

Impacts and Vulnerabilities



Adaptation Strategies isconsin boasts a wealth of water resources. The Mississippi River, Lake Superior and Lake Michigan help define our state borders, and the 84,000 miles of streams, 15,000 lakes, 5.3 million acres of wetlands and abundant groundwater nourish plants and animals, provide drinking water for urban and rural communities, support industry and agriculture, and enrich our recreational activities.

Wisconsin's climate is changing, and our water resources and aquatic ecosystems are changing, too. In this chapter, we will examine the ways in which climate change affects the quality and quantity of water resources, including inland lakes, rivers and streams, groundwater and wetlands. We will describe the physical responses within the water cycle to rising temperatures and shifting precipitation patterns, discuss the impacts of those changes, and present adaptation strategies where possible. (For discussion of impacts on the Great Lakes, see Chapter 6: *Coastal Resources* and Chapter 9: *Moving Forward*.)

Wisconsin's Water Resources

Wisconsin's waters respond to climate through a range of processes and, in some cases, serve as indicators of climate change. Historical records demonstrate that water resources are intimately linked to local and regional climate conditions. Long-term records of lake water levels, lake ice duration, groundwater levels, stream baseflow, and stream and river flooding have corresponding relationships with longterm trends in atmospheric temperature and precipitation.

CHAPTER THREE WATER RESOURCES

We anticipate that future climate projections will affect our state's water resources in both quantity and quality. The hydrological responses to climate change will vary, however, among different geographic regions of the state. This is clearly evident in Wisconsin's historical records as well as in the future climate projections produced from the WICCI downscaled climate data. The differences in hydrological responses reflect variations in land use, soil type and surface deposits, groundwater characteristics, and runoff and seepage responses to precipitation.

Climate Drivers

The two driving forces of climate change that will affect water resources are increased temperature and shifting precipitation patterns. Climate models forecast that Wisconsin's temperature will increase in all four seasons, with the greatest increase in winter. The models project precipitation increases in fall, winter and spring. The combination of warmer temperatures and changing precipitation patterns suggests that we will see a significant increase in the amount of winter precipitation falling as rain rather than snow and that freezing rain is more likely to occur. The magnitude and frequency of precipitation are also projected to increase in spring and fall.

These changes in temperature and precipitation will affect Wisconsin's water cycles, with major impacts on lakes, streams, groundwater and wetlands. Some of the physical responses we can expect to see include:

- Increased average surface water and groundwater temperatures.
- Shorter periods of ice cover on lakes and streams.
- Decreases in the thickness of lake ice cover.
- Increased evapotranspiration rates during the longer growing season.
- Increased number of freeze-thaw events.
- More groundwater recharge due to increases in winter and spring precipitation. (Groundwater recharge refers to water that infiltrates and moves downward into the saturated zone of an aquifer.)
- Changes in recharge and discharge based on whether precipitation falls as rain or snow. (Groundwater discharge refers to groundwater that reaches the surface, such as springs, seeps, lakes or rivers.)
- Increased number of high water events causing flooding.

Impacts and Vulnerabilities

To improve our understanding of how projected climate changes may affect Wisconsin's water resources, we consider future climate projections in the context of historical variability and hydrological trends of the past. When viewed together, a picture of climate change impacts on Wisconsin's waters emerges.

Hydrologic Processes

Hydrologic processes are the ways in which water moves through the water cycle (figure 1). When one part of the system is affected by the driving forces of a changing climate, all other parts are affected. Most of the water entering the landscape arrives as precipitation that falls directly on water bodies, runs off the land surface and enters streams, rivers, wetlands and downstream lakes or percolates through the soil, recharging groundwater that flows underground and re-emerges as springs into lakes, wetlands and streams.



Figure 1. Climate change may alter how water moves through the water cycle.

Other important hydrological processes include evapotranspiration and sublimation.

We may not always be able to predict the systemwide, sometimes abrupt, changes in hydrologic patterns across the state. Examples include groundwater flooding, with groundwater tables rising as much as 30 feet in one season, leaving formerly dry ground inundated for periods of time; streams drying up due to lack of groundwater recharge and discharge to the streams; or changes in aquatic ecosystems, such as the increasingly long periods of time when blue-green algae blooms occur in nutrient-rich lakes.

Evaporation: The process by which water is changed from a liquid into vapor.

Sublimation: Direct evaporation of snow and ice.

Transpiration: The process by which plants give off water vapor through their leaves.

Spatially, the state will not be affected uniformly. For example, parts of the state have experienced increased precipitation while other parts have experienced drought. Differences in the physical characteristics of a place – such as variations in land use, soil type and surface deposits, groundwater characteristics, and runoff and seepage responses to precipitation – can confound the influence of climate change, leading to a wide range in system responses.

There are also thermal impacts as atmospheric and water temperatures rise. Aquatic ecosystems can suffer if streams or other resources are taxed further by heavy influxes of warm water, either from overland flow, such as water picking up heat along a parking lot, or stormwater discharged from a stormwater management facility.



THE CENTRAL SANDS

The Central Sands region of Wisconsin is of particular hydrological interest because of how much its water resources are linked to groundwater. The Central Sands covers parts of five Wisconsin counties, and the region is characterized by a thick mantle of sandy glacial materials, more than 100 feet thick in many places, that covers impermeable bedrock. These sandy materials compose a produc-

tive aquifer holding an important groundwater resource that feeds the area's extensive lakes. streams and wetlands.

Groundwater, which originates from precipitation that percolates through soils, is ultimately discharged to surface waters. Lakes and wetlands exist where groundwater levels intersect depressions in the landscape, and streams occur where groundwater discharges to channels. Thus, changes in the landscape's hydrologic budget that affect groundwater also affect surface water ecosystems.

Although climate change is expected to drive changes in the hydrology and water resources of any Wisconsin landscape, the Central Sands region is a distinct case because of its heavy dependence on irrigation for agriculture. Groundwater reserves are tapped by Wisconsin's highest concentration of high-capacity wells, with the greatest amount of groundwater pumping in the state used chiefly for agriculture. Irrigated land has been increasing in the Central Sands region for about 50 years and currently covers about 175,000 acres. The potential effects of irrigation have been explored

in classic studies in the 1960s and 1970s as well Source: WICCI Central Sands Hydrology Working as in more recent works. These studies suggest



Figure 2. High-capacity wells in the Wisconsin Central Sands.

