waters of wisconsin

the future of our aquatic ecosystems and resources

A report of the

Wisconsin Academy
of Sciences, Arts and Letters

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The nonprofit Wisconsin Academy of Sciences, Arts and Letters connects people and ideas from all realms of knowledge to advance thought and culture in our state. Our many programs include an art gallery for Wisconsin artists, a quarterly magazine, public forums, and "the Wisconsin Idea at the Wisconsin Academy," a public policy program that brings the public together with a diverse array of experts and stakeholders to find solutions to statewide problems. Waters of Wisconsin is the first initiative of that program.

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Wisconsin Academy of Sciences, Arts and Letters
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WATERS OF WISCONSIN COMMITTEE

Stephen Born (co-chair)
University of Wisconsin–Madison
Madison, Wisconsin

Patricia Leavenworth (co-chair)
USDA Natural Resources
Conservation Service
Madison, Wisconsin

John Magnuson (co-chair)
University of Wisconsin–Madison (emeritus)
Madison, Wisconsin

Todd Ambs
River Alliance of Wisconsin (formerly)
Madison, Wisconsin

Anders Andren
Water Resources Institute
Madison, Wisconsin

Bruce Baker
Wisconsin Department of Natural Resources
Madison, Wisconsin

Lisa Conley
Wisconsin Association of Lakes
Rock River Coalition
Oconomowoc, Wisconsin

Michael Dombeck
University of Wisconsin–Stevens Point
Stevens Point, Wisconsin

Nancy Frank
University of Wisconsin–Milwaukee
Milwaukee, Wisconsin

Victoria Harris
Sea Grant Institute
Green Bay, Wisconsin

Barry Johnson
U.S. Geological Survey
La Crosse, Wisconsin

Paul Kent
Anderson and Kent
Madison, Wisconsin

Jim Koepke
Dairy farmer
Oconomowoc, Wisconsin

George Kraft
University of Wisconsin–
Stevens Point/Extension
Stevens Point, Wisconsin

Jim Meeker
Northland College
Ashland, Wisconsin

Kenneth Potter
University of Wisconsin–Madison
Madison, Wisconsin

Judy Pratt Shelley
Red Cliff Band, Lake Superior Chippewa
Bayfield, Wisconsin

Jeff Schoepke
Wisconsin Manufacturers and Commerce
Madison, Wisconsin

Bron Taylor
University of Wisconsin–Oshkosh (formerly)
Oshkosh, Wisconsin

Tom Yuill (WOW advisor)
University of Wisconsin–Madison
Gaylord Nelson Institute for
Environmental Studies
Madison, Wisconsin

WATERS OF WISCONSIN STAFF

Curt Meine, Director of Conservation Programs, WOW Initiative Director

Shaili Pfeiffer, Wisconsin Idea Fellow, WOW Associate

Michael Strigel, Associate Director, WOW Forum Chair

Amanda Okopski, WOW Forum Director

Joan Fischer, Director of Marketing and Communications

WISCONSIN ACADEMY BOARD OF DIRECTORS AND STAFF

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PREFACE

Over the last three years, the Waters of Wisconsin initiative of the Wisconsin Academy of Sciences, Arts and Letters has directly engaged hundreds of Wisconsin citizens in a conversation about our state's water resources and aquatic ecosystems. The effort culminated in October 2002 with a two-day public forum attended by more than 700 people — a remarkable event that linked scientists, water users and managers, officials and policy makers, business leaders, Native American tribes, nonprofit organizations and advocates, artists, poets, musicians, and other interested citizens. Forum participants reviewed the status of our world-class water resources and the trends affecting them. We took time to consider the varied ways in which water has shaped our history, our cultural traditions, and our lives. The event, and all that led up to it, validated what opinion polls tell us: Wisconsinites don't just value their waters — they love them.

Throughout our work on the Waters of Wisconsin, our attention has focused on one main question: How can we ensure healthy aquatic ecosystems and clean, abundant water supplies for tomorrow's Wisconsin? This report brings together our findings and recommendations. Woven through the report are the thoughts and experiences of hundreds of our fellow citizens regarding the status of our waters, the necessity of farsighted policies and effective monitoring, the importance of civic engagement and a guiding water ethic, and the vital role of education. Our goal in this report is to point the way toward a bright future for our state's waters, and for all that depends on them: our health, our communities, our economy, and our aquatic environment.

As co-chairs of the Waters of Wisconsin committee, we thank all those who have generously contributed to this work, and we invite our fellow citizens to build upon our efforts. This report is only a beginning. To extend awareness of the importance of water, Governor Scott McCallum and his successor, Governor James Doyle have designated 2003 as the Year of Water in Wisconsin, building on the celebration in 2002 of the 30th anniversary of the federal Clean Water Act and the declaration of the International Year of Freshwater. It is now up to citizens across Wisconsin to seize the moment and build support for sound long-term management of this irreplaceable resource. Our greatest hope is that Wisconsinites in 2075 will be able to examine their "waters of Wisconsin" and look back with pride on our stewardship efforts.

Finally, we wish to note that the Waters of Wisconsin initiative has demonstrated the continued vibrancy of the Wisconsin Idea. One hundred years ago, our forebears had faith that knowledge applied in the public interest could improve the quality of our lives as individuals, as members of our communities, and as citizens of our state. We hope that Waters of Wisconsin serves as a continuing reminder that the Wisconsin Idea, like our waters, defines life in Wisconsin.

Water of Wisconsin Committee Co-Chairs

Stephen Born ***Patricia Leavenworth*** ***John Magnuson***

ACKNOWLEDGMENTS

The Wisconsin Academy of Sciences, Arts and Letters gratefully acknowledges all those who have contributed to the Waters of Wisconsin (WOW) initiative. This report is the product of a three-year process. Over that time, hundreds of people and organizations from across Wisconsin have donated time, expertise, financial resources, and passion to the work of WOW. We hope that this report captures their collective commitment to our water future.

Among the many who contributed to the WOW initiative, we would like to draw special attention to several groups and individuals who have made exceptional contributions. The members of the Waters of Wisconsin Committee gave tremendously of their knowledge, enriching our understanding of Wisconsin waters with their varied backgrounds and views. Committee co-chairs Stephen Born, Patricia Leavenworth, and John Magnuson guided the WOW process from the beginning, participating in meetings in every region of the state and providing invaluable feedback on the contents of this report. Dozens of individuals and institutions contributed to WOW forums in Madison, La Crosse, Green Bay, Stevens Point, Milwaukee, Ashland, and Racine and to the WOW working groups. The WOW forum planning committee worked tirelessly to plan a two-day statewide forum that attracted more than 700 people. We also thank the many organizations and individuals who have supported the Waters of Wisconsin initiative with financial and in-kind contributions; they are listed at the back of this report.

Those who have assisted in preparing this report are too numerous to name, but we would like to thank the following individuals for their contributions and comments: Tim Asplund, Wisconsin Department of Natural Resources (WDNR); Bruce Baker, WDNR; Lisa Conley, Wisconsin Association of Lakes; Nancy Frank, UW–Milwaukee; Madeline Gotkowitz, Wisconsin Geological and Natural History Survey (WGNHS); Barry Johnson, United States Geological Survey (USGS); Dave Johnson, WDNR; George Kraft, UW–Stevens Point; Michael Kraft, UW–Green Bay; Jeffrey Helmuth, WDNR; Laura Hewitt, Trout Unlimited; Jim Krohelski, USGS; Donald Last, UW–Stevens Point; Charles Ledin, WDNR; Charlie Luthin, Wisconsin Wetlands Association; Al Miller, UW Sea Grant (emeritus); Janel Pike, WDNR; attorney Peter Peshek; Garry Peterson and co-authors at the UW Center for Limnology, UW–Madison; Jeffrey Potter, Wisconsin Wetlands Association; Ken Potter, UW–Madison; Carl Watrus, WDNR; Ed Wilusz, Wisconsin Paper Council; and Tom Yuill, Gaylord Nelson Institute for Environmental Studies, UW–Madison.

The Wisconsin Academy wishes also to thank the following group of advisors: former governor Anthony Earl; UW System president Katherine Lyall and UW System associate vice president Margaret Lewis; Wisconsin AFL-CIO president David Newby; Wisconsin Manufacturers and Commerce president James Haney; Robert Wood, chief of staff to Governor Tommy Thompson, and Michael Rogowski, chief of staff to Governor Scott McCallum. Their endorsement was critical in initiating WOW, and their advice and enthusiasm provided much-needed encouragement as the work of WOW unfolded.

Former governors Tommy Thompson and Scott McCallum and Governor James Doyle have provided invaluable support for the Waters of Wisconsin initiative through their offices, and in particular through the declaration of 2003 as the Year of Water in Wisconsin. We especially

appreciate the support of secretaries of the Wisconsin Department of Natural Resources George Meyer, Darrell Bazzell, and Scott Hassett in providing vital institutional support for WOW. We thank, too, the leadership of the Wisconsin legislature for their continued interest in, and support for, WOW.

Finally we thank the hundreds of citizens of Wisconsin who participated in the WOW Advisory Network, attended our WOW forums, and provided vital feedback through the WOW website. Their commitment to this process, and to the waters of Wisconsin, extended our effort to the borders of the state and beyond.

Wisconsin Wetlands Association

SUMMARY

> Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land.
>
> *Luna B. Leopold*

Water defines life in Wisconsin. Wisconsin's landscape, history, cultures, communities, ecosystems, and economy are fundamentally shaped by water: the Great Lakes on our eastern and northern borders; the Mississippi River on our western border; a vast network of surface waters — 15,000 inland lakes, 32,000 miles of perennial rivers and streams, 5.3 million acres of wetlands; and 1.2 quadrillion gallons of groundwater residing in four major aquifers. These waters interact to form an integrated hydrological system: life's essential element, our most precious resource, and an asset of inestimable global significance.

The unique importance of Wisconsin's waters confers upon us a special stewardship responsibility — for ourselves, for our neighbors, for future generations, and for the community of life that depends upon them. Through the Waters of Wisconsin initiative, we have explored the many dimensions of that responsibility. We summarize here our efforts to understand the state of our waters, the challenges we face in sustaining them, and the educational and policy actions we must take to be effective stewards of our waters over the long run.

Water Values, Water Challenges

The value of Wisconsin's water is at once immense and incalculable. A commitment to stewardship is critical if we are to sustain the economic and material benefits that we derive from our waters: for drinking water and domestic use, as a transportation avenue and recreational resource, for wastewater treatment and industrial production, as a provider of vital ecosystem services.

Yet, the full value of Wisconsin's water includes intangible qualities that defy easy measurement. As an essential element of life, water is an inherent part of who we are, and of the places we care about. Water flows through our lives, connects us within watersheds, places us within the global hydrologic cycle. Water stewardship is thus an expression of ethical responsibility to fellow citizens, to downstream users, and to other forms of life.

Wisconsin's people have long understood the importance and value of water, but we have not always appreciated its vulnerability. Water has long played a central role in Wisconsin's economy — in agricultural expansion and the forest products industry; in transportation and energy production; in commercial development and tourism. Early in our history, however, deforestation, soil erosion, pollution, wetland conversion, overfishing, and other factors led to widespread degradation of water resources and aquatic ecosystems. Beginning in the Progressive Era of the early 1900s, these problems prompted reforms that established Wisconsin as a national leader in conservation. Through much of the 20th century, Wisconsin remained at the forefront of environmental management. In particular, these measures helped to correct some of the most egregious forms of water pollution.

There is still much unfinished business to attend to in correcting past practices, cleaning up the waters, and restoring damaged aquatic ecosystems. Meanwhile, Wisconsin's water stewardship responsibilities are growing and changing in response to increasing understanding of hydrologic systems, growing and competing demands for water, and changing societal values. The next generation will face new and different challenges involving water quality and quantity, management of water resources, and the health of aquatic ecosystems. These challenges of the future are characterized by high degrees of complexity and uncertainty, and by difficult trade-offs.

In the past, we have tended to address varied water needs and problems separately. The overriding challenge of the future is to find new and better integrated approaches to stewardship. We can allow ourselves to drift into an uncertain water future that merely responds in a piecemeal, reactive manner to issue after issue and crisis after crisis; or we can try to anticipate and shape our water future as active and informed participants in our communities and our state as a whole.

Wisconsin's Changing Waters

Wisconsin's waters are changing in complex ways.

Wisconsinites can point with pride to important gains in protecting and restoring the state's waters. Some of our most pristine waters now enjoy special protected status. Soil and water conservation measures have stabilized watersheds that were badly degraded two generations ago. Over the last thirty years, point sources of pollution have been identified and largely controlled, and Wisconsin has adopted new runoff rules that bode well for efforts to better control non–point source pollution. These actions have allowed Wisconsin's aquatic ecosystems to recover (to some degree) from past declines, and many aquatic species have recovered with them. Appreciation of wetlands and free-running rivers has grown tremendously, and Wisconsin is recognized as a leader in wetland protection and river restoration. Citizen awareness and participation have expanded through the growth of community-based water and watershed stewardship organizations. Increasingly, too, citizens appreciate the importance of groundwater management issues that were little noticed until just a few years ago. These and other positive trends affecting our waters provide reason for hope, and a solid record of accomplishment to build on.

Other trends in our waters suggest the strong need for continued diligence. The long-term quality of our drinking water is not ensured. A variety of chemical and biological contaminants require constant and continued attention. Persistent and residual point source pollutants remain a problem. Permitted effluent discharges in some areas are running up against the assimilative capacity of surface waters. We continue to receive mercury and other contaminants through atmospheric deposition. Our gains in controlling polluted runoff are offset to some degree by continued inputs of excessive nutrients and the increase in impermeable surface area that has come with extensive land development. Wisconsin's diversity of aquatic life remains vulnerable to a suite of short- and long-term threats, and we are still experiencing the unintended consequences of past development on the hydrologic functioning of both surface waters and groundwater.

Other trends involve the amount of available water and its capacity to meet human needs, support economic development, provide services, and sustain ecosystems. These demand-driven trends present significant long-term challenges to Wisconsin's waters. Regional, national, and global demands for freshwater will continue to increase, bringing greater attention to both groundwater and surface water in Wisconsin, including the Great Lakes waters. Demands on groundwater supplies are growing across Wisconsin, and in some places are increasing dramatically. Rapid shoreline development is placing increased pressure on sensitive shore and near-shore habitats, especially in the northern lakes. Recreational demands on our waters are also increasing, in terms of both the number of recreationists using the waters and the cumulative impact of recreational activity. These and other demands will increasingly compete with one another.

Finally, Wisconsin's waters are also subject to a variety of emerging concerns and potential threats. Chief among these is climate change. The weight of evidence suggests that climate change will have significant impacts on Wisconsin's waters — some of which we can mitigate, but others we will have to learn to live with. The spread of aquatic invasive species is already having detrimental impacts and, in the absence of a coordinated response, will continue to degrade Wisconsin's aquatic life. Other potentially serious threats are poorly understood. We know, for example, that antibiotics, hormones, and other "microcontaminants" move into and through our water supply, but we have little understanding of their impacts. Other threats are new and difficult to anticipate: ensuring the security of our water supply, for example.

Sustaining the Waters

That Wisconsin's waters will continue to change is a given. How we understand and respond to these changes is uncertain. In the past, we have tended to take action only after water-related problems have developed. The key question now is whether we can better anticipate problems, shorten our response time, and take action before negative effects become obvious and widespread. To do so, we must take the future of our waters seriously, and think about it creatively.

As we look ahead, we see inevitable uncertainty and complexity. To chart a course that sustains our waters, we will need to think broadly over the long term and integrate multiple factors in our planning. We will need to avoid, as much as possible, decisions whose consequences foreclose future options. We will need to invent new decision-making processes that ensure fair, informed, and open public participation. And even as we try to prevent and correct degradation of our waters, we will need to encourage actions that restore them.

These needs come together in the concept of *sustainability*. Sustainability implies a commitment to protecting, managing, restoring, and using Wisconsin's waters in a manner that ensures the health of our aquatic ecosystems while securing their cultural, economic, and public health benefits for future generations. Behind the concept lies a basic reality: The fate of Wisconsin's waters and our communities are interdependent.

Ultimately, the "label" of sustainability is not so important as the commitment to the future that it implies. To ensure long-term economic health, community well-being, and environmental integrity, the value of water has to be fully appreciated, and water connections must be understood and respected. We can then identify policies and water management actions that can move us toward the elusive goal of sustainability.

Toward a Wisconsin Water Policy

Wisconsin does not have an explicit, comprehensive state water policy. We do have many policies pertaining to specific water uses, water types, water bodies, and water-related activities. In this sense, we could be said to have a de facto water policy. Now, however, we have clearly reached an important juncture in our history; the incremental and often reactive policies of the past no longer suffice to ensure a secure water future for the state. Wisconsin water policy must better reflect the interconnected nature of water and the interdependence of varied uses and demands. In the face of uncertainty and increasing pressures on water, both within the state and beyond, Wisconsin needs a forward-looking, broad-based, coherent, consistent, and integrated state policy to protect, manage, and sustain our waters.

