits on the lower elevation side, and
- Discharge lakes, where most of the water comes from groundwater, and the water level is affected mainly by the level of the water table, rate of evaporation, and the presence or absence of some outlet. Natural springs are a form of discharge lake.

The water level of a lake varies naturally within a range of seasonal highs and lows and occasional extreme highs and lows. This range of natural vari-

Apostle Islands National Lakeshore, Wisconsin: Bobak Ha'Eri

ability is affected not only by precipitation and evaporation, but also by the type of lake and its elevation and position in the landscape.

The water level of groundwater flow-through lakes tends to vary the most—in some cases by as much as 10 feet. Surface water flow-through lakes also tend to have a wide range of water levels as they respond to decreases and increases in surface water inflow due to droughts and heavy rains. Discharge lakes tend to have the most stable water levels because they are constantly being resupplied from groundwater.

Lakes in higher elevations or high in a watershed tend to be seepage lakes. The rise and fall of water levels in these lakes tends to be more affected by precipitation and evaporation, which is why seepage lakes in the upper part of a watershed have a greater response to droughts than drainage lakes.

Lower elevation lakes tend to be more of the flow-through variety and have greater groundwater inputs as well, so they are buffered from short-term dry periods and respond more to long-term changes in groundwater level and recharge rate. As a result, the water level of lakes lower in the landscape are generally more stable.

IS IT DROUGHT? As noted earlier, in 2007 much of Wisconsin was in a drought, which was especially severe in the northwestern part of the state. However, the drought in that part of the state has lasted only a few years so far, and we've had longer and much worse droughts in the past. The state as a whole is experiencing nothing near the last extreme drought we had in the late 1980s that lasted nearly five years. The drought of the infamous "Dust Bowl" years in the 1930s affected Wisconsin for most of that entire decade.

Actually, other than the short record-setting drought that occurred around 1977, Wisconsin has been in an unusually moist period since the mid-1970s. We've had many more wet years during the last 30 years than dry ones, including a wet period spanning nearly 10 years from the late 1970s until the late 1980s. Generally, Wisconsin has been much wetter than normal compared to past decades, and this explains the step increase in stream flow and water levels mentioned earlier.

The two areas that haven't shown a step increase in water levels are in two high elevation areas of the state with lakes of the seepage type that are most vulnerable to drought. Drought also reduces the flow of streams that may supply water to these and other lakes in the area. Lakes in the same area that are lower in elevation and have more groundwater inputs have been less affected by the drought because of higher groundwater levels resulting from three decades of generally wetter-than-normal conditions.

This is illustrated by a long-term groundwater monitoring well the U.S. Geological Survey maintains at a roadside park near Glidden, just south of Ashland at the Lake Superior-Mississippi River basin divide. This well is 1,550 feet above sea level and it doesn't show the step increase in water levels found elsewhere. The USGS record show the water table there has remained relatively stable since the 1970s, rising about a foot during the wet period that began in the late 1970s and dropping about a foot or so during the extreme drought in the late 1980s.

Like Anvil Lake, three of four lakes at the UW Trout Lake Experiment Station, also located in Vilas County, show a general decline in water levels spanning the last 25 years. In fact, they are lower now than during the period of extreme drought in the 1980s. The water level of the fourth lake shows a slight decline, but it is a drainage lake lower in the watershed, whereas the other three are seepage lakes higher in the watershed.

Moreover, all of these lakes are located in a part the state with forested, sandy soils, where groundwater levels are closely connected to precipitation levels and tend to rise and fall accordingly, which explains why lakes in this area have not shown the step increase in water levels and stream flow seen in other areas.

Anvil Lake and other lakes in higher elevation parts of the state are going to be the first to respond to a change in climate, so they may be sentinel areas responding to climatic signals of a change to generally warmer and drier conditions. Perhaps groundwater-flooded lakes lower in the landscape just haven't caught up yet.

THE HUMAN FACTOR Wet and dry periods will continue, and climate changes will not affect all parts of the state the same way due to variations in local geography and geology. However, climate is not the only driver affecting lake levels and other water resources. The other drivers are all human. Our current regional population of 60 million is expected to continue to grow, leading to more urbanization and sprawl and rising demands on available water supplies. In turn, these changes will likely lead to greater fragmentation of the landscape, disrupting watersheds and runoff patterns.

Along with climate change, these pressures on the environment are expected to worsen some existing water resource problems. Less rainfall in the summer will reduce the recharge of groundwater aquifers, and winter and spring precipitation may run off too quickly to make up the difference. Small streams, especially headwater streams, could run dry in summer. Reduced ice cover during winter and higher evaporation rates during hotter summers are likely to cause a general decline in average lake levels around the state, year-to-year fluctuations notwithstanding. The loss of wetlands coupled with the projected increase in the frequency of heavy rains will create growing problems with flooding, as well as erosion and runoff from agricultural fields and urban areas into streams and lakes. Wisconsin farmers may have to rely more on irrigation to grow crops, which can have significant effects on local water supplies.

A SAND COUNTY FORECAST The effects of human water use on lake levels and groundwater levels can be seen in the Central Sands region of the state. The Central Sands is a glacial lake plain that was promoted as a place to grow potatoes and vegetables in the 1950s as part of an economic development strategy. It is now one of the prime potato and vegetable growing areas of the state, and that requires a lot of water for irrigation. As result, the Central Sands watershed has the highest concentration of high-capacity wells in the state—as many as two per square mile.

Waushara County is located in this region and straddles the watershed divide between the Mississippi River and Lake Michigan. Along the divide, the flow of groundwater and surface water splits and goes in opposite directions. Over the last 10 years, the water levels of several lakes located along this divide in northwestern Waushara County have been dropping dramatically—some by as much as 10 feet since the mid-1980s. Located in sandy soil high in the watershed, these are landlocked seepage lakes with no outlet. They are also located in an area with a large number of high-capacity wells.

As water is pumped out of the ground, all wells create what is called a "cone of depression" in the groundwater table. As groundwater seeps in to refill it, this depression can direct the flow of groundwater away from a nearby lake or stream. If the cone is large enough and located near a groundwater divide, it can also reduce the flow of groundwater to one side of the divide or even reverse the flow to the opposite side.

It is unclear how much of the decline in these Waushara County lakes can be attributed to groundwater pumping by nearby high capacity wells and how much is due to the short recent drought in the area. It is likely some combination of the two—and perhaps a foreshadowing of what climate change may bring.

Storm in Duluth, Minnesota: Gene Clark

THINGS WE CAN DO The key to protecting our lakes and other water resources in a changing climate is to minimize pressures on the environment to reduce its vulnerability to future climate stresses. This means protecting water quality as well as water supplies. This is particularly important for drinking water but also for industries that rely on a steady supply of high-quality water for their operations. Upgrading sewer and septic systems and reducing nonpoint source pollution from urban areas, roads, farmlands and other sources are good examples. We can all increase the reliability of water supplies if we use this vital resource more efficiently.

Particularly valuable in terms of habitat protection would be the rehabilitation of riparian and floodplain forests, which would shade and help keep stream temperatures down and reduce flooding.

Urban and land use planning can reduce sprawl, which not only reduces greenhouse gas emissions from long commutes, but also the amount of paving and stormwater runoff. It also helps reduce destruction and fragmentation of farmland and forests and other natural habitat.

Finally, communities should consider infrastructure improvements and adjustments to water supply systems, floodplain structures and lake shore facilities to anticipate and accommodate drier summer and wetter winter conditions, and a generally much more variable climate in the future.