Group.

that irrigation can reduce net groundwater recharge by 20-25 percent compared with non-irrigated lands. In fact, the region has already experienced serious groundwater pumping impacts on lakes, streams and wetlands. This reduction has been sufficient to dry up some lakes and streams in the region under only moderate drought conditions. (Please see the Plover River case study in the Water Resources Working Group Report at www.wicci.wisc.edu).

Nutrient-Rich: Containing high concentrations of compounds of nitrogen, phosphorus and potassium that promote plant growth.

Lakes

Climate change will impact lakes in several ways. Some of the most significant impacts include greater sediment and nutrient loads washing into lakes from increased stormwater runoff, decreases in ice cover throughout the state, physical impacts on lakes, changes in lake levels and changes in the composition of aquatic species communities.

Increased Sediment and Nutrient Loading

Polluted runoff is the biggest cause of water pollution in Wisconsin. It results when large precipitation events wash sediment and nutrients off the landscape, threatening downstream surface water resources. When runoff containing nutrients such as phosphorus washes into water bodies, the result is excess nutrient loading. These nutrients fertilize algae and boost their growth.

Sediment from runoff along with algae makes waters murky and turbid, decreasing visibility for sight-feeding fish and diving birds. It also limits photosynthesis, making it difficult for submerged aquatic vegetation to grow. These underwater plants are essential for a balanced and productive aquatic insect and fish community, so increased amounts of sediment and nutrients impact every facet of aquatic habitats.

An increase in the size and frequency of heavy rainfall events and a shift to more rainfall in winter and spring will increase runoff from surrounding land when plant cover is reduced or absent, which means sediment and nutrient loading to lakes will also increase. The degree of sediment and nutrient loading across the state depends on land use, soils and geology. Most of the loading comes from a relatively small portion of the landscape, so soil conservation practices in those regions have a large effect on the degree of

THE PROBLEM WITH PHOSPHORUS

Lake Michigan's Green Bay is one of Wisconsin's water bodies being affected by excess nutrient and sediment loading. Sediment enters Green Bay mainly from the Fox River and its tributary streams. A nutrient of particular concern for Green Bay water quality is phosphorus. Phosphorus stimulates algae growth, and algal blooms contribute to the problem of reduced light penetration and lower oxygen concentrations in the water column. Blue-green algae are actually photosynthetic bacteria that can become a serious concern under high phosphorus conditions. These prolific microorganisms produce toxins of health concern to humans and wildlife, and they outcompete the more desirable species of microscopic algae that form the base of the aquatic food chain. If phosphorus concentrations increase and boost blue-green algae growth, food chain efficiency will be reduced and this could lead to an unbalanced fish community that favors invasive bottom-feeding carp to the detriment of native fish species like walleye. Currently, the likelihood of increased phosphorus concentrations from an increase in runoff is one of the greatest threats to the Green Bay aquatic ecosystem.



soil loss and subsequent sediment and nutrient loading throughout the watershed. (See Chapter 3: *Agriculture and the Soil Resource* for more on soil conservation practices.) In fact, scientists estimate that if we target soil conservation practices in the 10 percent of Wisconsin watersheds that lose the most sediment to runoff, we could reduce statewide sediment loading by 20 percent. Current soil conservation practices, which assume a certain tolerable level of soil loss, are insufficient to meet water quality standards. As our climate changes, meeting these standards will be even more challenging.

The seasonal timing of increased precipitation will play a critical role in the potential impacts on our lake resources. If the ground is frozen but precipitation falls in the form of rain, it will run off into surface waters S cientists estimate that if we target soil conservation practices in the 10 percent of Wisconsin watersheds that lose the most sediment to runoff, we could reduce statewide sediment loading by 20 percent.

PRECIPITATION AND NUTRIENT LOADING

Data analysis of Dane County's Lake Mendota from 1980 to 2007 highlights the significance of precipitation and runoff for nutrient loading to lakes. The lowest concentration of total phosphorus in the lake was in 1988 as a result of a two-year drought. There was a reduction in the amount of



polluted runoff entering the lake, and water clarity was at its best. In contrast, in 1993, total phosphorus concentrations were highest following very high-runoff spring and summer events. If Wisconsin's changing climate includes an increase in precipitation or heavy rainfall events such as those that occurred during the most recent decade (2000-2009) in Madison, these changes will lead to increased nutrient loading to lakes. This points to the need for best management practices to reduce sediment and nutrient loading.

Figure 3. Precipitation trends recorded in Madison.

Source: Updated from Steve Vavrus, Nelson Institute Center for Climatic Research, University of Wisconsin-Madison. and carry contaminants with it, particularly phosphorus and nitrogen from soil and manure. In contrast, when the ground is not frozen, precipitation is more likely to infiltrate the ground and recharge groundwater.

Changes in Ice Cover

Climate models predict that with rising temperatures in fall, winter and spring, ice cover will decrease in duration throughout the state. In the future many of Wisconsin's lakes, particularly in the southern part of the state, may even be ice-free all winter. Variability in the ice cover of lakes is quite sensitive to changes in weather and climate. Decreases in the duration of ice cover in lakes throughout Wisconsin have resulted from a combination of freeze dates coming later, indicative of warmer fall air temperatures, and ice breakup dates coming earlier, indicating warmer winter and spring air temperatures.

Ice cover records from throughout the Northern Hemisphere have been used to demonstrate long-term climate changes that have occurred over the past 150 years. They also reflect short-term climate variability. Scientists can graph historical ice cover records and weather-climate patterns and distinguish shortterm effects from long-term changes.

In shallow lakes during the winter, sunlight cannot penetrate heavy ice cover that is shrouded in snow for a long period of time. Consequently, oxygen is depleted by decomposing algae and other organic material, and many fish can die from asphyxiation in a process called "winterkill." Shorter periods of ice cover because of warmer winter temperatures would reduce these winter fish kills in shallow lakes.