As a starting point in developing such a state policy, the Waters of Wisconsin committee has adopted the following statement: *The goal of Wisconsin's water policy should be to assure for this generation and future generations a safe and plentiful supply of water to meet essential human needs; to strive toward efficient use and environmentally responsible management of our waters; and to ensure the resilience, viability, and beauty of Wisconsin's watersheds and aquatic ecosystems.* With this as a starting point, Wisconsin's citizens, leaders, and decision makers may explore the policy needs and opportunities we face.

Recommendations. *To encourage action toward a more comprehensive state water policy:*

- The Governor of Wisconsin, working together with the state legislature, and with Wisconsin's Native American tribes and bands, should establish in 2003 a Wisconsin Water Policy Task Force to outline steps toward a comprehensive state water policy.
- The proposed Wisconsin Water Policy Task Force should examine all major topic areas related to water use, management, and protection and address the long-term and cumulative impacts of current policies on Wisconsin's waters.
- The proposed Wisconsin Water Policy Task Force should undertake the following specific activities: (1) compile an inventory of the main elements of current statutory, administrative, and other policies pertaining to water; (2) identify and assess gaps, conflicts, duplications and weaknesses in the existing policy framework; (3) identify scientific data, sources, and additional

information and monitoring needs on which Wisconsin can base effective water policy; (4) provide a clear statement of future directions and a general policy framework to ensure a sustainable water future for the state; (5) develop specific recommendations for the modification of statutes and other needed reforms; and (6) assess needs associated with water education, as described below.

Wisconsin Wetlands Association

2003: A Springboard to Broader Public Education and Civic Participation

Over the long run, effective stewardship of water in Wisconsin depends on broad citizen awareness and on actions taken at the individual, community, and watershed level. This in turn depends on the widespread acceptance of a shared water ethic that combines a critical understanding of water with an attitude of care and concern. Although adoption of such an ethic cannot be ensured, it can be encouraged through actions that offer opportunities for expanded public education and participation.

In October 2002, Governor Scott McCallum designated 2003 as the "Year of Water" in Wisconsin, a commitment that Governor James Doyle reaffirmed upon assuming office. This exceptional recognition of the value of water in our lives provides special opportunities to involve students and citizens in water stewardship activities. It also serves as a springboard to actions that will extend beyond 2003.

Recommendations. *To encourage such activities in the short-term, and to promote a broader commitment to education and participation in the long-term:*

- Wisconsin's "Year of Water" should serve as a catalyst for public education about the future of the state's waters, and for expanded public and private participation in water stewardship activities. In particular, the Year of Water provides opportunities for Wisconsin citizens, decision makers, schools and universities, businesses, and organizations to celebrate and acknowledge water quality improvements; to understand and appreciate water use in Wisconsin and key water issues we face in the state; to focus attention on water education projects to increase public awareness; to highlight water-related work and encourage creative activities around the theme of water and water stewardship; and to stimulate water celebrations and activities in communities across Wisconsin.
- A broad partnership of Wisconsin's educators and institutions should conduct a full review and assessment of statewide water education efforts at all levels.
- As part of the general review of water education in Wisconsin, special attention should be given to assessing K–12 water education programs and needs.
- The Wisconsin Department of Natural Resources, working with partner organizations, businesses, schools, and communities, should lead efforts to support, expand, and improve volunteer monitoring programs, and to coordinate an effective statewide volunteer monitoring network.

Measuring and Monitoring the Health of Wisconsin's Waters

Effective public policy decisions involving water require accurate, reliable, and timely scientific information, compiled and analyzed consistently over time. Today our system for assessing the state of our waters and watersheds is incomplete. Our capacity to acquire, manage, and provide information about our waters faces a number of challenges. We lack sufficient understanding in key areas of water science. The "feedback loops" in our water assessment system — the links between databases, available information, and use of that information in water management activities — are inadequate. Funding for essential water monitoring programs is at risk due to state and federal budget stringencies.

Recommendations. *Wisconsin should seek to develop and maintain the most cost-effective, efficient, well organized, and responsive water monitoring, data collection, and data analysis system possible. To attain this goal:*

- The State of Wisconsin — working in partnership with federal, tribal, and local governments; the private sector; and nonprofit organizations — should maintain the state's long-term commitment to, and capacity for, effective water monitoring.
- The State of Wisconsin, in partnership with relevant state, tribal, federal, and private entities, should explore options for improving coordination of water information within the state and identifying key research and monitoring needs.

- The State of Wisconsin should coordinate and prepare a regular "State of Wisconsin's Waters" report to make information on Wisconsin's waters more available and useful to educators, state legislators, local officials, and other decision makers.
- Institutions engaged in gathering and analyzing water information should collaborate in developing an interactive, web-based repository of water status and trend data, as a way of making information on Wisconsin's waters more accessible to the public.

Managing Wisconsin's Water for Sustainability

The ways in which the people of Wisconsin have used and protected the state's waters have evolved throughout the state's history in response to changing economic forces, demographic trends, environmental threats, scientific information, legal mandates, policy tools, and stewardship opportunities. In the past we have regarded water as a discrete "resource" and have sought to manage particular water uses, activities, or impacts. Increasingly we understand water as an integral part of the landscapes and watersheds where it occurs. To sustain water for human health, environmental quality, and economic prosperity, we must sustain as well the hydrologic systems and ecosystems through which our waters flow.

Managing for sustainability means taking the long view, and seeking ways to integrate human needs and ecosystem values without compromising either. It implies constant assessment of the impacts of our decisions and actions. It depends upon citizens becoming more aware of Wisconsin's waters, and more involved in the decisions that affect them.

Recommendations. *To meet changing and emerging water management challenges:*

- Sustainability should be recognized as the foundation and guiding principle of Wisconsin's water policy. The proposed Wisconsin Water Policy Task Force should consider sustainability principles in its work and should further define how they may be embraced and implemented in decision-making processes.
- Our approach to the protection and management of Wisconsin's water resources and aquatic ecosystems should be flexible, adaptive, and responsive to the complex nature of hydrologic systems.
- Water basin and watershed-based approaches should be supported and strengthened through both private and public sector actions.
- Local governments, organizations, institutions, and businesses in Wisconsin should be encouraged to discuss, test, and apply sustainability principles, in both public and private decision making.

Facing Tomorrow's Water Challenges

The recommendations outlined here reflect varied needs, within a broad strategy for sustaining our waters. Wise water stewardship requires accurate assessment of the overall status of our waters, and the trends affecting them. Based on this information, we may speculate intelligently about the impact of our decisions and possible long-term outcomes. To achieve a sustainable future for Wisconsin's waters, and all that depends on them, we need to define principles that can inform and guide decision making. These principles, in turn, suggest necessary changes in Wisconsin's water policy.

We should not expect that we can address all our water challenges easily or quickly, or that we can anticipate all the water problems that future generations will confront. We can, however, begin to act on recognition of the connections that characterize water — between the waters of the atmosphere, surface waters, and groundwater; between human uses and ecosystem needs; between water quality and water quantity; between Wisconsin and our neighbors; between our generation and generations yet to come. Recognizing those connections, we can better prepare the way for future stewards of Wisconsin's waters. In so doing, we should pause, too, to refresh ourselves, and remember to celebrate the great gift of the waters.

CHAPTER 1

THE WATERS OF WISCONSIN: AN OVERVIEW

Water defines Wisconsin. Wisconsin's geology and geography, ecosystems and history, cultures and communities, economy and character, all reflect our natural endowment of water. Our lakes, rivers, wetlands, and underground aquifers are essential to human well-being and support the diverse array of species and ecological communities that share Wisconsin's landscape. Water, in all its forms, underlies public health, prosperity, and the quality of life that Wisconsin's citizens and visitors enjoy.

The value of Wisconsin's water is at once immense and incalculable. The economic worth of Wisconsin's water — for drinking water and domestic use, as a transportation avenue and a recreational resource, for wastewater treatment and industrial production, as a provider of vital ecosystem services — is vast (Postel and Carpenter 1997; Marcouiller in press). A firm commitment to water stewardship is critical if we are to sustain these economic and material benefits for future generations.

Yet, the full value of Wisconsin's water includes intangible qualities that cannot easily be reduced to numbers. As an essential element of life, water is an inherent part of who we are, and of the places we care about. Water courses through our lives, connects us within watersheds, and ultimately binds us to the global hydrologic cycle. How we interact with water as it moves through our lives defines *us* as well — as individuals, as members of communities, and as participants in ecosystems. Water stewardship is thus an expression of ethical responsibility to fellow citizens, to downstream users, to future generations, and to the larger community of life (Leopold 1990).

THE CHALLENGE OF STEWARDSHIP

Wisconsin's people have long understood the importance and value of water. After the retreat of the glaciers, the watersheds of Lake Superior, Lake Michigan, and the Upper Mississippi River sustained generations of Wisconsin's native peoples. Literally and figuratively, Wisconsin's waters brought European explorers to the land that would become Wisconsin, and into contact with the native people. The advance of European settlement in the 1800s and the economic development of Wisconsin were intimately tied to our waterways, and to our wealth of water. New ways of life brought new uses of water, and new forms of prosperity (Bogue 1990).

Although Wisconsin's people have long appreciated water's value, we have not always appreciated its vulnerability. Rapid conversion of Wisconsin's forests, grasslands, wetlands, and surface waters in the 1800s and early 1900s coincided with the rise of industrialism in the new cities of the state. Water played a central role in the state's economic expansion. However, the unprecedented changes in Wisconsin's human economy altered the quality and flow of its waters, disrupting centuries-old hydrologic processes and degrading native communities of aquatic life.

The changes wrought in this period of severe exploitation of natural resources gave rise to the Progressive-era conservation movement. In the early 20th century, Wisconsin established itself as a national leader in adopting new approaches to reforestation, soil and water conservation, watershed rehabilitation, fish and wildlife management, and conservation education. This legacy endured through the 20th century as new environmental problems arose and public awareness continued to expand. Environmental protection laws and resource management programs brought important reforms, especially in treating the most egregious forms of pollution. Meanwhile, across Wisconsin, watershed groups, lake associations and lake districts, land trusts, and other community-based conservation organizations formed to provide local leadership and involvement in water stewardship. As we move into the new century, those stewardship responsibilities are changing in response to our increased understanding of hydrologic systems, growing and competing demands for water, and shifting societal values. Increasingly, too, we understand that Wisconsin's stewardship responsibilities exist within a larger context of intensifying national and global water concerns (see sidebar).

There is still much unfinished business to attend to in regard to past practices in water use, protection, and management in Wisconsin. Since passage of the federal Clean Water Act in 1972, Wisconsin's water resources have, in many ways, improved remarkably (Gaumnitz 2002). Those improvements have yielded significant economic, environmental, and public health benefits. We need to persist in these efforts to clean up the waters, a task that will continue to require long-term, creative commitment.

Even while continuing this work, the next generation will face new and different challenges involving water quantity and management, and the health of aquatic ecosystems. The challenges exist throughout Wisconsin, and throughout the larger watersheds that we belong to. In retrospect, we may come to regard the point source water pollution problems of the recent past as relatively easy to address. Such pollution sources were, by definition, more discrete and more easily identifiable. Options for responding to them were clearly defined (if not always agreed upon).

By contrast, the water challenges of the future are characterized by higher degrees of complexity and uncertainty: polluted runoff from non–point sources; the spread of aquatic invasive species; the hydrologic impacts of climate change; the recreational and residential demands of a growing human population; the cumulative impacts of contaminants; unsustainable withdrawal of groundwater from our aquifers; maintenance and improvement of our water treatment infrastructure; increased pressures to divert, and even export, Great Lakes waters — to name just a few. These problems involve intricate connections between natural processes, human behavior, and economic forces. Meanwhile, the social, economic, and environmental context in which we make decisions related to water has itself grown more complex and uncertain. To meet the challenges of the future, we will need to devise responses different from those that we have adopted in the past (White 1999). Above all, Wisconsin's citizens and institutions will need to work together in new ways to achieve real results on the ground — and in the water.

OVERVIEW OF THE REPORT

Wisconsin is blessed not only with its abundance of water, but also with its wealth of existing knowledge, the depth of its conservation tradition, and the steadfast interest of its citizens in issues involving their home waters. The challenges facing Wisconsin's waters would be even more daunting without this expertise, legacy, and commitment. The Waters of Wisconsin initiative has sought to draw upon and focus these assets in considering the long-term future of this vital natural resource.

This report captures the main ideas, findings, and recommendations developed over the course of the Waters of Wisconsin initiative (see appendix A). The chapters that follow correspond to the main themes that WOW participants explored. Four WOW working groups were established to develop these themes, and each theme was highlighted during WOW's committee meetings, public forums, and working sessions.

Chapter 2 focuses on the status of Wisconsin's waters and the trends that characterize them. Many volumes can be filled with more detailed information on most, if not all, of the specific topic areas covered in this chapter. This chapter aims to condense available information, offer

WATERS OF THE WORLD: WISCONSIN IN CONTEXT

Living as we do amid abundant freshwater, Wisconsinites are liable to forget how fortunate we are. People around the world — by some estimates, one-half of the global population — are not so well-off. Instead, they face chronic water shortages, and the water they do have is often unfit to drink (Colwell 2002). The quantity, quality, availability, and sustainability of water are now the focus of increasing attention at the international level (Simon 1998; Postel 1999; Gleick et al. 2002).

Three main causes lie behind the growing water shortages. First, the world's population has been rapidly growing. There is no less water in the world, but the water that exists is shared among more people. Population Action International estimates that by 2025, 29 countries will suffer moderate to severe water shortages, and stressed water supplies will exist in an additional 20 countries, affecting some 2.94 billion people (Engelman and LeRoy 1993). Three hundred of China's 517 northern cities experience chronic water shortages. Egypt, which depends almost entirely on the Nile River for water, is doubling its population every 29 to 37 years. The seven upstream countries in the Nile River's watershed suffer civil conflict and have yet to use their share of the Nile. As they do, and as Egypt's population continues to grow, the demands upon the Nile will become more acute.

Second, we have abused available water supplies. Almost 50% of the world's freshwater is polluted. About 25,000 people die every day from poor water quality, and an estimated 3.8 million children in developing countries die every year. In Mexico City, 90% of industrial liquid waste and 95% of treated hazardous waste effluent are added to residential waste and dumped into the sewer system. All of Mexico City's untreated wastes then pass downstream, to be used to fertilize vegetable crops that are sold back in Mexico City (NRC 1995). Millions of people in Bangladesh are drinking groundwater with arsenic concentrations well in excess of acceptable standards. Thousands have already been diagnosed with the symptoms of poisoning. The source of their problem is water from untreated tube wells. As the groundwater table drops, mineral concentrations — in this case, arsenic — increase.

The third cause of water shortages is increasing per capita consumption as nations shift from primarily agrarian economies to mixed economies. From 1900 to 1980, the population of the readers an accurate overview, and provide a sound knowledge base for the discussions that follow.

Chapter 3 focuses on the future. We argue for the importance of considering the future, with all its uncertainties, in our decisions and actions. Knowing what we do about the current status of our waters, what might we expect the future to hold? The goal in this chapter is not to predict or prescribe a particular future, but to encourage more critical consideration of possible futures as a way of understanding the impact of today's and tomorrow's decisions.

Chapter 4 focuses on basic concepts that may allow us to manage our water resources and aquatic ecosystems more sustainably over the long run. In the past, we have managed water in ways that have sometimes produced unintended results, often to the detriment of human welfare and the waters themselves. This chapter asks if there are principles that can help us to sustain our waters through a future of inevitable uncertainties.

United States increased threefold. The nation industrialized at the same time, however, and per capita use of water quadrupled. As a result, we used 11 times as much water in 1980 as we did in 1900 (Van der Leeden et al. 1990). As developing countries improve their standards of living, their per capita requirements for water are likely to increase in a comparable fashion.

There is another important dimension to water consumption around the world. Many regions depend upon nonrenewable water sources — waters captured in the ground eons ago and not recharged in current times. Libya, for example, withdraws water from ancient aquifers under its southern desert to augment its annual renewable supply. At the current rate of withdrawal, the expected life of the aquifer is about 50 years. Saudi Arabia also depends heavily (75%) on groundwater and will likely exhaust its supplies in about the same time frame. Once these and other countries deplete their supplies through overdrafts, they will simply run out of fresh water.

Compounding the problem is the fact that, worldwide, more than 250 river basins are part of two or more countries. Water treaties between riparian countries exist in only about 64 of these. Africa, which has 56 international basins, has only three basin treaties. Many international basins contain countries with strong cultural and political differences. Perhaps the most acute example is the Jordan River. We hear daily news reports of the tragic conflict between Israelis and Palestinians. Yet Israel, Syria, Jordan, and the Palestinians all share the Jordan River as a common water source. Here, too, rapidly growing populations draw water from a fairly small river.

An eye to our water context, and to water troubles around the world, can help Wisconsinites anticipate potential difficulties for our own water resources. As other parts of this report document, Wisconsin, despite its abundant waters, has situations similar to those found elsewhere in the world. We, too, are experiencing overdrafts of groundwater, high levels of arsenic and other contaminants in drinking water, and increasing international interest in the freshwater of our state and region. However distant the world's water problems and challenges may seem, they are ours as well.