In summer, deeper inland lakes could face increasing challenges of depleted oxygen levels in the bottom waters where coldwater fish such as lake trout and cisco live. Under normal circumstances, seasonal changes in temperature trigger a fall mixing of the thermal layers of a lake after a period when colder bottom waters are relatively isolated from the warmer surface waters – a process called thermal stratification. This fall mixing redistributes oxygen to the deeper waters of the lake where the oxygen has been depleted over time, especially in cases where lakes have become more fertile with more organic matter for bacterial decomposition.

Prolonged periods of warm weather due to either early spring warming or warmer fall temperatures – or both – would lengthen the period of thermal stratification and allow for more oxygen depletion throughout the entire zone of bottom waters. As a result, coldwater fish would no longer find oxygenated waters in their required temperature ranges because the oxygenated surface waters would be too warm for them.

LAKE ICE

The long records from these lakes make it clear that ice cover is declining even in the face of great variability over years and decades. Note that the unusually long or short ice covers in individual years are not a change in climate but yearly variations in weather affecting ice formation and decay. For example, a detailed examination of the ice records for Lake **Mendota shows that** the total duration of ice cover has declined at a rate of about 1.9 days per decade, or **19 days per century.** The shortest ice cover period for the lake was 21 days in the winter of 2001-02. This is in contrast to the average ice cover period of about 100 days over a 154-year long record. The change in ice cover can also be seen in the occurrence of extreme years. The winters with the 10 longest periods of ice cover all occurred before 1900, while the winters with the 10 shortest periods of ice cover occurred mostly in recent years.

TRENDING TOWARD SHORTER DURATION



Figure 4. This illustration shows that over the past 150 years ice cover occurs later and breaks up earlier. The circles indicate the location of the lakes and the colors key to the trends.

Source: Magnuson, J.J., J.T. Krohelski, K.E. Kunkel, and D.M. Robertson. 2003. Wisconsin's waters and climate: Historical changes and possible futures. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 90: 23-36.



Figure 5. Ice duration of Lake Mendota. The straight line indicates an overall decrease of 19 days per century in ice cover during the 154-year period of record. The winters with the 10 longest periods of ice cover are identified with blue circles and the 10 shortest periods of ice cover are identified with red circles. Source: John J. Magnuson, Center for Limnology, University of Wisconsin-Madison.

The loss of coldwater fishes such as cisco or lake trout would be a negative impact on biodiversity. The decline in winterkill would allow game fishes like northern pike to become established, which could increase fishing opportunities; however, a diverse community of small fishes intolerant of pike predation could become less common in Wisconsin.

Recreational opportunities will also shift as a result of changes in ice cover on lakes and streams. An increase in the ice-free period may increase recreational opportunities for boating, fishing and swimming; however, winter recreational opportunities like skiing, snowmobiling and ice fishing would decline.

Physical Impacts

Climate change makes lakes susceptible to increases in a host of physical impacts. With ice cover on the lakes for less time, the longer period of open water increases the impact of wave action on the shoreline. Heavy rainfall events are another factor. Climate scientists predict an increase in the magnitude and frequency of heavy downpours, and these events can cause shoreline flooding and erosion, increase property damage and cause dam failures. In some cases, intense rainfall events redefine the boundaries traditionally considered the limits of a lake's shoreline as waters spread beyond historical boundaries.

A recent example that illustrates the physical impacts of heavy rainfall events on lakes is the 17 inches of rain that fell in southern Wisconsin in June 2008. During this 10-day period of rainfall that was capped by one intense event, the water in Lake Delton breached a portion of the lakeshore, washing out a road and homes. The lake drained completely into the Wisconsin River, resulting in millions of dollars in damage.

CASE STUDY: THE STORMS OF 2008

Heavy rainfall across parts of southern Wisconsin during June 2008 overwhelmed stormwater management infrastructure, causing widespread flooding. Intense rainstorms have varied widely in the past but have increased in number in recent years and are forecast to become more frequent in a warming climate. Such storms led to a massive increase in nutrient and sediment loading to surface waters caused by erosion, and:

- Stage readings on 38 river gauges broke previous records.
- 810 square miles of land was flooded.
- 28 percent of the 2,500 private wells tested were contaminated.



Figure 6. 2008 Spring Flooding Radar Map

- 90 million gallons of raw sewage overflowed from 161 wastewater treatment plants.
- The Federal Emergency Management Agency paid a total of \$34 million in flood damage claims.

Changing Lake Levels

Lake water-level fluctuations are important to lake and water managers, lakeshore property owners, developers and those using the lakes for recreation. Lake levels change from year to year, and extreme high or low levels can present problems by restricting access to water, hampering navigation, flooding lakeshore property, damaging shorelines and structures, and changing near-shore vegetation. We focus in this section on changing levels in inland lakes, and the effects of changing water levels in Lake Michigan and Lake Superior are discussed in Chapter 6: *Coastal Resources*.

Lake levels may change as a result of climate change, but these changes may not be the same throughout the state. In addition, the net balance between precipitation and evaporation remains difficult to predict with high confidence. Because of this, lake levels may go up or down dramatically based on the geographic location of a lake and local rainfall patterns. If more evapotranspiration than precipitation and groundwater recharge occurs in an area, lake levels will drop. Lake levels will rise if precipitation, recharge or increased runoff to urban lake systems is greater. In addition, regional differences in soil type and land cover will affect how climatic changes translate into hydrologic changes.



Lake Mendota ice breakup, Spring 2010.

CASE STUDY: SILVER LAKE IN BARRON COUNTY

Changes in lake levels, both up or down, will have impacts on aquatic habitats. A study of Silver Lake in Barron County found that during periods of low water, the lake has low levels of nutrients, low algal growth and very good water clarity. During periods of high water, the lake becomes eutrophic and has excessive nutrients, higher algal growth and poor water quality. Silver Lake is in a relatively pristine area of Wisconsin where phosphorus concentrations in surface water runoff are relatively low and where phosphorus loading would most likely be diluted. Changes in land use that result in increased phosphorus concentration in stormwater runoff will likely exacerbate the effects of increases in precipitation from climate change.

Water levels of lakes and shallow groundwater tables integrate the effects of hydrologic processes within a given landscape. Therefore, changes in the water levels of lakes and groundwater can be the result of natural climatic phenomena or other changes in their watersheds, such as changes in land use. Based on results from climate model projections, it is likely that future

> climate change will either cause changes in hydrologic budgets, such as increases or decreases in water levels or flows, or cause water levels to fluctuate more widely in response to larger fluctuations in precipitation and runoff.

Seepage lakes, those with no outlet and for which most water input comes from precipitation and groundwater, are more sensitive to changes in precipitation and groundwater elevations than drainage lakes, which have stream inlets and outlets. Water in many seepage lakes in northern Wisconsin is at its lowest levels in 60 years (see Anvil Lake sidebar). In the southern part of the state, water levels in most seepage lakes have

ANVIL LAKE

Anvil Lake (Vilas County), a northern Wisconsin seepage lake for which water-level records have been kept for 74 years, demonstrates pronounced, recurring highs and lows. The data appear to indicate that lake levels are getting progressively lower during each succeeding dry period and especially during the present period for this lake. In the future, water loss through evapotranspiration associated with warmer temperatures would exacerbate any drought effect if increases in evapotransporation exceed increases in precipitation, as future climate scenarios suggest. Other lakes and wetland systems that are at higher elevations in landscapes where water levels depend on local groundwater inputs and direct precipitation countered by evaporation are expected to be subject to this same phenomenon.





increased. This increase is believed to be partly caused by changes in the amounts and timing of precipitation and by watershed land use changes.

For all but the smallest lakes, flooding generally results from unusually high amounts of rainfall over weeks to months. As with stream and river flooding, increases in winter and spring rainfall are likely to have the greatest affect on lake flooding. As mentioned earlier, this can be complicated by the role of frost and frozen ground, which can either increase or decrease runoff and recharge. Slow-draining lakes and seepage lakes without natural outlets will be most vulnerable.

Change in Species Composition

Climate change will affect the composition of aquatic species living in lakes, including invasive species. Floods and droughts alter the physical conditions of a lake, affecting the suitability for plant and animal species and in some cases making them better suited for invasive species. Unusual floods can connect water bodies and allow invasive species to enter waters that had typically been confined or isolated. Rising temperatures affect thermal thresholds of plant and animal species, and polluted runoff from increased precipitation or heavy storms affects many facets of aquatic ecosystems, such as algal communities.

Increased temperatures may lead to introductions and survival of aquatic invasive species not previously recorded in Wisconsin. Species not native to the area may be more likely to survive when temperatures rise because many species, such as *hydrilla*, water hyacinth or red swamp crayfish, will be able to overwinter. These species are native or well-established in the southern U.S. but thought to be limited by cold temperatures and ice cover; however, two recent findings of these species in small constructed ponds in Wisconsin have shown that overwintering is possible and will become even more likely with reduced or no ice cover. An example of a southern native fish species that could further invade due to warmer temperatures is the gizzard shad, a problem species in reservoirs in Ohio and other areas south of Wisconsin.

Please refer to Chapter 4: *Natural Habitats and Biodiversity* for more detail on climate change impacts on lakes and other aquatic habitats.

Drainage lakes: Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems but generally have shorter water residence times than seepage lakes. Watershed protection is usually needed to manage lake water quality.

Seepage lakes: Lakes without a significant inlet or outlet, fed by rainfall and groundwater. Seepage lakes lose water through evaporation and groundwater moving on a downgradient. Lakes with little groundwater inflow tend to be naturally acidic and most susceptible to the effects of acid rain. Seepage lakes often have long water residence times, and lake levels fluctuate with local groundwater levels. Water quality is affected by groundwater quality and the use of land on the shoreline.



THE GREEN BAY ECOSYSTEM

Lake Michigan's Green Bay is one of the largest freshwater estuaries in the world. Green Bay is characterized as an estuary because it functions as a nutrient trap, has very high biological productivity, and the water of its tributaries differs thermally and chemically from that of Lake Michigan. While representing only seven percent of the surface area and 1.4 percent of the volume of Lake Michigan, the bay receives approximately one-third of the total phosphorus loading within the Lake Michigan basin.

The head of Green Bay originates at the mouth of the Fox River, the largest tributary of Lake Michigan. The biogeochemical cycles in Green Bay are dominated by the nutrient inputs from the Fox-Wolf River watershed, whose area of 6,400 square miles is equivalent to one third of the Lake Michigan watershed. Approximately 70 percent of the phosphorus and suspended sediment load in the southern bay enters from the Fox River, including an estimated 330,000 tons of sediment annually and 1,210 tons of total phosphorus.

Public and private stakeholders have spent hundreds of millions of dollars in efforts to reduce pollution and restore habitat in the Green Bay ecosystem. Over the last 40 years or more they have made progress in restoring the ecological integrity of the bay and the many benefits it provides. Scientists and managers have recognized that the Fox River and the Green Bay ecosystem have become degraded because they are impacted by multiple stressors, not just one or two causal agents. Climate change poses a new kind of threat to the bay and its resources because it may alter the impact of the already existing stresses on the system.

Based on previous experience, the Green Bay Working Group assessed the potential consequence of climate change by evaluating the risk posed to the Green Bay ecosystem from regional shifts in temperature, precipitation and storm events. The relative magnitudes of risk to valued components of the ecosystem were estimated by examining the interactions among ecosystem stressors and the valued components of ecosystems. Working group members were assigned to one of five breakout groups to address the conservation targets:

- Northern pike
- Coastal wetland community
- Littoral zone community
- Lake sturgeon
- Benthic community

The groups applied five overarching principles of adaptive management:

- Reduce other non-climate stressors.
- Manage for ecological function and protection of biodiversity.
- Establish habitat buffer zones and wildlife corridors.
- Implement proactive management and restoration strategies.
- Increase monitoring and facilities management under uncertainty.

From these deliberations, one overarching adaptive principle emerged: Reduce other non-climate stressors and thereby increase the resilience and adaptive capacity of the system.