International Crane Foundation

Chapter 5 focuses on water policy needs in Wisconsin. We conclude that policies must be updated to take into account new information, to meet emerging needs, and to anticipate future problems. This chapter seeks to provide a foundation for this reassessment.

Chapter 6 summarizes the findings and recommendations of the Waters of Wisconsin initiative in four main areas: water policy, water education and public participation, water information and assessment, and water management and stewardship.

The report as a whole seeks to bind these themes together. Wise water stewardship requires accurate assessment of the overall status of our waters and the trends affecting them. Based on this information, we may speculate intelligently about the impact of our decisions and possible long-term outcomes. To achieve a sustainable future for Wisconsin's waters and all that depends on them, we need to define principles that can inform and guide decision making. These principles, in turn, suggest necessary changes in Wisconsin's water policy.

RISING TO THE CHALLENGE

Wisconsin's waters are assets of inestimable global significance. Sitting astride the great freshwater systems of the Great Lakes and the Mississippi River, with its vast network of inland surface waters and its extensive groundwater reserves, Wisconsin is uniquely situated in terms of both geography and obligation. The special significance of its waters confers a special responsibility for leadership.

Meeting this responsibility will require the best available scientific information and understanding, along with an ethic that allows that information to be applied in the long-term public interest. In Wisconsin we are also fortunate to have a tradition of leadership in science, conservation, and civic engagement. In the past, these advantages have worked together: the more we know, the more we care; the more we care, the more Wisconsin's citizens, organizations, businesses, institutions, and governmental bodies have taken up the challenge of stewardship.

The Waters of Wisconsin initiative has been undertaken in this spirit. We can allow ourselves to drift into an uncertain water future that merely responds in a piecemeal and reactive manner to issue after issue, and crisis after crisis; or we can try to anticipate and shape our water future as participants in what Aldo Leopold called "a thinking community." We offer this report in the hope that leadership will emerge, as it has emerged in the past, from Wisconsin's thinking community, and secure a healthy water future for ourselves and for generations to come.

CHAPTER 2

WISCONSIN'S WATERS: STATUS AND TRENDS

A sustainable future for Wisconsin's waters must begin with an assessment of their condition over time. Answers to seemingly simple questions are essential. In what condition are Wisconsin's water resources and aquatic ecosystems? How are our waters changing? What are the positive and negative signs? How can citizens use information about status and trends to make sound decisions about our waters? Where is the necessary information? These are a few of the fundamental questions that Waters of Wisconsin participants have sought to address. The questions — and answers — are pertinent whether we are interested in the future of state water policy or the future of a nearby lake, stream, spring, or wetland.

Wisconsin is fortunate to have extensive information on many aspects of the state's waters. A WOW working group developed a list of water information sources (appendix B). Organizations responsible for collecting and analyzing this information are a valuable asset. They provide the tools and data that inform our decisions and directions in water management. With such information we can take stock of our waters, be alert to emerging problems, evaluate failures and successes, and devise paths toward a desired future.

Our goal here is to provide an overview of Wisconsin's water resources and aquatic ecosystems, and to consider what we know about their current status and changing condition. Many important gaps do exist in our knowledge of water in Wisconsin. Integrating existing knowledge from different sources to arrive at a "big picture" view of Wisconsin's waters is itself a key challenge. Thus, we conclude this chapter with a discussion of water information needs.

AN OVERVIEW OF OUR WATERS

Wisconsin is blessed with plentiful water, expressed in diverse water bodies across the landscape and along our borders (figure 1). Continental glaciers once covered all but the southwest portion of Wisconsin. The state even gave its name to the period: the Wisconsin Glaciation. Our "waterscape" is the 12,000-year-old legacy of the receding glaciers. Today, these interconnected waters constitute a state resource with global significance. Although we may regard rain, snow, and water vapor; wetlands, streams, and lakes; and soil moisture and groundwater as separate entities, they interact to form a single hydrologic continuum, a "round river" that flows into and out of itself (Leopold 1990; Pielou 1998; Alley et al. 2002). What happens in one part of the cycle affects the entire water system. Atmospheric water falls to the earth; water in wetlands, streams, and lakes flows to and from and recharges the groundwaters; in turn, groundwater renews the surface waters; people, plants, and animals depend on the waters; water returns to the atmosphere as it evaporates or is transpired by plants.

Precipitation

Each year Wisconsin receives 30 to 34 inches of water from the atmosphere in the form of precipitation (figure 2). Of this, 18 to 25 inches evaporates from water surfaces or is transpired by plants back to the atmosphere. The rest (7 to 13 inches) either runs off to surface waters or infiltrates into the ground (USGS 1968–75). On average, there is less precipitation in central Wisconsin, more in both the north and the south. Average snowfall varies greatly, with Beloit in

WISCONSIN'S LAKES, STREAMS, AND MAJOR WETLANDS

Figure 1

WDNR

AVERAGE MONTHLY PRECIPITATION IN WISCONSIN (1971–2000)

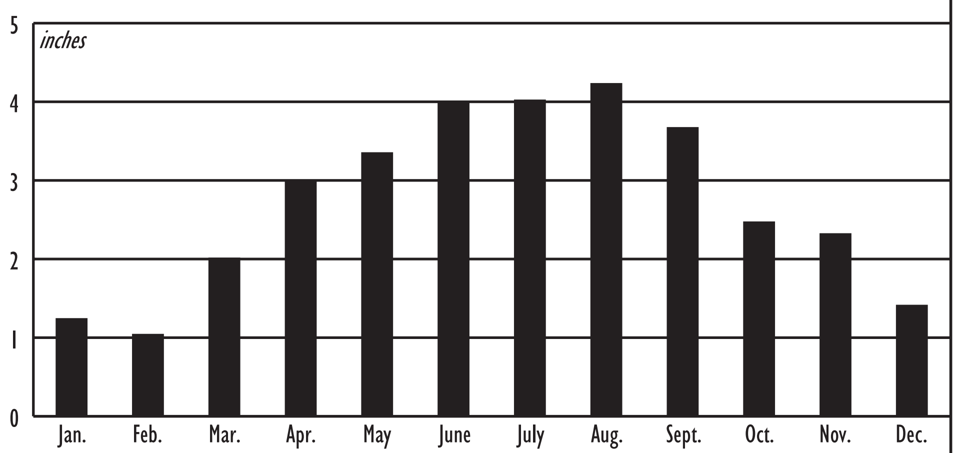


Figure 2

State Climatology Office

the south receiving about 30 inches and the snowbelt near Lake Superior receiving more than eight feet. The amount of water that infiltrates or runs off varies widely, depending on climate, season, soil type, topography, plant cover, and land use. Urban areas have more runoff than forests, fields, and pasturelands. Rock and clay soils have more runoff than organic soils. Steep slopes have more runoff than flatter lands. Intense rainstorms produce more runoff than slow, steady rains. Snowmelt and spring rains typically coincide in April, and so this is the most likely time for flooding.

Lakes

More than 15,000 lakes are embedded in the Wisconsin landscape. One thousand miles of coastline, along two of the Laurentian Great Lakes, Michigan and Superior, form our eastern and northern shores. The inland lakes range in area from tiny bogs and ponds — two-thirds of the inland lakes are less than 10 acres — to Lake Winnebago at 137,708 acres (WDNR 2001). While the inland lake waters total about 983,000 acres in surface area (WDNR 2001), Lakes Superior and Michigan constitute the first- and fifth-largest lakes in the world in terms of surface area (31,700 and 22,300 square miles respectively). These two lakes alone contain 10 to 15%of the world's fresh surface water.

Not all lakes are the same. Lakes differ not only in size and depth, but also in their position in the landscape, their connections to groundwater and streams, the nature of their shorelines, their inherent water chemistry, their internal thermal structure and stratification, the variability of their water level, the diversity of aquatic life they support, their history of human settlement and development, and the land uses along their shorelines and in their watersheds. These differences influence the nature of the lake and its susceptibility to change from human activities. In southern Wisconsin, for example, most lakes are situated in urban and agricultural watersheds where water sources, land use, and plant cover determine the level of nutrient input. A lake's size and water sources determine the residence time of water molecules in the lake, and its ability to dilute contaminants or recover from the effects of excess nutrient inputs. A contrasting example from northern Wisconsin might be a small upland lake that has no inlet or outlet streams and that receives few inputs of acid-buffering chemicals from rain or groundwater. Such a lake is especially susceptible to changes in acidity (pH) from acid rain.

The trophic status of lakes is an important and visible indicator of differences among them. People notice if a lake is green and *eutrophic* owing to the input of abundant nutrients (especially phosphorus); or clear and *oligotrophic* owing to limited inputs of nutrients; or clear brown and *dystrophic* owing to decomposed plant materials carried in from nearby wetlands. Eutrophic, oligotrophic, and dystrophic lakes support different communities of aquatic life and favor different human activities (for example, fishing, swimming, waterfowl hunting, hiking, and residential and commercial development). Often, nutrient inputs to a lake from development and agriculture are excessive and can convert a clear lake into a eutrophic one with high concentrations of algae. Excessive nutrients eventually reduce the value and quality of lake water for all users; many lake groups find that dealing with eutrophication forms a large part of their stewardship and restoration activities.

Human settlement, recreation, and industry have long been drawn to the inland lakes and Great Lakes (Bogue 1990). Wisconsin's native people have for millennia depended upon lakes to support their cultures and livelihoods. The state capital of Madison is nestled in and around the Yahara lakes. "Up North" is defined by the aesthetic quality, wooded shorelines, and recreational opportunities provided by the region's myriad lakes — one of the richest concentrations of freshwater glacial lakes on Earth (Korth and Cunningham 1999).

The Lake Michigan coast contains many of the state's industrial centers. Lakes Michigan and Superior support important commercial and recreational fisheries, while providing abundant water for Wisconsin municipalities, tourism, industry, and energy production (Bogue 2000). More than 40 million metric tons of cargo, accounting for 10 percent of Wisconsin's total freight tonnage and valued at about $7 billion, pass through Wisconsin's fifteen active commercial Great Lakes ports every year. The larger ports of Milwaukee, Green Bay, and Superior are estimated to contribute more than $200 million annually to their local economies (WCMP 2002; WDOT 2002).

Rivers and Streams

More than 32,000 miles of perennial flowing waters, in 12,600 named rivers and streams, connect Wisconsin's uplands to the Mississippi River and the Great Lakes — and eventually to the Atlantic Ocean through the Gulf of Mexico and the Gulf of St. Lawrence (WDNR 2000a). Because many upland streams are fed by cool (about 52°F) groundwater, this water network includes almost 10,300 miles in more than 2,931 trout streams.

The Mississippi River, like the Great Lakes, is internationally significant. The Mississippi-Missouri river system covers about 40% of the United States, including all or parts of 31 states, as well as portions of two Canadian provinces. Two-thirds of Wisconsin is in the Mississippi River's watershed, covering an area from Solon Springs in the northwest, to Eagle River in the northeast, to near Kenosha in the southeast. This great river system is the third longest in the world (3,700 miles), third largest in watershed area (1.25 million square miles), and fifth largest in average discharge (651,000 cubic feet per second) (Kammerer 1990).

Wisconsin's streams, like its lakes, are highly diverse in their character and in the aquatic biodiversity and human activities they support. Road-bridge views of streams provide only a limited impression of what in fact are large and interconnected flowing ecosystems. Each reach of a stream interacts with the adjacent land, the upstream reaches and watersheds, the flowing waters downstream, and the people and communities along its course. More than simple conduits of water and waste to the ocean, they are the arteries of the continent, with the capacity to recycle nutrients, retain productivity, and store and detoxify contaminants.

Differences among streams result from differences in the watershed's size, topography, land cover, and land use; the source water (precipitation, groundwater, lakes, wetlands) and volume of water; the stream gradient (how fast the water runs); stream geology (the materials — rocks, gravel, sand, silt, or clay — over which streams flow); and the character of the stream channel (braided or single channel, pools and riffles). The dynamic nature of streams is readily apparent in the relentless seaward flow of their water, sediment, and floating debris. Their dynamism is also reflected in the seasonal rise and fall of waters with spring ice melt and runoff, rains, and summer droughts. River biota and riparian ecosystems are adapted to this flow and to the seasonal pulse of flood and drought that characterize the functioning of a free-flowing river.

Remarkably, the number and mileage of trout streams has been increasing in Wisconsin with the adoption of land conservation practices and habitat restoration and protection efforts (WDNR 2002a). In addition, concerns about the health of warmwater streams and the costs of dam maintenance and reconstruction have resulted in the removal of many small dams around the state (Born et al. 1998).

We value streams for their scenic beauty; biodiversity; recreational opportunities; and capacity for wastewater assimilation, commercial use, and power generation. The Mississippi River, a major shipping route, is navigable from the Gulf of Mexico to Minneapolis, with 26 operating locks and dams that maintain water levels for boats and barges (Wiener et al. 1998). Wisconsin's stretch of the upper Mississippi River includes 10 lock and dam facilities. In 1999, the Mississippi River carried 1.1 million tons of grain from Wisconsin, and 2.7 million tons of coal to Wisconsin (USACE 1999). The Upper Mississippi River National Wildlife and Fish Refuge is the longest wildlife refuge in the continental United States, extending more than 250 miles and encompassing 194,000 acres in Wisconsin, Minnesota, Iowa, and Illinois. The river corridor is a major flyway route for migrating waterfowl in both spring and fall.

The Wisconsin River has been called "the hardest working river in the world," with 21 storage reservoirs and 26 hydroelectric dams along its course — more dams per mile than any other river in the world. Even with these intensive uses, the lower 90 miles of the Wisconsin River have been designated as a Scenic Riverway under state law; any who have canoed or fished the wild floodplains of the lower Wisconsin will testify to its natural power and charm. The Lower Fox River is home to the highest concentration of paper mills in the world. Even so, the Fox-Wolf system is well known for its excellent walleye fishery. Some rivers have been protected under state or federal law as "wild rivers" because they have largely undeveloped shorelines and excellent water quality and fisheries. Wild rivers include the Pine, Pike, and Popple in northeast Wisconsin, and the Namekagon and St. Croix in northwest Wisconsin. Special regulations have also been enacted through state law to protect other rivers, including the Bois Brule in Douglas County and the Wolf.

Wetlands

At the time of European settlement, Wisconsin contained approximately 10 million acres of wetlands. The most recent inventory of the state's wetlands indicates that about 53% of this area remains (WDNR 2000a). The inventory was based on aerial photographs taken in 1978–79. The dramatic decrease is attributable to ditching, draining, and filling for development and agriculture, and to the straightening and channelization of streams. Much of the loss was concentrated in the southern and central portions of the state, where agricultural development was more intensive (Prince 1997). Until the 1970s, federal and state government programs actively promoted wetland drainage and conversion. The remaining 5.3 million wetland acres in Wisconsin cover about 15% of the state's total land area.

As with our lakes and streams, Wisconsin's wetlands are highly varied. Wetlands are characterized according to variations in soil type, water chemistry, associated vegetation, and degree and frequency of soil saturation. They include open water wetlands, deep and shallow marshes, sedge meadows, wet meadows, wet prairies, fens, alder thickets, shrub carrs, coniferous swamps, hardwood swamps, floodplain forests, and bogs (figures 3a and 3b) (Curtis 1959; Thompson and Luthin 2000). The source of water to a wetland, and thus the chemistry of the water, is especially important. For example, the bogs of northern Wisconsin are fed primarily by precipitation, resulting in acidic waters and low nutrient concentrations, conditions essential to their unique communities of plants and animals. Calcareous fens are fed predominantly by calcium-rich groundwater; calcium-tolerant plants thrive under these conditions, forming a community very different from that found in the more acidic bogs. Floodplain forests occur in areas where seasonal floodwaters remain long enough to allow tree species adapted to these conditions to flourish.

Wetlands provide a variety of important ecosystem services, supplying wildlife habitat, flood regulation, water filtration, and shoreline protection. Because they exist at the interface of aquatic and terrestrial ecosystems, wetlands support an unusually rich variety of vertebrate, invertebrate, plant, and microbial life. During rainfall and snowmelt events, wetlands store water, resulting in lower peak flows and less flooding. Water slows as it moves through wetlands, allowing sediments and pollutants to settle out and resulting in cleaner water. Thus, wetlands are sometimes described as "the kidneys of the landscape." On large lakes, wave action confines wetlands to the protected bays behind barrier islands and spits. These wetlands, especially those along the Great Lakes coastlines, are among our most aesthetically and biologically significant aquatic ecosystems. On small lakes, wetlands can form along the shorelines and are critical for absorbing the energy of wave action, anchoring soils and sediment, and thereby reducing the incidence of shoreline and streambank erosion (WDNR 2002b).