Figure 8. Map of Green Bay watershed Source: The Nature Conservancy

Rivers and Streams

The state's thousands of miles of rivers and streams will also be affected by a changing climate. These impacts include changes in baseflow, more runoff with increased precipitation, and changes in fish habitat and land use.

Baseflow

To understand how projected climate change may affect hydrologic flows of rivers and streams in Wisconsin in the future, it is important to provide context by analyzing historic flows (figure 9). Similar to the historical temperature and precipitation trends analysis for 1950-2006 summarized in Chapter 1: *Climate Change in Wisconsin*, stream flow data collected by the U.S. Geological Survey for the same 57-year period from 48 stations in Wisconsin were analyzed in relation to spatial precipitation patterns. During the study period, precipitation increased approximately 10-15 percent on average across the entire state, with some areas of the state exhibiting much wetter trends and other areas exhibiting drier trends. Interestingly, the average statewide percentage change in annual flows observed for the 48 gauging stations over this same 57-year period was a comparable 14 percent, pointing to the strong coupling between basin precipitation and stream flow, with stream flows increasing in areas having increasing precipitation and flows decreasing in areas trending drier.

Baseflow: The sustained low flow of a stream, usually groundwater inflow to the stream channel.

Future annual precipitation projections for the next half century average in the 2-7 percent increase range. Thus, the increases in precipitation we have seen over the past half century are equal to, if not greater than, projected precipitation changes. Scientists cannot say with certainty that this will translate into a corresponding increase in annual flow for the state because seasonal precipitation patterns and extreme events are also expected to change, which will impact runoff amounts and consequent flows. In addition, tempera-



Figure 9. From 1950 to 2006, Wisconsin as a whole became wetter, with an increase in annual precipitation of 3.1 inches. This observed increase in annual precipitation was primarily in southern and western Wisconsin, while northern Wisconsin was drier. The southern and western regions of the state had increases in baseflow (left) and annual flow (right) between 1950 and 2006, corresponding to the areas with greatest increases in precipitation.

Source: Steve Greb, Wisconsin Department of Natural Resources, unpublished data.

tures are projected to increase, which will increase evaporation rates and decrease water yield to the receiving waters.

Where temperature increases, more evapotranspiration occurs and soil moisture declines, requiring an increased demand for irrigation from streams or groundwater in agricultural areas. When groundwater levels decrease, baseflow also decreases; therefore, groundwater-fed streams, which may provide habitat for coldwater fish species like brook trout, may be more profoundly affected.

Polluted Runoff

Increases in winter and spring precipitation will likely cause increases in large runoff events, leading to soil erosion, channel erosion, sediment and nutrient transport, increased eutrophication, habitat degradation and mobilization of contaminated sediment, all reducing surface water quality. Increased runoff will lead to flooding of small rivers and streams. In some instances streams that respond quickly to incoming and outgoing flows have a drier period between high flow periods, resulting in a "first flush" effect containing higher concentrations of sediment.

Changing rainfall patterns may impact flows on the Mississippi River and its tributaries, and large rivers, in general, will be affected. On rivers such as the Wisconsin River, where hydroelectric power is generated, the change in the timing of rainfall may affect the supply of electricity.

In Wisconsin's urban watersheds, the primary water quality issues relate to stormwater runoff or, as is the case in Milwaukee, combined sewer overflows. In both cases, changes in the magnitude and frequency of large daily or shorter-duration rainfalls are the most relevant. Climate change in Wisconsin is expected to result in modest increases in daily rainfall magnitude over the next century as well as increases in the frequency of large rainfalls. These changes will require greater investments in stormwater infrastructure for both new and existing development. We discuss the implications of climate change on infrastructure in Chapter 7: *People and Their Environment*. In rural areas, nutrient and sediment runoff from agricultural lands is the most critical water quality concern. As is the case with urban watersheds, changes in the magnitude and frequency of large daily or shorterduration rainfalls are most critical. But unlike urban areas, agricultural lands are particularly vulnerable to large rainfall events that occur in the spring when soil is bare. Hence, nutrient and sediment runoff from agricultural watersheds is likely to increase as a result of the combined impact of the projected increases in the magnitude and frequency of large rainfalls and in cold-weather precipitation. (See the Soil Resources Working Group report at www.wicci.wisc.edu for more detailed discussion.)

Eutrophication: The process by which lakes and streams are enriched by nutrients and the resulting increase in plant and algae growth. This process includes physical, chemical, and biological changes that take place after a lake receives inputs for plant nutrients-mostly nitrogen and phosphorus-from natural erosion and runoff from the surrounding land basin. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Fish Habitat

Another impact of climate change on rivers and streams is its effect on fish habitat. Rising water temperatures, changes in groundwater recharge and stream baseflow, and an increase in large runoff events from heavy storms may all affect stream channels or other habitat characteristics that fish require for survival. The details of research by the Coldwater Fish Working Group are discussed in Chapter 4: *Natural Habitats and Biodiversity*.

Flooding

In most watersheds outside urbanized areas, soil conditions are a more important factor in the extent of flooding than impervious surfaces. The occurrence of a large flood usually results from large rainfall events over soils that have reduced infiltration capacity because of soil saturation by previous rainfalls, snow melt or heavy frost. In Wisconsin, stream and river flooding can occur in all seasons, although the largest floods are usually in spring and summer. Expected increases in the magnitude and frequency of large rainfall events will very likely increase flood magnitudes in all Wisconsin streams and rivers, although the amount of increase will vary from place to place. The increase is likely to be the greatest in watersheds that are most vulnerable to flooding in late winter or early spring, when the likelihood of increased rainfall resulting from climate change is greatest.

Land Use

Both rural and urban land use changes will influence water cycle components such as groundwater infiltration and resultant river flows. Given that annual flow characteristics are a product of multiple factors, it is difficult to predict changes in future flows. Hydrologic modeling on a basin scale, which simulates these dynamic hydrologic processes and accounts for changing land use conditions, temperature regimes, precipitation timing and characteristics, is needed to fully understand the impact of future climatic conditions on Wisconsin's river and stream flow regimes (see "Ongoing Research" in Chapter 9: *Moving Forward*). Large rainfall events will impact floodplains, which will have impacts on the built environment. Zoning codes and dam safety precautions may need to change.

Urban areas face additional challenges because urban streams are already stressed. An increase in precipitation will selectively degrade such streams where a high percentage of land is impervious. Here, stormwater causes high water conditions from heavy rainfall over relatively small areas even when events last only minutes to hours. Because large portions of an urban watershed are usually impervious, the peak rate of surface runoff is relatively unaffected by soil moisture conditions before the initiating storm. For these reasons, the design of stormwater infrastructure is usually based on single storm events. For urban stormwater, changes in the magnitude of rainfall at the daily or shorter time scale are the most relevant. It appears that climate change in Wisconsin will result in modest increases in daily rainfall over the next century, resulting in greater storm flows in urban watersheds.

Groundwater

Climate change will affect groundwater resources across the state. Increases in total annual precipitation, changes in the seasonal distribution of precipitation, increased frequency of intense rainfall events and increased average temperature all will affect groundwater quality and quantity. Given Wisconsin's diverse geology and hydrogeology, impacts will vary depending on site-specific conditions including soil and surface material characteristics, topography, depth to bedrock, depth to groundwater and land use practices. Climate change will have the most significant impacts on shallow groundwater systems, such as sand and gravel aquifers, whereas deep sandstone aquifers, such as those used by public water systems in Dane County and in southeast Wisconsin, will be less affected.

Many warmwater species, such as the channel catfish, will benefit as water temperatures rise, while coldwater species will not. More is discussed on this topic in Chapter 4: Natural Habitats and Biodiversity.

Recent Trends

Only a few long-term groundwater-level records exist in Wisconsin. These records do not demonstrate consistent long-term trends in water level; however, fluctuations of water levels ranging from annual to many years occur in each well. These monitoring wells from northern and southern Wisconsin appear to follow similar patterns over some periods (1965-1990) but follow divergent patterns in others (1950-1965 and post-1990) (figure 10). During the past few years, groundwater levels in the south have increased because of several wet years, whereas water levels in the north, especially north central areas, have decreased during drought. Records of groundwater and surface-water levels from specific areas demonstrate similar fluctuations; however, the long-term trends appear to be more dramatic in seepage lakes.

Groundwater Recharge

Generally, climate change impacts will occur as changes in groundwater recharge, which in turn will lead to other water resource impacts. An increase in precipitation normally corresponds with an increase in recharge and, ultimately, a rise in groundwater levels; however, concurrent increases in temperature and resultant changes in land use and water use patterns may offset any increase in recharge. Certain areas of the state could actually experience declines in groundwater levels. As time goes on, temperature and increased evaporation may dominate changes in precipitation, resulting in lower levels in general.

Groundwater recharge in the spring depends largely on the interplay between the amount of winter snowpack, the timing of spring thaw and the timing of the opening of leaf buds, all of which are temperature-dependent. Climate change projections call for increased winter precipitation, but because of the predicted warmer winter temperatures, there is also greater likelihood that an increased amount of the precipitation will fall as rain rather than snow. If significant rain events occur during the winter and the surface of the ground is frozen, much of the rain will run off and will not contribute significantly to groundwater recharge. Warmer temperatures could also result in shorter periods of frozen ground conditions, leading to longer periods of time when the melting snowpack or rain could infiltrate and ultimately increase groundwater recharge. Soil type, soil moisture, vegetation and frost are critical factors that help determine the amount of recharge versus runoff.



Figure 10. Groundwater levels for three wells in Wisconsin show that oscillations in water level can range in length from annual to multi-decadal.

Source: Dale Robertson, U.S. Geological Survey.



Groundwater flooding in Spring Green, Wisconsin, July 12, 2008.

In contrast, a longer growing season and warmer summer temperatures would result in a decrease in groundwater recharge during the summer months. With a longer growing season, plants would use all available soil moisture for a longer period of time and soils would begin to dry out earlier in the year, resulting in a shorter effective period of recharge. All of these effects would lead to lower groundwater levels and less groundwater discharge to surface waters, potentially leading to reduced summer flows in streams and lower lake levels.

Significant changes in groundwater recharge could result in dramatic changes in the dynamics of lake, stream and wetland systems. Decreased recharge would result in reduced flow from springs, lower baseflow in streams, loss of some wetlands and lower lake levels in most lakes, but especially groundwater-fed seepage lakes situated relatively high in the landscape. On the other hand, an increase in recharge would produce the opposite effects and, if taken to an extreme, could result in increased flooding and conversion of some wetland systems to lakes.

Groundwater Flooding

More frequent large-precipitation events may result in localized areas of groundwater flooding, especially where groundwater recharge occurs quickly, depth to groundwater is normally fairly shallow and there is little topographic relief. Frequent high-intensity storms could cause groundwater levels to rise above the ground surface, leading to flooding conditions.

Areas with high groundwater recharge rates are most vulnerable to negative impacts if these areas are built over during prolonged dry cycles or drought and the groundwater table subsequently rises (sometimes as much as 12 feet in only a few weeks) given a significant amount of precipitation (see Spring Green sidebar).

The human impacts of flooding can be great, including flooding of basements, homes and septic systems. This can lead to other environmental impacts if the septic systems are near other surface waters or sources of drinking water. We discuss these human impacts in Chapter 7: *People and Their Environment*.

GROUNDWATER FLOODING NEAR SPRING GREEN

In the summer of 2008, about 17 inches of rain fell in a 10-day period in southern Wisconsin, resulting in overflowing stream banks and groundwater flooding. About 4,300 acres of land near Spring Green – beyond the Wisconsin River floodplain – became inundated with water that rose from the ground and overtopped the land surface.

The land remained underwater for more than five months. No amount of pumping would reduce the water level because there was no place for it to drain. Computer modeling and data from nearby monitoring wells showed that the groundwater level in the shallow aquifer had risen by as much as 12 feet. Residents in 28 homes left uninhabitable moved out and received compensation from the government for the value of their homes.