Groundwater

Wisconsin is estimated to have 1.2 quadrillion gallons of groundwater (USGS 1987). If this water were evenly spread over Wisconsin's total surface area (35,000,000 acres), it would be 105 feet deep. Wisconsin's groundwater is contained in four major aquifers: the sand and gravel aquifer, the Silurian dolomite aquifer, the sandstone aquifer, and the crystalline bedrock aquifer (figure 4) (WDNR 1999a).

The *sand and gravel aquifer* is generally shallow, residing in sand and gravel deposits at or near the surface where they were deposited by the receding continental glaciers. In the southwestern unglaciated ("driftless") portion of Wisconsin, the sand and gravel deposits are due primarily to river deposition.

The *Silurian dolomite aquifer* occurs only in eastern Wisconsin and consists of dolomite underlain by shale. Interconnected cracks hold the groundwater in this aquifer. Water yields of wells in this region depend upon the number of fractures that a well intercepts. Karst features such as sinkholes characterize the Silurian dolomite. Such features create a direct surface-to-ground-

GENERALIZED CROSS-SECTION OF A MEADOW–MARSH–OPEN WATER COMPLEX

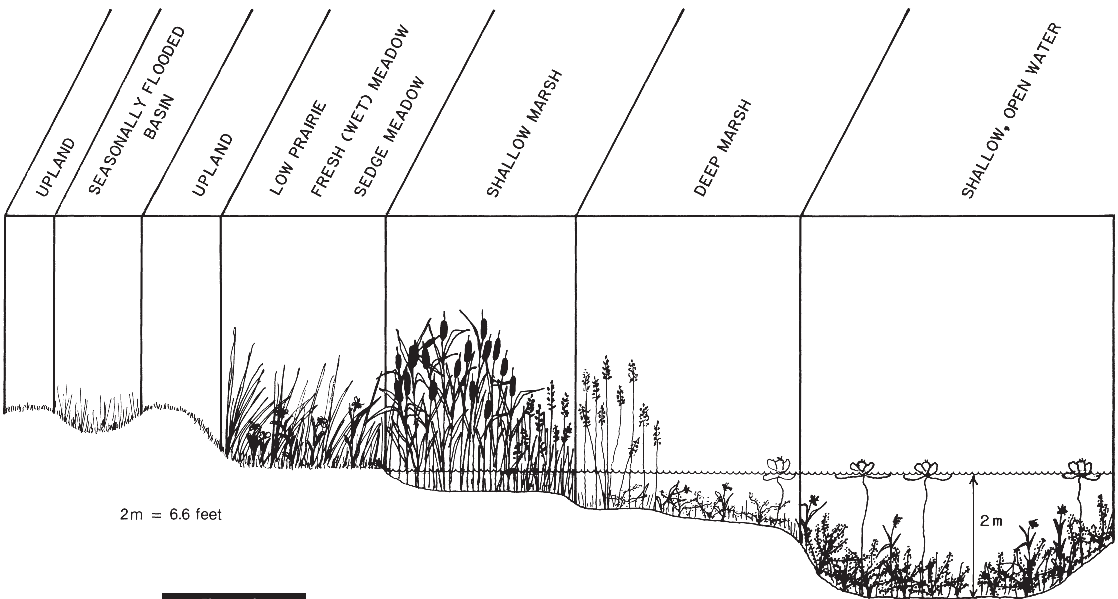


Figure 3a

Eggers and Reed 1997

GENERALIZED CROSS-SECTION OF RIVER VALLEY WETLAND PLANT COMMUNITIES

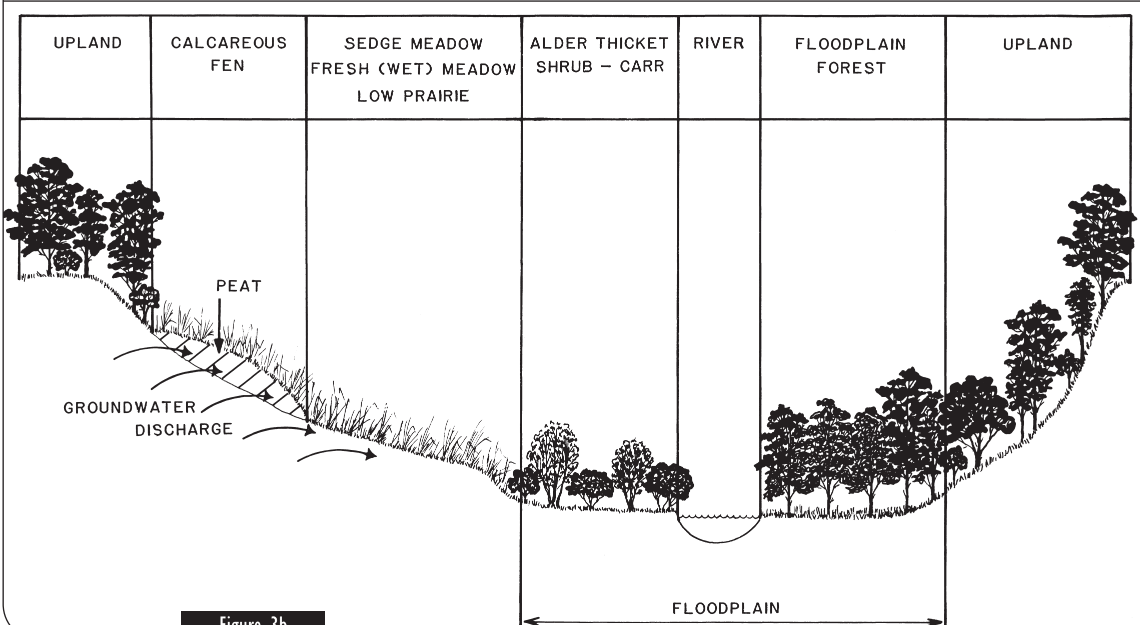


Figure 3b

Eggers and Reed 1997

water connection, which makes the aquifer especially sensitive to land use and creates the potential for dramatic impacts to both the quality and flow of groundwater.

The *sandstone aquifer* consists of alternating layers of sandstone and dolomite. These layers vary greatly in their water-holding capacity. In eastern Wisconsin this aquifer occurs deep below the Silurian dolomite and the confining unit of shale. Elsewhere in Wisconsin, the aquifer lies

MAJOR AQUIFERS IN WISCONSIN

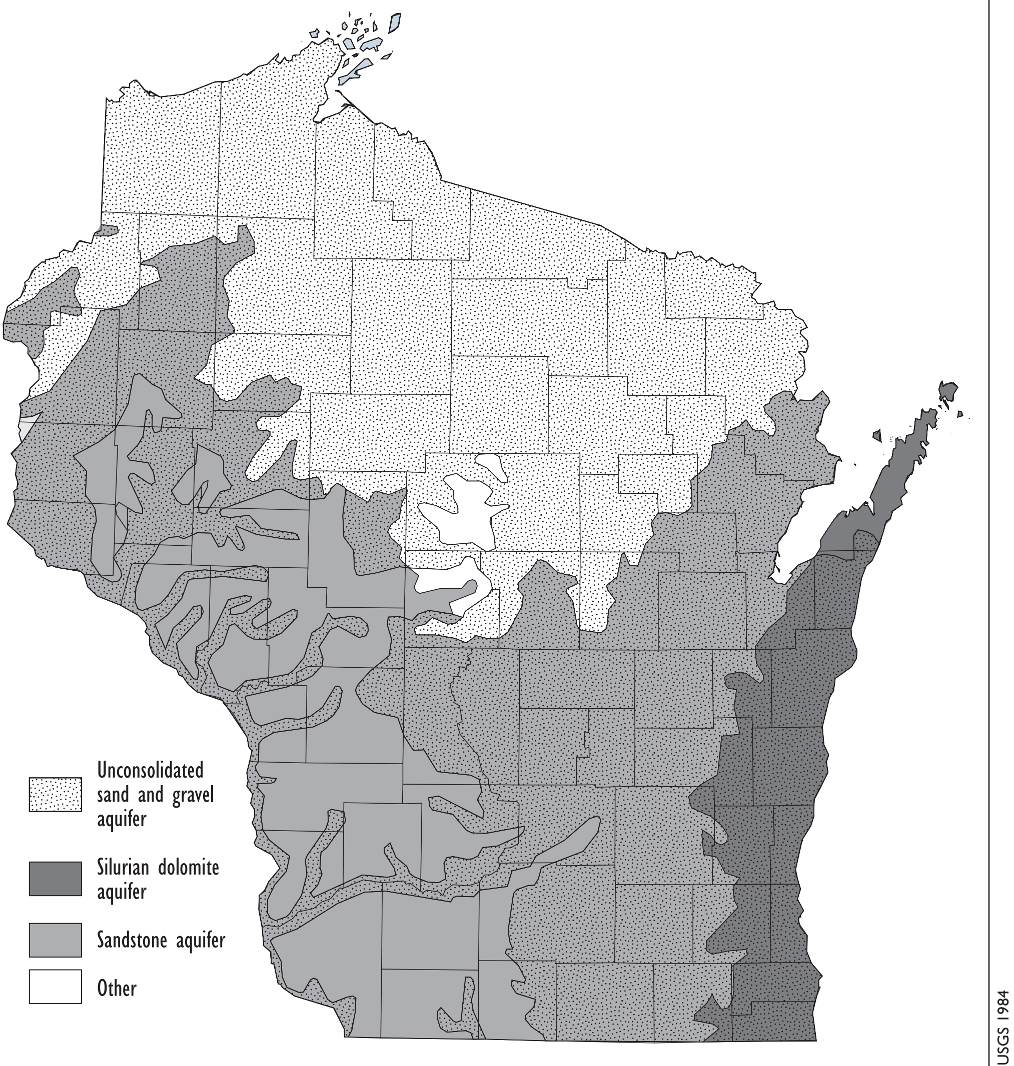


Figure 4

Note: Some aquifers overlap. This map does not show the crystalline bedrock aquifer

beneath the sand and gravel aquifer or at the land surface. This thick aquifer can yield large quantities of water.

The *crystalline bedrock aquifer* consists of granitic, crystalline rock and underlies the entire state. The groundwater is held within networks of fractures in the rock. This aquifer typically has low yields and is used primarily in northern Wisconsin, where it occurs directly beneath the sand and gravel glacial deposits (WDNR 1997a).

The value of these aquifers to our aquatic ecosystems, our economy, and our quality of life is incalculable. The "buried treasure" of groundwater is simply indispensable to life on the "surface" of Wisconsin. Groundwater connects to and feeds our wetlands, streams, and lakes; supplies water to 750,000 private wells and 97% of Wisconsin's municipalities; supports farming across the state, including more than 340,000 acres of irrigated land; and contributes in countless ways to Wisconsin's commercial, industrial, and recreational economy (WDNR 1999a). Groundwater use has changed over the decades as the population of Wisconsin has grown; land use and the economy have changed; and new pumping, water transport, and irrigation technologies have been adopted. The demands upon Wisconsin's groundwater are increasing. The consequences of these increased demands are discussed later in this chapter.

Aquatic Ecosystems and Biodiversity

Wisconsin's lake, stream, wetland, and groundwater ecosystems are characterized by the interaction of physical-chemical and biological components and processes. Ecosystems provide essential goods and services. Many of the goods or products, such as high-quality water and food, are easily appreciated. Ecosystem services can be harder to see but are just as important to our well-being (Postel and Carpenter 1997; Baron et al. 2002). These services include the biogeochemical cycling of carbon and nitrogen, flood control and regulation, and water filtration as well as such human uses as swimming, boating, and transportation.

For many goods and services, water is not the product but the medium; the living organisms and communities are the doers. Plants convert inorganic carbon dioxide and water through photosynthesis into food for animals, which then become prey for other animals. A healthy food web is essential for sound ecosystem functioning, and for such human activities as commercial and recreational fishing, bird watching, and waterfowl hunting. Microbes and invertebrates are off the radar screen (or microscope slide) for most people but are the means by which aquatic ecosystems support higher forms of life, process and recycle nutrients, and detoxify contaminants (among other basic functions) (Wilson 1987).

Following the retreat of the continental glaciers, life recolonized Wisconsin's newly formed water bodies from the Mississippi River system and the Great Lakes drainages. The diversity of life now found in and near Wisconsin's waters reflects the history of subsequent arrivals and species migrations, changing climatic conditions, and the wide variety of water bodies available for life to inhabit. Wisconsin's lakes, streams, and wetlands now form a complex mosaic of aquatic communities, containing a diverse array of mammals, birds, reptiles, amphibians, fish, insects, other invertebrates, plants, and microorganisms. These complex communities are themselves in constant flux as waters change over the seasons, years, decades, and centuries. The variety of life — expressed in its genetic material, populations and species, and communities — has come to be called *biodiversity*.

How many species live in or use Wisconsin lakes, streams, wetlands, and groundwaters? For several reasons, it is difficult to arrive at precise numbers. All living things depend on water to some degree. Many species use water in different ways at different times during their life cycles. Moreover, species inventories for many taxonomic groups are incomplete. We can derive relatively accurate estimates of native vertebrate species that predominantly live in or depend on Wisconsin's surface waters:

- Wisconsin's fish fauna includes 156 species (141 native species and 15 exotic species). Six native fish species have been extirpated (see discussion later in this chapter) (Lyons et al. 2000; Lyons pers. comm.).

- Of Wisconsin's 53 reptile and amphibian species, about 35 species of salamanders, frogs and toads, turtles, and snakes are associated with wetlands and other water bodies (Vogt 1981; Christoffel et al. 2000; Hay pers. comm.).
- Of the 381 species included on the Wisconsin Society for Ornithology's checklist of Wisconsin birds, 207 are associated with lakes, shorelines, marshes, bogs, and swamps (Barger et al. 1988; Temple pers. comm.).
- Wisconsin's mammalian fauna includes 72 species (including three non-native species). Of these, several are associated primarily with aquatic or wetland habitats (beaver, otter, muskrat, mink, water shrew, star-nosed mole, bog lemming, red-backed vole). Another 20 to 30 utilize water bodies and wetlands extensively (WDNR 1995; Watermolen and Murrell 2001; Kearns pers. comm.).

Much less conspicuous are the myriad snails, mussels, crayfish, mayflies, dragonflies, caddisflies, stone flies, beetles (such as the whirligig), water bugs (such as the large predaceous diving bug), and other gastropods and arthropods; the freshwater sponges, bryozoans, and jellyfish adapted to freshwater; and animal plankton, including cladocerans, copepods, and mites. Even today, species previously unknown to the world are being found, described, and named in Wisconsin's waters. In the last decade two new species of aquatic fungi that live on rooted aquatic plants have been found in lakes in Vilas County (Fallah et al. 1997).

Aquatic plants range from the minute algae (including the desmids, green algae, and diatoms) and tiny floating duckweeds, to wetland-adapted trees such as the black spruce, cottonwood, and swamp white oak. Submergent and emergent plant species, rooted in the bottom of water bodies, include sedges, rushes, cattails, lilies, arrowheads, and wild rice. Wisconsin's flora also includes many bog and fen specialists as well as mosses, ferns, and fern allies that require moist microenvironments (Curtis 1959). The total number of aquatic/wetland plant species in Wisconsin is difficult to determine; a minimum estimate would be 300 to 600 species (Kearns pers. comm.). According to the U.S. Fish and Wildlife Service's Wetland Indicator Status database (as listed at http://plants.usda.gov), over 900 species of vascular plants in the upper Midwest have a wetland affinity (this figure includes invasive plant species).

Most people think of groundwater as sterile water that exists in dark and lifeless places. In fact, groundwater supports a remarkable diversity of life. Populations of free-living bacteria decrease with depth but are present even in deep aquifers. Shallower groundwaters (such as the water that appears when one digs a hole in a sandy beach) contain free-living bacteria, protozoa, tiny tartigrades ("water bears"), and ostracods (a subclass of crustaceans). Significant chemical and biological exchange occurs between surface streams and near-surface groundwaters. In addition to microorganisms, these near-surface waters contain immature aquatic insects; blind mites; and a variety of ostracods, isopods, and other freshwater crustacea. One organism, the Wisconsin well amphipod, lives only in the groundwaters of Wisconsin. It survived the ice age underground and lives today in the water between the rocks, relying on nutrients carried in from above (which also renders it vulnerable to pollutants) (Kitchel pers. comm.). All of these diverse forms of life play functional roles in Wisconsin's aquatic ecosystems.

Wisconsin's ecosystems, and the life they support, have changed continually since the retreat of the glaciers. They continue to change, but now the changes — climate change, hydrologic alterations, disruption of ecosystem functions, disturbance of aquatic communities, species invasions and extirpations — reflect not only natural processes, but also the increased role that human beings play in the landscape. These changes are discussed in greater detail later in this chapter.

WATER STATUS AND TRENDS

Effective stewardship and responsible management of Wisconsin's aquatic ecosystems and water resources require wide-ranging information on the waters' status and trends. Such information allows us to appreciate patterns in our water use, broaden the time horizon for planning, respond to early warnings of threats to our waters, check the effectiveness of our policies, and act with confidence in adapting our ways of doing business.