Scientists and policy-makers can use real-life weather events like the Spring Green example to help predict where groundwater flooding may occur in other geologically similar areas of the state. The Wisconsin Geological and Natural History Survey is conducting research that will apply a series of climate forecast and hydrologic models to selected landscapes that are vulnerable to water table rise and groundwater flooding.



Impacts on Groundwater Use and Interactions with Land Use

Increased temperatures will lead to an increased length in the growing season in Wisconsin and higher rates of evapotranspiration during the summer and early fall months. If current statewide cropping practices continue, a longer growing season without significant increased precipitation during the summer months could lead to increased reliance on irrigation systems, putting greater demand on groundwater resources, such as in the Central Sands region.

If agricultural practices change in response to changing climatic conditions, the impacts on groundwater could be exacerbated. The longer growing season could result in more land being put into agricultural use and, therefore, more land area being subject to nutrient and pesticide applications. This could lead to increased risk of contamination of both surface water and groundwater. For example, if development of biofuels using corn as a source were to expand, additional irrigated acreage would likely be converted to growing corn, increasing groundwater use and petroleum-based inputs and ultimately resulting in even greater adverse impacts on groundwater resources. On the other hand, if cropping patterns were to switch to more droughttolerant varieties, the reliance on groundwater would diminish and the impacts would be less than currently projected.

As with agriculture, groundwater withdrawals by municipal water systems would also be expected to increase with elevated summer temperatures and greater demand for water, putting additional pressure on scarce groundwater resources and potentially affecting surface waters.

Groundwater Quality

Climate change has the potential to affect the quality of groundwater through a number of different mechanisms. Less recharge water could mean less dilution of contaminants and higher levels of total dissolved solids in groundwater. In situations where groundwater recharge occurs rapidly, a rising water table will reduce the distance between land surface and groundwater, making the groundwater more susceptible to contamination from sources such as septic systems. Higher winter temperatures and increased winter precipitation could result in more frequent icing conditions on roadways, leading to increased application of road salts. This would create greater potential for contamination from chlorides.

Shallow groundwater is typically the same temperature as the mean annual air temperature. In shallow wells, the expected increase in water temperatures could lead to more microbial activity, biofouling of wells and an overall decrease in water quality.

Finally, an increased frequency in intense precipitation events could lead to inundation of drinking water wells, which could result in groundwater contamination. Surface water that enters groundwater through wells and other conduits can lead to oxidation of sulfides, increased microbial activity, increased sulfate and releases of arsenic and heavy metals.

Wetlands

Wetlands can act as flood storage areas, so where wetland acreage exists, flooding will have a less negative impact. Wisconsin has lost about 4.7 million of the 10 million acres of wetlands that were present in 1848, mostly from farm drainage and filling for development and roads. While the conversion of wetlands to other uses has slowed, they continue to be destroyed and degraded by invasive plants, overuse of groundwater and increased stormwater runoff from development.

Changes in Hydrology

If winter and spring runoff increases, the area of some wetlands may increase, but there may also be a shift to wetter, deeper wetland types. We can also expect to see an increase in flooding duration of wetlands in lowlying areas. Ephemeral ponds will have higher initial water levels. Some will become connected with other water bodies, and fish will populate and prey on or



Pheasant Branch Conservancy wetland and spring system, Middleton, Wisconsin.

compete with amphibians, reducing their reproductive success.

Increased spring runoff may also increase streambank erosion, making stream channels wider and deeper, and they may become disconnected from wetland-rich floodplains. As these streambeds cut downward and improve drainage they lose the associated benefits of floodplain wetlands for sediment trapping, nutrient retention and aquatic habitat.

An increase in infiltration may enhance the extent of groundwater-fed wetlands, but it depends on the timing of precipitation events. If winter rains are accompanied by a longer frost-free period, recharge could increase and shift the water budget toward larger groundwater input, benefiting saturated-soil wetlands. If winter rains fall on frozen ground, however, winter flooding could greatly increase delivery of pollutants to downstream wetlands and result in little or no recharge.

Responses to increased air temperatures will vary depending on the degree of groundwater inputs to a wetland. Shallow wetlands could dry out earlier in the summer with greater evaporation and warmer water. Wetlands with high levels of groundwater inputs are less likely to dry up from evapotranspiration, but their size may decrease.

Increased Sediment and Nutrient Loads

Shifts in both temperature and precipitation will change the nutrient dynamics in wetlands. Increased precipitation could cause some wetlands and hydric soils to release phosphorus, while methane emissions may increase in others, such as the sedge meadows in southern Wisconsin. Increased summer droughts and evapotranspiration will increase decomposition and change nutrient dynamics, leading to, among other things, an increase in carbon dioxide emissions.

CHALLENGES TO RESTORING DRAINED WETLANDS

Wetlands are an essential tool for managing high water, providing flood storage capacity for overflowing streams and rivers and precluding runoff that would occur if low-lying areas were to be developed. By restoring wetlands that were previously converted to croplands and by preventing the loss of existing wetlands, we can increase our capacity for adapting to future high-water conditions. However, wetlands that were drained for agricultural use prior to 2005 are exempt from regulation under the Clean Water Act and state wetland laws even when agricultural production ends. Once agricultural production is discontinued the landowner can continue to maintain the property's drainage system (surface and subsurface) to prevent the reestablishment of wetlands at the site. If the drainage is maintained, the site remains outside the jurisdiction of the Clean Water Act and the landowner can develop the site. However, if the drains are not subsequently maintained, the land might revert to wetland conditions, and surface or groundwater flooding of areas where development has taken place. Suburban and rural development where drained wetlands has resulted in significant property damage.

Shifts in plant, aquatic and animal communities and the proliferation of invasive species are also concerns that wetlands will face as climate continues to change, and these impacts are discussed in Chapter 4: *Natural Habitats and Biodiversity*. In Chapter 6: *Coastal Resources*, we discuss climate change impacts on coastal wetland ecosystems.