Both the time and space dimensions of the data are important. Both are needed, for example, to answer basic questions: Is our water quality improving or declining? Where in the state is water pollution (of various types) a problem? How quickly can a degraded water body recover? Where are extensive cleanup efforts warranted? Is water use growing, and are water supplies adequate to meet expected demands? Where are the areas deserving of extra protection to conserve especially pristine water? In this section, we use existing information to summarize status and trends across a range of issues and characteristics involving Wisconsin's waters. Many of the trends we describe fit within several categories of interest, illustrating that the same information can be used to address a broad range of questions.

Water and Climate Change

Wisconsin's climate is changing in ways that are influencing the waters of the state. Between 1900 and 2000, the average temperature in the Great Lakes region has increased. In the last four winters (1997–98 to 2001–02), temperatures averaged 7°F above the long-term average, and annual temperatures averaged 2 to 4°F above the long-term average (Kling et al. 2003). Precipitation in the Great Lakes region has also been above the long-term average over the last three decades, and it may be that the proportion of precipitation falling in intense events has increased. Scenarios for the Great Lakes region project that warming trends will continue, and by the end of the century will result in temperatures rising by 7.2 to 12.6°F in winter and 3.6 to 14.4°F in summer. Precipitation scenarios are less certain, but precipitation is expected to increase in winter and decrease or stay the same in summer (Sousounis and Bisanz 2000; Kling et al. 2003). Evapotranspiration is expected to increase with temperature, resulting in a dryer climate.

Evidence of climate change can be found in Wisconsin's waters as well. The effects of warming can be seen in ice-cover changes on Lake Mendota; ice duration decreased from about four months 150 years ago to about three months today, a decrease of 25 percent, or 19 days per century (figure 5). Observed changes in the duration of ice cover on lakes and rivers in northern and southern Wisconsin, across the Great Lakes region, and around the northern hemisphere support the finding of reduced ice cover observed on Lake Mendota (Magnuson et al. 2000;

Kling et al. 2003; Magnuson et al. in press). Change in ice cover provides independent indications that warming is occurring. More important, the trend indicates that aquatic ecosystems are responding to the warming.

Other changes are apparent in Wisconsin's waters. Groundwater levels, stream baseflows, and seepage lake levels (lakes with no inflow or outflow streams) have risen abruptly since 1970 in most of Wisconsin. Groundwater levels have been rising in most areas where groundwater withdrawal is relatively limited. These increases may reflect either long-term climate change or a shorter-term wet cycle; both could account for greater recharge. Climate change can lead to increased recharge rates by increasing the amount of precipitation or by altering its timing (recharge increases when more rain falls during the autumn and early winter, when evapotranspiration rates are low and the ground is not frozen). The rise in water levels may also reflect improvements in land management; however, the abruptness of the recent changes suggests that it involves a combination of improved land management and climate change (Magnuson et al. in press). The trend in higher groundwater levels described here is distinctly different from the trend toward lower levels observed in areas of intensive groundwater development and extensive hydrologic alteration. These are discussed in the "Water Quantity" and "Hydrologic Alteration" sections below.

In the future, climatic and hydrologic trends will interact in complex ways. Climate change models predict that evaporation rates will increase in response to rising temperature, outpacing the predicted increase in precipitation. The result eventually is a reversal of the trends described previously: more droughtlike conditions, with decreased stream flows, lower lake levels, and decreased soil moisture (Sousounis and Bisanz 2000; Lofgren et al. 2002; Kling et al. 2003). The scenarios for water-level changes in Lake Michigan range broadly from a drop of 27 feet to a rise of six inches, with a median predicted change, using all models, of a 10-foot drop (Sousounis and Bisanz 2000). While research on the causes and potential consequences of climate change continues, the available evidence suggests that Wisconsin's waters will experience significant impacts in the decades ahead.

DAYS OF ICE COVER ON LAKE MENDOTA (1850–2000)

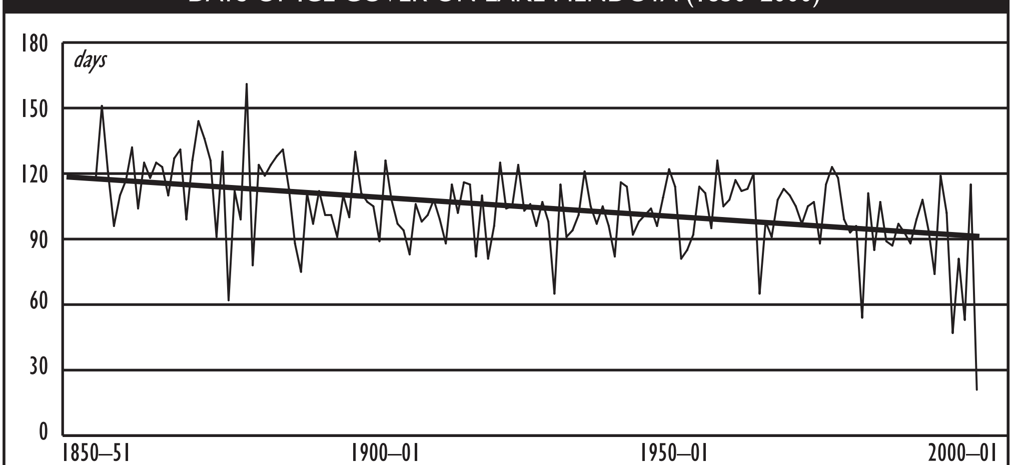


Figure 5

Magnuson et al. in press

OUTSTANDING AND EXCEPTIONAL WATERS

The Wisconsin DNR lists 1,855 (6.7% of Wisconsin's 27,723 water bodies) Outstanding or Exceptional Resource Waters (figure 6). These waters have the highest-quality water in the state and are free from point source and non–point source pollution. The designations help to protect waters that already meet or exceed clean water standards under the federal Clean Water Act. Any new wastewater discharges to these waters must meet or exceed background water quality to prevent degradation. Exceptional Resource Waters have superb water quality and fisheries, even though they may have discharges into them. New discharges that minimally lower water quality can be permitted for exceptional waters, but only if the discharge would prevent an environmental or public health problem (WDNR 2000a).

OUTSTANDING AND EXCEPTIONAL RESOURCE WATERS

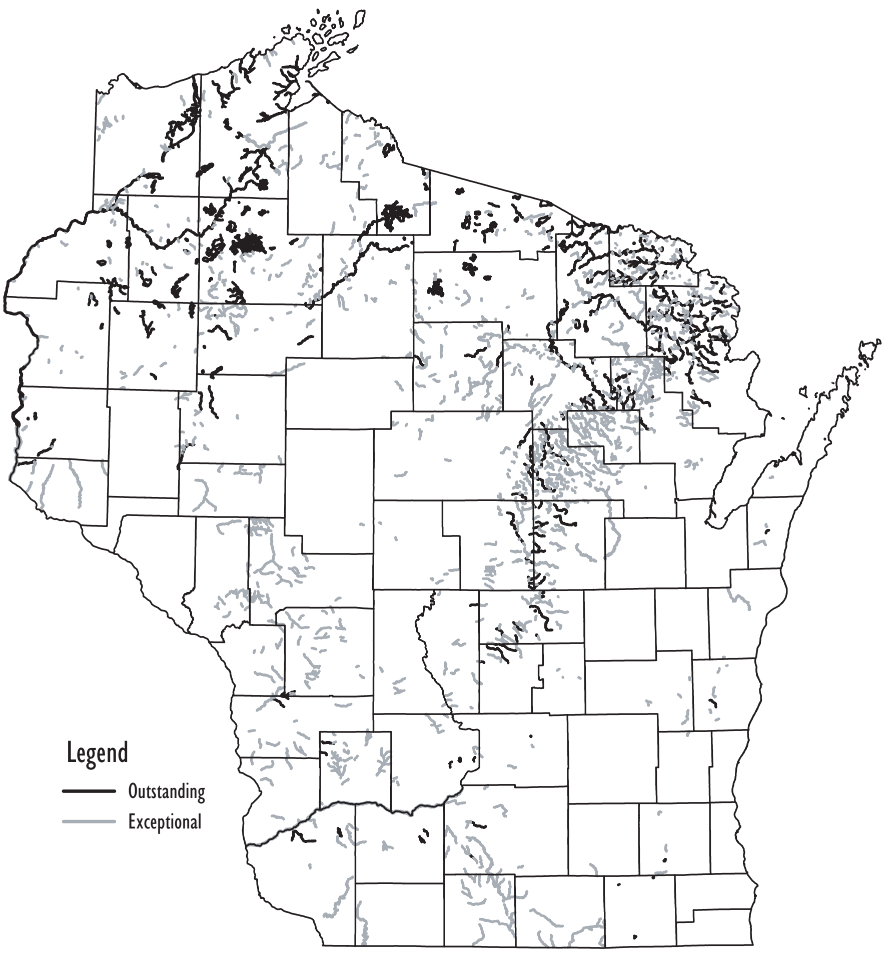


Figure 6

WDNR

IMPAIRED WATERS

Wisconsin is required every two years to submit to the U.S. Environmental Protection Agency a list of state waters that do not meet water quality standards or designated uses under the federal Clean Water Act. Impairment classifications are used to develop management strategies to remediate the impairments. The classifications are point source dominated; non–point source dominated; point and non–point source combined; contaminated sediment waters; habitat/physical impairment; atmospheric deposition; and "other." Key to making decisions on whether or not impairments exist is access to good data. With so many waters in the state, current and comprehensive data are not available to evaluate the status of all waters. Thus, the discussion here is limited to those waters where data has been collected and analyzed by resource managers in the DNR's Water Quality Assessment reports (figure 7) (WDNR 2000a).

IMPAIRED WATERS (1998)

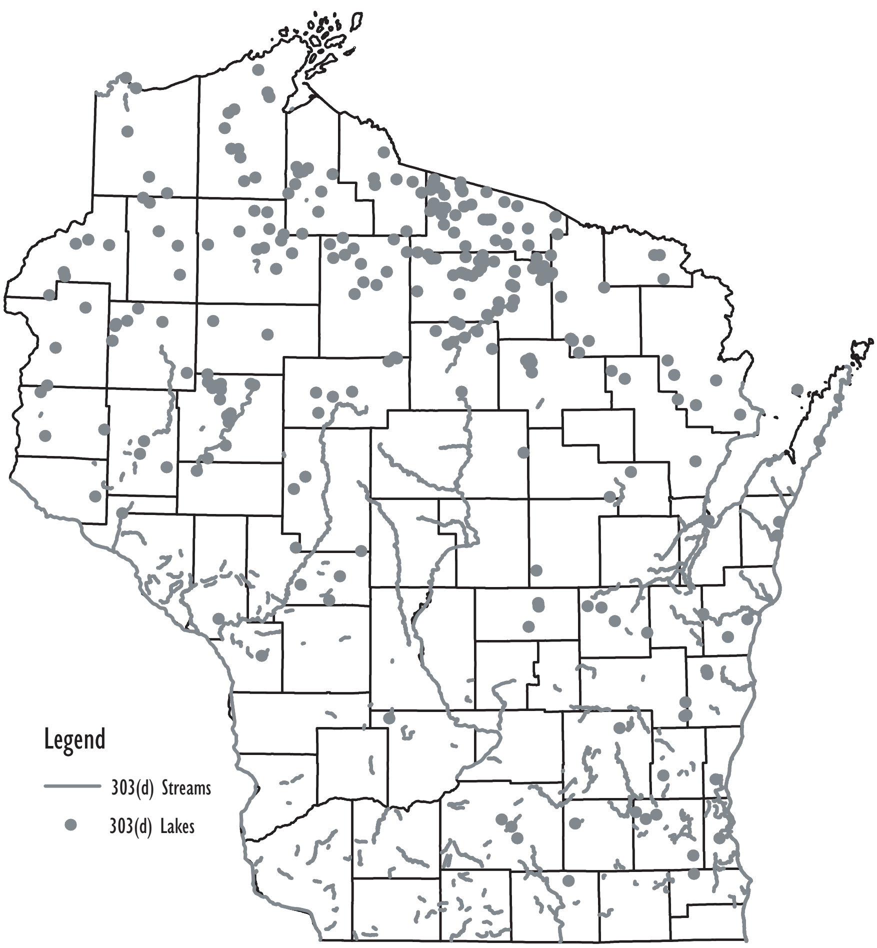


Figure 7

WDNR

Point Source Pollution

Since enactment of the 1972 Clean Water Act, water quality problems associated with point discharges have decreased dramatically. Dissolved oxygen levels in the Wisconsin, Fox, and other rivers have increased substantially, allowing for recovery of the aquatic communities in these streams. In the Lower Fox River, for example, only two fish species were recorded in surveys in 1967. By 1997, after point source pollutants had been reduced, 30 fish species were present in the river, and a tremendous walleye fishery had developed (Ledin pers. comm.). However, point source discharges remain a significant cause of pollution in Wisconsin's waters. Pollutants from old discharges are still present in bottom sediments, and some, like PCBs and mercury, bioaccumulate in food webs and thus continue to impair water quality. Statewide, more than 2,000 point source discharges currently are authorized to use Wisconsin waters for assimilation of treated wastewater. While the compliance rate of sewage treatment plants is high, the capacity of state waters to assimilate increased wastewater discharges in the future is extremely limited at many sites.

Non–Point Source Pollution

The quality of many waters in Wisconsin continues to be plagued by non–point source pollution (also known as polluted runoff). Runoff from agricultural, urban, and suburban lands carries sediment, pollutants, and nutrients into wetlands, streams, and lakes. Sediments blanket streambeds and encroach on wetlands, eliminating fish spawning habitat. Pollutants include pesticides, metals, oil and grease, and coliform bacteria. Nutrients of concern include nitrogen and phosphorus, which can cause algal blooms that produce excess organic matter, increased rates of decomposition, and reduced dissolved oxygen levels. Lower oxygen, in turn, lowers fish diversity and can cause massive fish kills. In addition, non–point source pollution impairs waters for other uses such as swimming and boating, and harms the scenic and economic values associated with our waters.

Phosphorus is of particular (and growing) concern because of its importance as a limiting nutrient in Wisconsin's surface waters. It occurs naturally in the soil and is essential to plant and animal growth. However, it can be a serious pollutant when it moves from the land to water. Phosphorus plays a significant role in agroecosystems, and phosphorus inputs from agricultural lands — in the form of fertilizers, manure, livestock feed, and runoff from concentrated livestock operations — are the major source of nutrients causing accelerating eutrophication in lakes and streams in the United States. Over the past three decades, soil test values for phosphorus from Wisconsin cropland fields have increased substantially, from an average of 29 parts per million phosphorus in 1964–67 to 52 parts per million in 1995–99 (figure 8). This is well above the 25–35 parts per million that is considered optimal for most Wisconsin crops and reflects excessive addition of fertilizer to croplands. Although the majority of phosphorus in Wisconsin's waterways comes from agricultural lands, urban contributions of phosphorus from construction site erosion, lawns, and streets can be locally significant (Sturgul and Bundy 2002).

Assessing the impacts of nonpoint source pollution is challenging. Monitoring and evaluating impacts is technically complex because they often occur in pulses from storm-related discharges, and because they involve the combined effects of multiple pollutants. In-stream

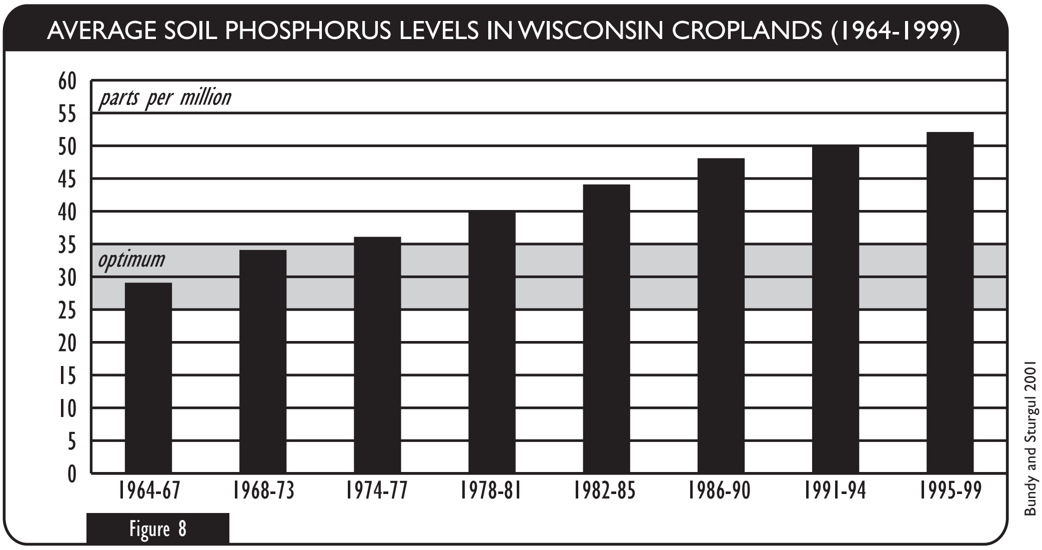


Figure 8

habitat alteration and degradation often accompany uncontrolled runoff events. Without continuous monitoring, this type of event monitoring is always incomplete. Unfortunately, continuous instrumented monitoring is rare in Wisconsin at present. Yet, these pulsed releases of non–point pollution can close beaches, accelerate eutrophication, and even kill fish by depleting oxygen. Controlling polluted runoff is likely to be more effective than attempting to respond to a monitored event.

In October 2002 Wisconsin adopted administrative rules to control non–point source pollution. These rules create minimum performance standards for agriculture and non-agriculture land use practices. The rules include best management practices and technical standards for manure storage systems, livestock fencing, riparian buffer development, construction erosion control, stormwater management, and restoration of shoreland habitat. Grants and other cost-sharing measures are available to governmental units and state agencies to implement best management practices to reduce both urban and agricultural nonpoint pollution. Federal, state, and local agencies offer costsharing and incentives to private landowners who are implementing best management practices to control excessive nutrients.

Contaminated Sediments

Contaminants from discharged water or atmospheric deposition often reside in the bottom sediments of surface waters for decades or centuries. Because contaminants have the tendency to attach to organic materials in these sediments, they often enter the food chain through the lower trophic levels — microbes and algae in stream and lake beds and open water. Once in the food web, some contaminants bioaccumulate and concentrate at magnified levels higher in the food web, all the way up to the top predators. Fish become a major vehicle for transfer, leading to contaminant buildups in turtles, fish-eating birds, mink, otters, and other species, including humans. Contaminants in sediments originate from coal-burning power plants, historic coal gasification production facilities, chemical industries such as chlorine production plants, historic recycling of carbonless paper, municipal treatment plants, agricultural runoff, and a variety of other point and nonpoint sources.

Along our Great Lakes, five areas of concern were proposed by the state of Wisconsin and designated by the International Joint Commission as needing remedial action plans to deal with sediment contamination: Green Bay/Fox River, Sheboygan Harbor/Sheboygan River, Milwaukee River estuary, Marinette Harbor, and Superior Harbor. Plans have been developed for each site and remedial measures are under way. Issues involving cleanup methods and disposal sites for contaminants are always controversial, and cleanup costs are high.

Regulations to reduce the quantity of these contaminants are in place (WDNR 2000a). For example, the U.S. Environmental Protection Agency banned polychlorinated biphenyls (PCBs) in 1977. However, PCBs break down slowly and persist in sediments. PCBs bioaccumulate in the fatty tissue of animals and can cause serious health problems in aquatic animals and in humans. Human health impacts of PCBs include liver cancer, liver damage, and immune system effects (WDHFS 2000). PCBs and mercury are the primary contaminants responsible for the issuance of fish advisories in Wisconsin.

Habitat/Physical Impairment

Physical alteration of Wisconsin's waters has resulted in significant loss of habitat or deterioration of habitat quality. Sedimentation and erosion from construction sites, filling or drainage of wetlands, stormwater management premised on flood control, and physical barriers such as dams and shoreline development have resulted in changes in wetland, stream, and lake ecosystems. Stormwater discharges can change hydrologic conditions, scouring banks and increasing downstream sedimentation in important fish habitat areas. Shoreline development can alter riparian and near-shore habitats, which are critical spawning and nursery areas for many forms of wildlife. Dams restrict fish movements related to seasonal migrations and reproduction and can cause fluctuations of water levels that limit the amount of quality habitat.

Remedial action plans, nonpoint source abatement priority watershed plans, and Federal Energy Regulatory Commission (FERC) license reviews have assessed the quality of aquatic habitat for specific sites. Results of these analyses can be generalized for the whole state, but quantification of loss or impairments is currently not possible except where types of habitats have been irretrievably altered (for example, the filling of a wetland). Programs to help reverse habitat loss include USDA's Wetland Reserve Program, Conservation Reserve Program, and Environmental Quality Incentive Program; the U.S. Army Corps of Engineers' Upper Mississippi River System Environmental Management Program; the U.S. Fish and Wildlife Service's North American Wetlands Conservation Act matching grant program; and the Wisconsin DNR's Lake and River Protection Grant Programs. Local governments implement other protection and restoration programs (for example, through purchase of development rights). Nonprofit conservation organizations have many initiatives to support the protection and restoration of private land across the state.

Atmospheric Deposition

Atmospheric transport and deposition of substances such as mercury, PCBs, pesticides, sulfur, and nitrogen cause impairments to surface waters even if there are no direct discharges of these pollutants from the land. Such contaminants from human activities around the world are injected into the lower atmosphere, transported by global weather patterns, and ultimately enter surface waters through dry fall and precipitation or related storm runoff.

• *Acid rain*

Acid rain occurs when oxides of sulfur and nitrogen enter the atmosphere; combine with water vapor to form sulfuric and nitric acid; and then return to Earth as acid rain, fog, or snow. Sulfur dioxide and nitrogen oxides are produced by combustion of fossil fuels in coal-fired power plants, factories, automobiles, and residential furnaces. As a lake or stream becomes more acidic, aquatic biodiversity declines. Acid-sensitive plants and animals fail to reproduce or are killed either directly or in some cases indirectly as new aquatic predators become common. Acidity in water bodies is associated with increased mercury levels in fish and fish-eating animals because acidity influences the methylization of mercury (see following discussion of mercury) (WDNR 1994).

The acid-neutralizing capacity of the lake's water determines the susceptibility to acid precipitation. Wisconsin DNR research indicates that about 2%of Wisconsin's lakes are now acidic; 10% are "extremely sensitive" to acid rain; 25%are moderately sensitive; and 60% are not sensitive. Acid rain has had the greatest effects in the northeast and north-central portions of Wisconsin, where lake waters have low acid-neutralizing capacity. Approximately 9% of lakes in these regions are classified as acidic (WDNR 1994). (These figures exclude naturally acidic lakes.)

Nationwide, sulfur dioxide emissions have decreased since passage of the Clean Air Act (1970) and the Clean Air Act Amendment (1990). Wisconsin passed its own legislation regulating sulfur dioxide emissions in 1986, and adjacent states passed similar laws. Consequently, some Wisconsin lakes are recovering from the effects of acid rain (figure 9, c and d). Other lakes have remained acidic, perhaps reflecting low buffering capacity within the affected watersheds (Stoddard et al. 1999). Buffering capacity is linked to changes in the rates of groundwater discharge and recharge related to drought and rainfall cycles. It is not clear how long it may take for these lakes to return to historic pH levels.

• *Mercury*

The major source of mercury to Wisconsin surface waters is atmospheric deposition. Many of Wisconsin's remote northern lakes are listed as impaired waters because of mercury contamination in their fish. The Wisconsin DNR adopted a new standard for mercury consumption in 2001, with the result that nearly all of the 1,200 lakes tested in northern Wisconsin contain fish that exceed the standard. With the lowered threshold, a statewide health advisory is in force limiting human consumption of game fish by children and by women in their childbearing years. Young children and fetuses are particularly susceptible to the risks of mercury exposure, with damage to the central nervous system a primary concern (ATSDR 1999).

Atmospheric mercury deposition occurs mainly in the form of rain. Combustion of fossil fuels and waste incineration are the major sources of atmospheric mercury. Between 10 and 40% of the mercury in Wisconsin's waters originates within the state; the remainder is carried into Wisconsin from outside sources, including sources outside the United States. After deposition on land or water, some of the mercury is converted to a highly toxic organic form, methylmercury. Methylmercury bioaccumulates in aquatic food webs and poses the major health threat to humans and wildlife, such as loons, eagles, and otters, that eat fish. Unlike PCBs, which accumulate in fatty tissue, mercury bioaccumulates in nervous system tissue. Fortunately, organisms can purge the mercury from their systems if the consumption source is removed.

Changes in atmospheric mercury deposition may be followed quite rapidly by changes in the mercury content of lake waters and fish. During the 1990s, mercury deposition gradually declined in the Trout Lake region of northern Wisconsin. In Little Rock Lake in Vilas County this decline was soon followed by declines in mercury in lake water and in fish (figure 9, a and b). This is consistent with the seasonal cycle of mercury in lake water, which follows the seasonal cycle of mercury in precipitation. Thus, lakes may respond rapidly to either improvement or deterioration in air quality (Watras et al. 2000).

Mercury levels in our waters appear to be decreasing in response to reductions in anthropogenic emissions of mercury. Because Wisconsin has many mercury-impaired waters and improvements in lakes can result quickly from reductions in air pollution, options for achieving further reductions through state and federal action continue to be proposed and debated. However, even if deposition is dramatically reduced, the persistence time of mercury in different lakes remains uncertain (Watras et al. in press).

ADDITIONAL GROUNDWATER AND SURFACE WATER CONTAMINANTS

Nitrate, pesticides, volatile organic compounds, arsenic, pathogens, and other substances in our waters are of concern to the health of people and aquatic ecosystems. Causes of contamination vary. Nitrate and pesticide contamination comes from the application of fertilizers and pesticides that then infiltrate to the groundwater and end up in wells or surface waters. Arsenic too is a groundwater contaminant, but the source is naturally occurring arsenic in the bedrock; elevated levels of arsenic are often caused by overpumping and the resulting liberation of the arsenic. Septic systems and stormwater are primary sources of pathogens that contaminate both groundwater and surface water.

Nitrate

Nitrate is the most widespread contaminant in Wisconsin's groundwater; 10 to 14% of private wells exceed 10 parts per million, the federal and state maximum (figure 10) (WDNR 1999b). Nitrogen leakage from agriculture (in the form of fertilizers, manure, and organic matter decomposition) accounts for over 90% of the nitrate in Wisconsin groundwater, with most of the remainder originating from septic systems (Shaw 1994). Thus nitrate contamination is concentrated in agricultural areas of the state, where 17 to 26% of wells typically exceed drinking water standards (LeMaster and Baldock 1997). In Calumet County, 30% of 200 wells

TRENDS IN MERCURY, METHYLMERCURY, SULFATE, AND ACIDITY LEVELS IN LITTLE ROCK LAKE

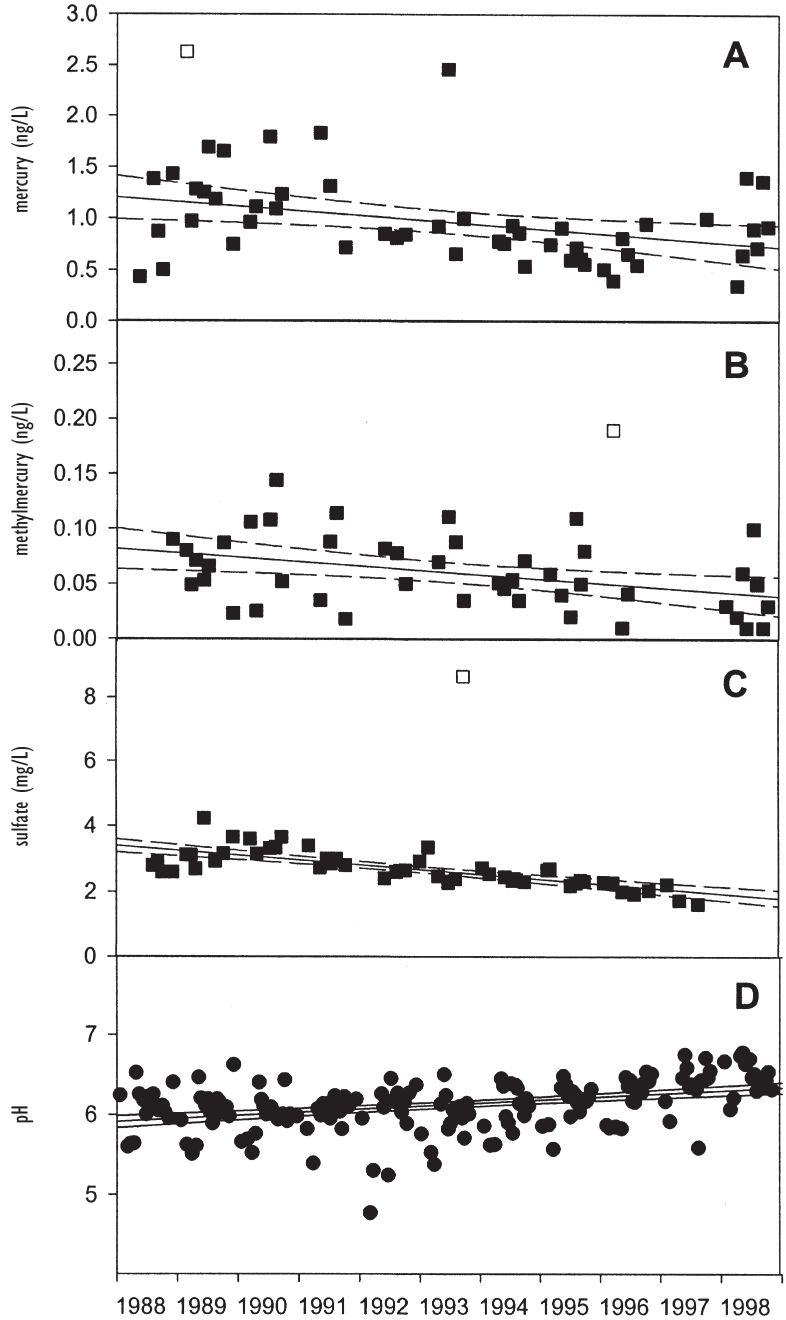


Figure 9

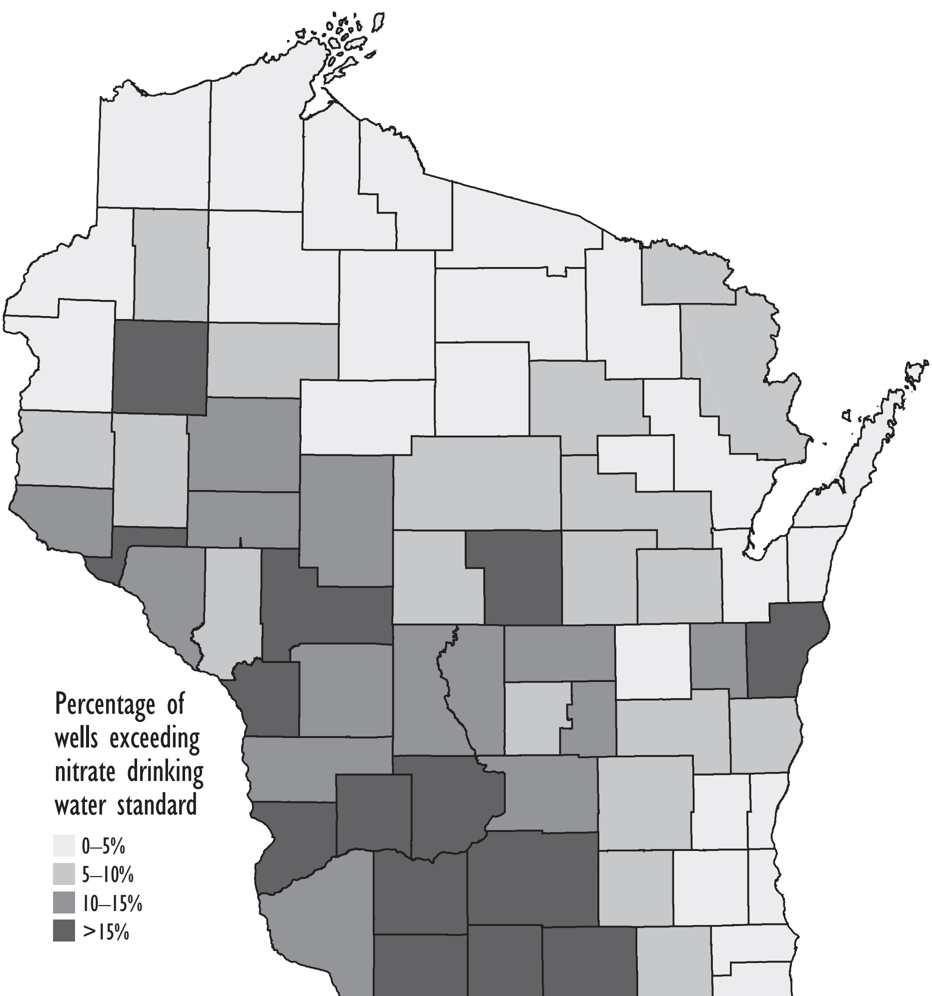
Watrus et al. 2000

tested exceed the drinking water standard; in parts of Portage County, 70% of wells exceed the standard (Johnson pers. comm.).

The primary human health-related concern from high nitrate levels in drinking water is "blue baby syndrome," or methemoglobenemia, which occurs in infants under six months of age. If nitrate-contaminated water is used to make baby formula, the nitrate is converted in the stomach to nitrite. The nitrite deprives the baby's blood of oxygen, as hemoglobin is converted to methemoglobin. While this is a serious condition, very few cases have been reported in Wisconsin. In addition, nitrate exposure is a possible risk factor in lymphoma, gastric cancer, hypertension, thyroid disorder, birth defects, and miscarriages (Weyer 2001).