Impacts on People and the Built Environment

Hydrologic responses to climate change will also have many impacts on the built environment and on human health. With more frequent heavy rainfall events, current infrastructure, such as underdesigned stormwater detention basins, could be overwhelmed. Other existing infrastructure may also be taxed, such as sanitary sewer overflow systems that will not be able to keep pace with increased volumes of stormwater. These impacts are discussed in greater detail in Chapter 7: *People and Their Environment*.

> Source material for this chapter was drawn from the Central Sands Hydrology, Green Bay, Stormwater and Water Resources Working Group reports, available online at www.wicci.wisc.edu.



Adaptation Strategies

The great diversity of water resources in Wisconsin and the variations in impacts on quantity and quality from region to region lead to a wide range of possible adaptation strategies. In keeping with the organizational framework presented in Chapter 2: Understand*ing Adaptation*, we present here several adaptation strategies relevant to Wisconsin's water resources. (Please see the working group reports at www.wicci. wisc.edu for a more detailed discussion of adaptation strategies.)

TAKING ACTION

- Restore prior-converted wetlands in upland areas to provide storage and filtration and to mitigate storm flows and nutrient loading downstream. Protect and restore wetland hydrologic regimes. Control polluted runoff to wetlands.
- Promote integrated water management planning using long-term projections of supply and demand, tied to land use and economic growth forecasts. Encourage large water users to locate in areas with sustainable water sources (for example, near large rivers or the Great Lakes). Encourage water conservation (rural and urban) through incentives and regulation.
- Enhance infiltration in headwater areas, near watershed divides, and in areas with lower groundwater levels by reducing impervious surfaces in urban/riparian areas and improving land management practices. Protect recharge/ infiltration areas and riparian buffers from overland flow of polluted runoff.
- Incorporate water management strategies based on climate projections into farm-based nutrient management plans. Resize manure storage facilities, wastewater facilities, stormwater drains, and infrastructure to accommodate increased storm flows to protect water quality. Complete and implement total maximum daily load (TMDL) plans and best management practices, particularly using stream buffers.
- Continue current and proposed regulatory controls for nutrient and solids loading (for example, TMDLs), biochemical oxygen demand, and nonpersistent toxic substances. Continue existing programs for identification and remediation of legacy pollutants. Update the

ADAPTATION

waste load allocation rule (NR 212) to determine need for adjustment resulting from climate change. Examine policies and regulations protecting lands below the ordinary high water mark.

- Continue existing programs to restrict spreading of dreissenids (zebra and quagga mussels), and consider seed bank manipulation to counter Phragmites invasions along Great Lakes shorelines. Encourage regulatory activities aimed at preventing future invasions of exotic and invasive species.
- Enhance and restore shoreline habitat (coarse wood, littoral and riparian vegetation, bio-engineered erosion control) to withstand variations in water levels.
- Develop statewide standards for blue-green algal toxins and take appropriate action to protect public health.

BUILDING CAPACITY

- Improve models relating weather, soil hydrology, groundwater hydrology, and groundwater discharge to streams. Use these models to evaluate vulnerabilities and potential adaptation strategies. Use updated models to predict groundwater impacts on development.
- Incorporate climate change scenarios into modeling efforts, watershed management and restoration plans, then engage in community planning. Create or designate new surface flood storage areas (for example, wetlands) to mitigate high-water impacts. Identify, map and prioritize potentially restorable wetlands in floodplain areas.
- Provide local units of government with technical and financial assistance to assess and mitigate their vulnerabilities to potential high-water conditions caused by



Conclusion

Wisconsin is a water-rich state. Our lakes, rivers, groundwater and wetlands are critical components of our state's natural habitats, our coastal communities, industry, agriculture, recreation and public health. Impacts on one part of the water cycle will affect the quality and quantity of the rest. Our climate is chang-

STRATEGIES

today's and future climates. For example, examine the adequacy of wastewater treatment systems and stormwater infrastructure to accommodate climate change conditions.

- Provide assistance to local governments by developing regional continuous hydrologic simulation models for both surface water and groundwater, increasing the capacity of the Wisconsin Geological and Natural History Survey, partnering with the U.S. Geological Survey, or funding private studies.
- Develop rapid response planning and implementation methods to improve existing aquatic invasive species control programs. For example, evaluate the potential benefits of temporary lake drawdowns and investigate the possibility of isolating the Great Lakes from oceangoing vessels via cargo transfer.

COMMUNICATING

- Propose and adopt a framework for managing groundwater withdrawals that is consistent with societal goals for surface water health.
- Adjust and modify expectations about lake water levels. Recognize that some lakes may not be suited for all uses (for example, recreational boating in shallow waters or during low-water periods).
- Account for changing water levels in planning and zoning standards for lakeshore development. Establish a clear understanding of the ordinary high-water mark.
- Develop guidance to control the amounts and types of artificial riparian modifications to shoreline and runoff

ing, and increasing temperatures and shifting precipitation patterns are already impacting – and will continue to impact – Wisconsin's water resources. These impacts trigger subsequent changes in aquatic ecosystems and human communities. Addressing climate change in Wisconsin necessitates a strategic approach to adapting to impacts on our water resources. We can begin by relying on and expanding tools and policies that are already in place.

conveyance mechanisms.

- Continue exotic and invasive species education/awareness programs for boaters, anglers, and others.
- Disseminate findings from climate assessment studies to water resource managers, municipalities, academics and conservation and environmental organizations.

FILLING GAPS

- Improve systems for monitoring lake and groundwater levels and stream flows. Collect stream monitoring data (for example, water temperature, flow and fish abundance) to test predictions of the effects of climate change on the distribution of coldwater fish in streams and determine how changes in air temperature and precipitation effect changes in stream temperature and groundwater input to streams.
- Create a surveillance program to collect data and identify ways in which climate change processes may increase the occurrence of human and animal exposures to harmful algal blooms. Increase monitoring of inland beaches for blue-green algal toxins and associated water quality to improve predictive capacity.
- Encourage research and regulatory attention to pollutants of emerging concern. Repeat the Green Bay Mass Balance Study of PCB fate and transport and food web modeling for climate change conditions.
- Investigate the need for a targeted strategy to manage spring runoff. Assess the effectiveness of conventional best management practices and support development of new methods.