Nitrate-contaminated groundwater is typically shallow and readily discharged to surface water, where it creates problems for aquatic communities. Nitrate concentrations typical of agriculturally affected groundwater are sufficient to harm eggs and young of some salmonids and amphibians (Kincheloe et al. 1979; Hecnar 1995; Marco et al. 1999; Rouse et al. 1999), promote eutrophication in nitrogen-limited freshwaters, and increase growth of rooted aquatic plants (Lillie and Barkow 1990; Rogers et al. 1995). The export of nitrate from freshwater basins to nitrogen-limited saltwater systems causes eutrophication and hypoxia. The hypoxic zone at the mouth of the Mississippi River is similar in size to the state of New Jersey (Rabalais et al. 1996; Goolsby et al. 2000).

NITRATE CONTAMINATION OF WISCONSIN WELLS



Krohelski et al. 2001 (CWGC, WGNHS, USGS data)

Figure 10

Problems with nitrate contamination can be dated to a 10-fold increase in agricultural fertilizer sales between 1960 and 1978. Since 1978, fertilizer sales have remained constant. Unless these impacts are reduced, we can expect continued increases in nitrate concentrations and in the spatial extent of nitrate contamination of groundwater (WDNR 1999b).

Pesticides

Sources of pesticide contamination to groundwater include field application, spills, or improper storage and disposal. Studies of Wisconsin groundwater contamination from pesticides began in 1983. The most common pesticides in Wisconsin groundwater are metabolites of alachor and metolachor, atrazine and its metabolites (figure 11), metribuzin, and a breakdown product of cyanazine (WGCC 2002). The Wisconsin Department of Agriculture, Trade, and Consumer Protection (WDATCP) estimates that 38% of Wisconsin wells contain at least one pesticide or pesticide metabolite, with alachlor metabolites and metolachlor metabolites being the most common. A significant decrease in atrazine concentrations occurred between 1994 and 2001, although concentrations of atrazine metabolites did not decrease (WDATCP 2002).

Many pesticides have been identified as cancer-causing agents and endocrine disruptors in humans and other animals. The effects of pesticides at typical concentrations on aquatic ecosystems are not well known. Only a few of the possible substance-organism combinations have been investigated (Hall et al. 1995; Howe et al. 1998).

Volatile Organic Compounds

Volatile organic compounds (VOCs) are chemicals that evaporate when exposed to air. Frequently used to dissolve other materials, these compounds are used in solvents, medicines, cosmetics, fuel, polishers, and paint thinners. Sources of VOCs to groundwater include landfill, underground storage tanks, and hazardous substance spills. When VOCs are spilled, some evaporate and some soak into the ground, where they can reach the water table and be transported through groundwater flow. Fifty-nine kinds of VOCs have been found in Wisconsin's groundwater. Trichloroethylene is the most common. All 2,230 of Wisconsin's community wells have been tested for VOCs since 1982. Of these, 5% had detectable levels and 1% exceeded the state health advisory level (WDNR 2000c). Unlined landfills release considerably higher concentrations of VOCs than lined landfills. Currently more than 600 households have drinking water contaminated by VOCs leaking from underground storage tanks (WGCC 2001).

Arsenic

In the last 10 years, arsenic has emerged as a significant contaminant in shallow groundwater in some portions of Wisconsin (figure 12). Arsenic occurs naturally in many minerals and has been detected in groundwater in every county in Wisconsin. According to a statewide survey performed by the DNR in 2002, concentrations above the federal drinking water standard of 10 parts per billion occur in much of eastern Wisconsin. Levels above this standard are not uncommon, especially in sand and gravel aquifers along glacial ice margins. In particular, Outagamie and Winnebago counties have been severely affected by arsenic in drinking water;

ATRAZINE DETECTIONS IN DOMESTIC WELLS (1997)

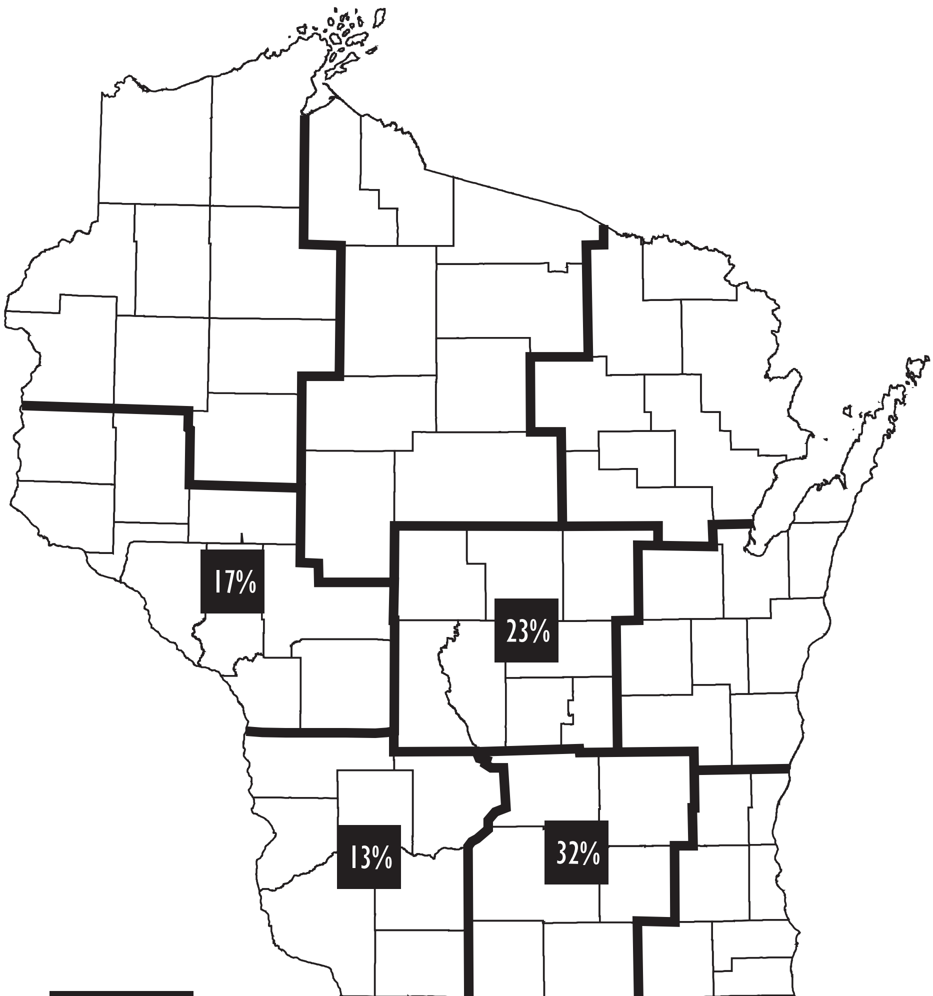


Figure 11

LeMaster and Baldock 1997

20% of several thousand private wells sampled in these counties exceeded the drinking water standard (WGCC 2001).

Increased groundwater use and the subsequent drop in the water table to the level where the sulfide minerals occur may explain the increase in affected wells. As the water table drops, oxygen comes into contact with the sulfide minerals, releasing arsenic to the water. This is thought to account for the high incidence of arsenic contamination in the Fox River Valley. In the Lake Geneva area arsenic concentrations are lower than in the Fox River Valley and are present in both the sand and gravel aquifer and the Silurian dolomite aquifer (Gotkowitz pers. comm.). Human health effects from long-term exposure to arsenic-contaminated water include increased risk of skin, bladder, lung, and other types of cancer (ATSDR 2000). Other naturally occurring metals such as cadmium, chromium, cobalt, nickel, zinc, radium, and lead have also been detected at levels above state groundwater quality standards.

PUBLIC WELLS WITH ARSENIC DETECTIONS >10 PARTS PER BILLION

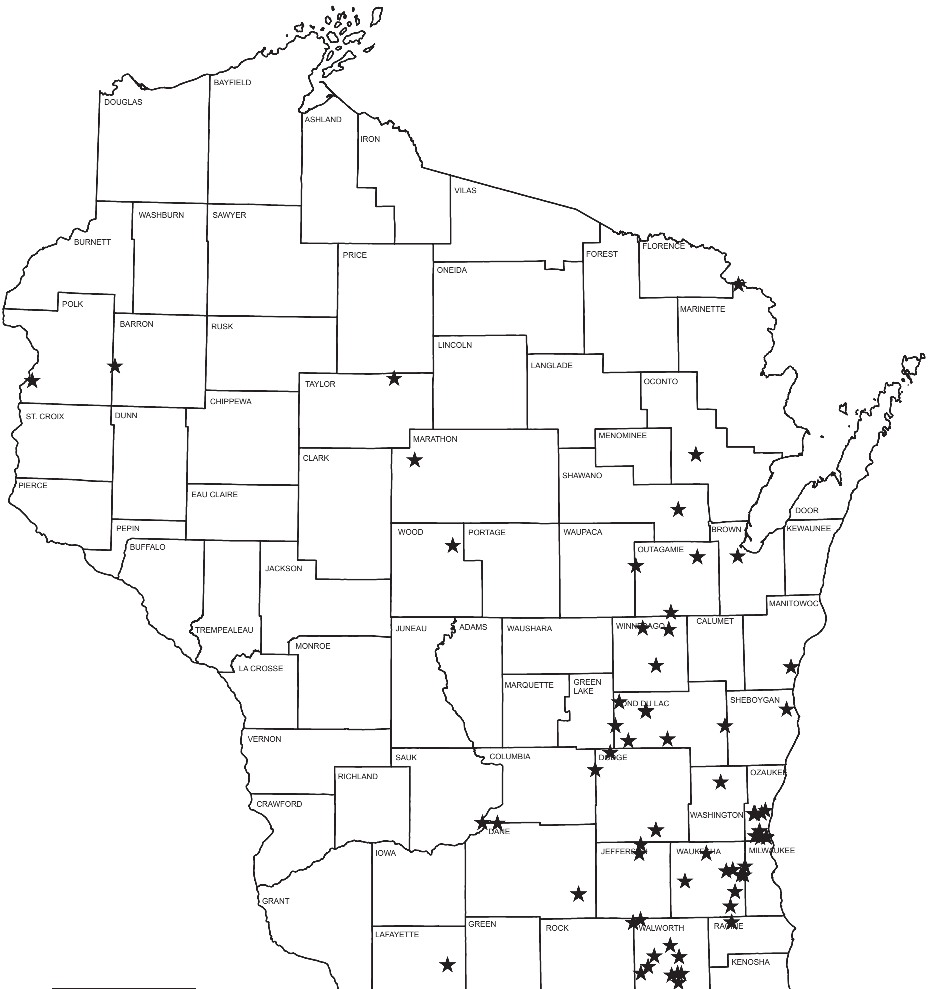


Figure 12

Naturally Occurring Radioactivity

Naturally occurring radioactivity occurs in Wisconsin's groundwater. Radionuclides found include gross alpha, radium, radon, and uranium. Areas of particular concern include eastern Wisconsin (with high levels of radium), northeastern and southeastern Wisconsin (with gross alpha problems), and north-central Wisconsin (with radionuclides). Almost 70 public water systems in Wisconsin exceed or are close to the gross alpha drinking water standard of 15 picocuries per liter. The U.S. EPA is expected to set a new standard for radon in drinking water, and a DNR study is under way to determine the impact of this proposed standard. Preliminary results from the DNR and the State Lab of Hygiene suggest that total uranium is the major source of high gross alpha.

Ingestion of radium is linked to bone cancer, while uranium has been linked to kidney cancer (Hahn 1984; USEPA 2000). Radon in drinking water can become airborne from normal household activities; inhalation of airborne radon is the second leading cause of lung cancer (Milvy and Cothern 1990).

Pathogens

Known waterborne pathogens include parasites (such as *Cryptosporidium parvum*), bacteria (such as *E. coli*), viruses, and other microorganisms (Kleinheinz et al. in press). Gastrointestinal viruses are likely the most common pathogens in groundwater. Pathogens cause illness when ingested with drinking water or while swimming or otherwise coming into contact with water. Based on current literature, a best guess is that between 10 and 20% of non-outbreak gastrointestinal illnesses in Wisconsin are attributable to contaminated groundwater (Borchardt pers. comm.). An epidemiological study in central Wisconsin found that approximately 5% of the incidences of infectious diarrhea among children who drink from household wells is attributable to wells contaminated with fecal enterococci bacteria (Borchardt et al. in press). Another study found that 8% of 50 monitored household wells were contaminated with human gastrointestinal viruses (Borchardt et al. 2003).

The largest incident of microbial-caused illness in Wisconsin occurred in 1993, when a cryptosporidium outbreak in Milwaukee's water supply resulted in a reported 403,000 cases of human illness and 50 deaths (MacKenzie et al. 1994; Fox and Lytle 1996). Concern over microbial contamination at beaches has also increased in recent years. With increased sampling in Lake Michigan and on inland lakes, beach closings have become more frequent. In Madison, beaches were closed three to nine times per year between 1996 and 2001 because of algal blooms and high bacteria counts. Detection of illness-causing microbes is uneven, as testing is not funded in many communities.

Emerging Contaminants

Concerns have recently emerged involving the inadvertent contamination of water resources by commonly used chemical compounds, including antibiotics, other pharmaceuticals, hormones, and industrial and household chemicals (WDNR 1999a). The potential toxicological effects of these widely used substances (sometimes referred to as "microcontaminants") have led to increased apprehension over their environmental and human health impacts. There is scant toxicological information on the long-term effects of exposure to small doses of these compounds. In addition, it is possible that the mixture of chemicals in our water may have synergistic or antagonistic effects (Buxton and Kolpin 2002). Research on such cumulative or synergistic effects is also very limited.

Water Quantity

The total *quantity* of water falling on Wisconsin through precipitation, circulating through our surface waters, and residing in our aquifers has likely changed relatively little over the last 150 years. However, human activities have significantly altered the movement and distribution of water. Groundwater withdrawn for human use is discharged into surface waters. Surface water drainage patterns have been transformed through dam and dyke construction and the channelization of streams; through land use practices such as road construction and wetland drainage; and through construction of water treatment facilities and stormwater systems. Urban development has spread impervious surfaces over the landscape. Thus, while the total amount of water in Wisconsin may have changed little, the ways in which it is used and moves through the landscape has changed continually.

Since 1950, the amount of water used by Wisconsinites has tripled, while our population has increased at only half that rate (figure 13, a and b). Each day we use hundreds of millions of gallons of water in Wisconsin — in the home and the workplace, and for agriculture, industrial processing, and electric power generation (figure 14). Power generation is the most water intensive activity in Wisconsin, yet this mainly involves once-through cooling in which only 1% of the water is not returned to the source. Water use in power generation has increased 83% between 1950 and 2000.

Industrial water use is the next largest category, with estimates that 15% of industrial use is consumptive (not returned to the water source). Three-fourths of the water used by industry is self-supplied (that is, not supplied by municipal water sources), a significant increase over the last 50 years. One in three Wisconsin residents draw their water directly from wells or surface waters; the other two-thirds rely upon municipal water supplies. Water use for irrigation

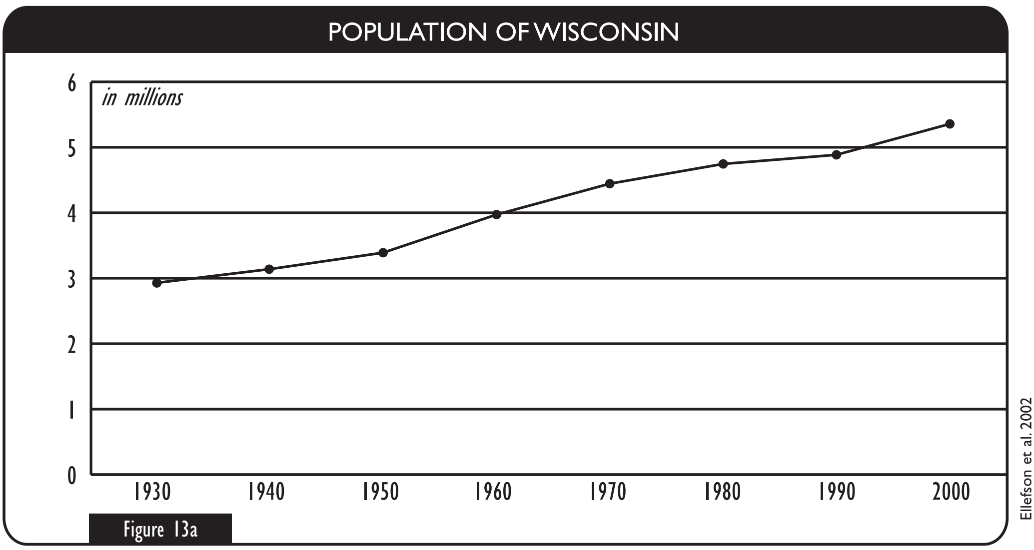


Figure 13a

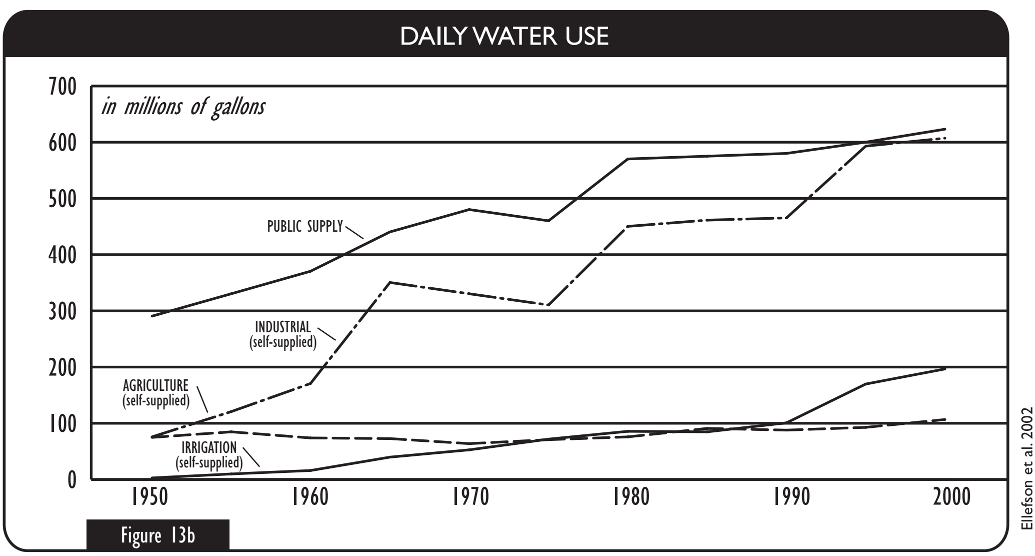


Figure 13b

has more than doubled since 1980. Ninety percent of the water used in irrigation is consumptive use; 99% of this irrigation water originates as groundwater. Nonirrigation agricultural use (for example, in livestock watering and fish hatcheries), commercial use, and public use together account for about 6% of water use in Wisconsin (Ellefson et al. 2002).

In general, Wisconsin's water supply remains plentiful. However, the available information reveals a more complicated picture. Data from a 132-well network across Wisconsin indicate that groundwater levels in some areas of the state are rising, but they are falling dramatically in heavily developed areas (figure 15). Declining groundwater levels are most acute in the Lower Fox River Valley and southeast Wisconsin. In these areas, pumping of groundwater from the sandstone aquifer has resulted in maximum drawdown levels of 350 and 450 feet respectively. The rapid rate of decline (3–6 feet per year) reflects the combined impact of closely spaced wells and a slow rate of recharge to the deep sandstone aquifer (WDNR 1997a; Zaporozec 2000). Excessive groundwater withdrawal is of concern elsewhere in Wisconsin. In Dane County, the declining water table is reducing the flow of groundwater to streams, springs, and wetlands (Krohelski et al. 2000). In the Central Sand Plains, surface waters are susceptible to reduced baseflow as irrigated agriculture has increased (WDNR 1997a).

These trends raise important questions about the long-term water supply in many parts of Wisconsin. Even though groundwater remains abundant in most of the state, concern is growing about the availability of groundwater to meet growing human demands while providing sufficient baseflow to lakes, streams, and wetlands. Other concerns connected to declines in water levels include the possibility of severe reductions in well yields, the expense of pumping water longer distances, and pumping-induced water quality problems (especially high concentrations of naturally occurring arsenic, total dissolved solids, and radium). Providing adequate water supplies in some areas may become increasingly costly. Existing water supplies in regions experiencing declines need to be conserved. Alternate water supplies need to be

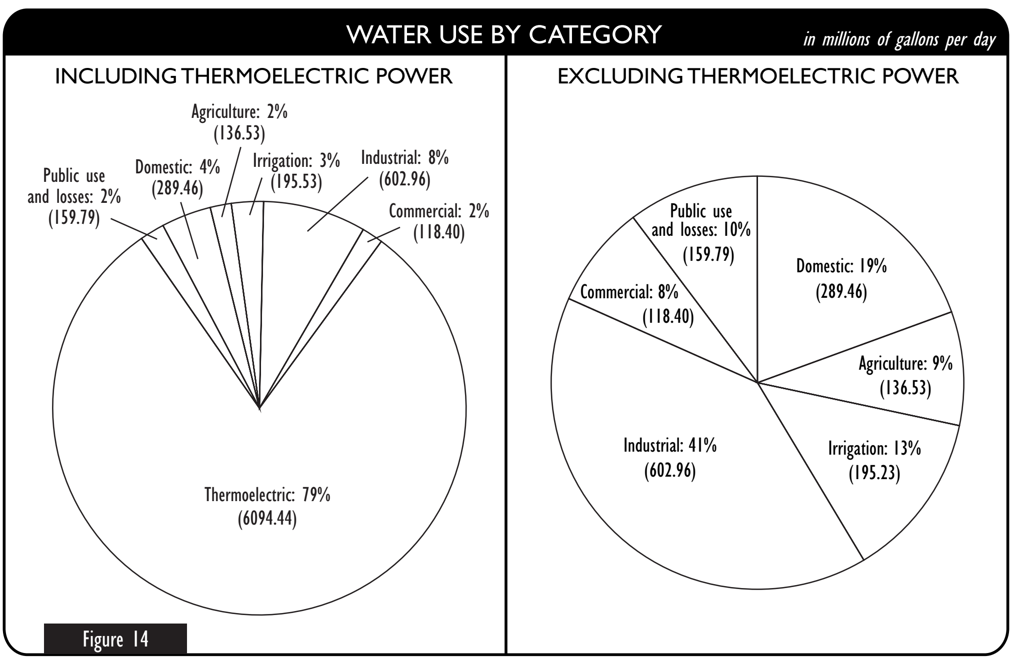


Figure 14

Ellefson et al. 2002

SIMULATED DRAWDOWN IN THE SANDSTONE AQUIFER (1998-2000)

USGS, WGNHS data

Figure 15

identified. Meanwhile, areas not currently affected by depleted aquifers should read these warning signs and take steps to ensure that their water resources are managed sustainably.

Water quantity also affects transportation, recreation, and water supplies dependent on the Great Lakes and the Mississippi River. Low water levels can affect the capacity to ship cargo; the use of ports, harbors, piers, and other water structures; and the operation of water intake structures. Conversely, high water levels can disrupt human activities and structures through flooding and contribute to shoreline erosion. The expected impact of climate change on surface water levels is discussed elsewhere in this chapter.

Protection of the Great Lakes waters has gained attention in Wisconsin and throughout the region as population growth, urban development, and chronic water shortages have continued elsewhere in the United States. Since 1999, the Great Lakes governors and Canadian provincial premiers have worked to bolster the legal basis for governance of the Great Lakes. The Annex

2001 process will have far-reaching consequences for the protection and management of these globally significant waters (see sidebar).

Other Water Uses

WASTEWATER TREATMENT AND ASSIMILATION

Treated municipal sewage is discharged into our waterways. As communities grow, the wastewater generated increases, potentially increasing the amount of wastewater we expect our waterways to assimilate. The assimilative capacity of our waters is neither uniform nor

GOVERNING THE GREAT LAKES WATERS: THE ANNEX 2001 PROCESS

What would Wisconsin do if California wished to import 500 million gallons of water per day from Lake Michigan? Or China? Or Atlanta? Or Phoenix? Or … Waukesha? All those places are confronting serious water shortages and might conceivably look to the Great Lakes to solve their water woes. But all rest beyond the borders of the surprisingly compact Great Lakes basin (even Waukesha lies just outside the basin's edge). Under existing law they would need the approval of all eight Great Lakes governors to divert water from the Great Lakes.

In 1985 the governor of Wisconsin, along with the seven other Great Lakes governors and the provincial premiers of Ontario and Quebec, adopted what is known as the Great Lakes Charter. The charter provided for cooperative governance of the Great Lakes. Among other things, it established a consultative process through which the governors and premiers could address proposals for large diversions and withdrawals of Great Lakes waters. The charter also established that such proposals would be considered on the basis of their impact on Great Lakes waters. In 1986, Congress passed the Water Resources Development Act (WRDA), expanding the charter's provisions under federal law: No water diversions could occur without the approval of all eight Great Lakes governors. If one governor were to reject a diversion proposal, it would be rendered void. Since then, three Midwestern communities have sought permission to divert Great Lakes water. Two (Akron, Ohio, and Pleasant Prairie, Wisconsin) proceeded after consulting with all of the governors. One (Lowell, Indiana) was formally turned down.

Despite the adoption of the Great Lakes Charter and WRDA, concern remained that more needed to be done. This apprehension swelled in 1998 when a private enterprise known as the Nova Group in Sault Sainte Marie, Ontario, secured a permit to ship tankers filled with Lake Superior drinking water to Asia. When news of these plans became public, protests erupted throughout the Great Lakes and the permit was withdrawn. However, Great Lakes officials became increasingly concerned that the charter and WRDA might be vulnerable to a legal challenge, whether from a business such as the Nova Group, a municipality, or a trade organization.

In 1999, the Great Lakes governors and Canadian premiers began work on the Great Lakes Charter Annex 2001 (or simply "the Annex"). The Annex was signed in the summer of 2001 at a unlimited. Many communities have already reached the assimilative capacity of the receiving waterways (figure 16). These communities will either need to cap the amount of water they are discharging or treat their wastewater to a higher standard. This could be a critical problem, especially for communities that have not planned properly.

RECREATIONAL USE

Recreation along, on, and in our waters is important to the character and quality of life in Wisconsin and supports a vital tourism industry. Recreation is clearly valuable to the state's economy and way of life but can have harmful impacts on aquatic ecosystems and the goods and services they provide. Fishing, swimming and scuba diving, bird-watching and waterfowl hunting, canoeing and kayaking, motorboating, jet-skiing and snowmobiling, sailing and ice boating, and second home development all have their own range of intensity and types of impact.

meeting in Niagara Falls. It did not impose an outright ban on diversions of Great Lakes water but rather called for a new binding agreement to be developed by the end of 2004 on both sides of the international border. It recommended a new approval standard for diversions and withdrawals, barring any that would have a detrimental impact on the Great Lakes' environment.

Annex 2001 goes still further by instituting an "improvement requirement" for proposed diversions and withdrawals. How can improvements occur? Suppose, for example, that Waukesha would request that 50 million gallons of Lake Michigan water per day be diverted to compensate for its declining groundwater reserves. To receive permission, Waukesha might be required to spend millions of dollars to restore 5,000 acres of Great Lakes wetlands (the intent being to make up for the diversion through improvement in wetland acreage and function). A proposal from, for example, Atlanta might entail a much higher improvement standard.

The new recommended approval standard has been suggested in response to the legal concerns about the current system. Under the existing rules of Great Lakes governance, governors and provincial premiers can "just say no." However, their decisions may be vulnerable to legal appeals and could conceivably be reversed in court. Under the proposed agreement, the governors and premiers can allow a diversion, but only if it meets the new approval standard, which would be applied equally to all proposals. This is thought to be less vulnerable to litigation.

Since Annex 2001 was signed, Great Lakes officials have been working to complete the new binding agreement. There was substantial momentum — both within government and beyond — toward reaching final agreement before the November 2002 elections in the United States. The elections brought five new Great Lakes governors into office. As of April 2003, the proposed new binding agreement and approval standard have not been adopted. With the new governors settling into office, the Annex 2001 process is set to resume — although the results remain uncertain. When the governors and premiers finalize the new agreement, the State of Wisconsin will be required to pass new statute language. Because the agreement will change the way proposals to withdraw and divert Great Lakes waters are handled and will establish new decision-making standards, it could have fundamental impacts on Wisconsin water law.

COMMUNITIES AT CAPACITY FOR WASTEWATER ASSIMILATION

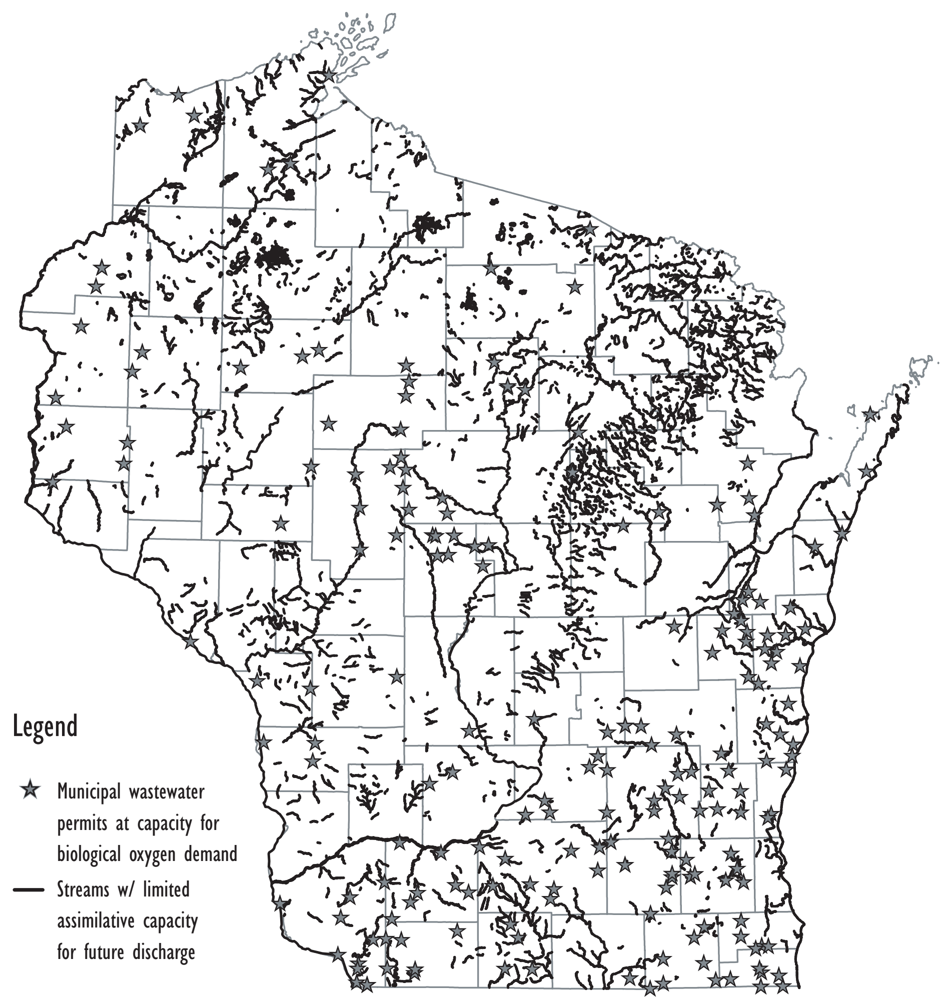


Figure 16

WDNR

Recreational use of Wisconsin's waters is increasing and changing. Between 1960 and 2000, the number of registered motorboats in Wisconsin went up by 300%, from 190,000 to 576,000, while the state's population increased only 35% (figure 17). The size of motors on boats has doubled between 1970 and 2001, to an average 80 horsepower. Personal watercraft (jet ski) use has increased dramatically; by 1998 they represented 5% of all registered watercraft. The rapid growth in use of large motorboats and personal watercraft has increased conflicts with shoreline residents and nonmotorized recreationists, and raised concerns about the transport of exotic species and impacts on water quality, aquatic plants and animals, and shoreline erosion. Management responses to these problems exist — for example, creation of no-wake zones and posting to prevent the spread of exotic species — but overall impacts and conflicts have not been addressed systematically (Asplund 2000).

While the number of fishing licenses sold annually in Wisconsin has remained near 1.4 million for the last five years (WDNR 2002c), the pattern of fishing activities has changed. The traditional summer vacation has been replaced by second home development and increased time on the water. Bigger boats and advanced technology have changed the way anglers fish. The emergence of large reward-driven fishing tournaments has converted some of these angler activities from leisurely recreational or aesthetic pursuits to highly competitive sports where winning awards is the objective.

SHORELINE DEVELOPMENT

Lakeshore development has been increasing rapidly, especially in northern Wisconsin (WDNR 1996). In a 1999 study of 235 lakes in northern Wisconsin, the percentage of lakes with developed shorelines increased from less than 5% in 1900 to more than 40% in 1995 (figure 18). Undeveloped lakeshore along Wisconsin's 15,000 lakes is not unlimited. Projections indicate that shorelines in public ownership may eventually provide the only remaining undeveloped lakeshores in the state (Korth and Cunningham 1999).

Shoreline development affects both lakes and rivers. Lake water quality can be degraded as development provides new sources of nutrients, especially lawn fertilizers and septic systems. Development can result in drastic alteration of shoreline vegetation, increased erosion, and loss of wildlife habitat. Such changes have been shown, for example, to result in significantly lower frog populations (Woodford and Meyer 2003). Development often entails removal of coarse woody debris from shorelines and near-shore waters, reducing the habitat available to fish and their prey. The effects can be dramatic. Growth rates of bluegills, for example, are up to three times faster in lakes that have more woody habitat than in lakes where woody habitat is reduced (Schindler et al. 2000).

MOTORBOAT REGISTRATIONS IN WISCONSIN

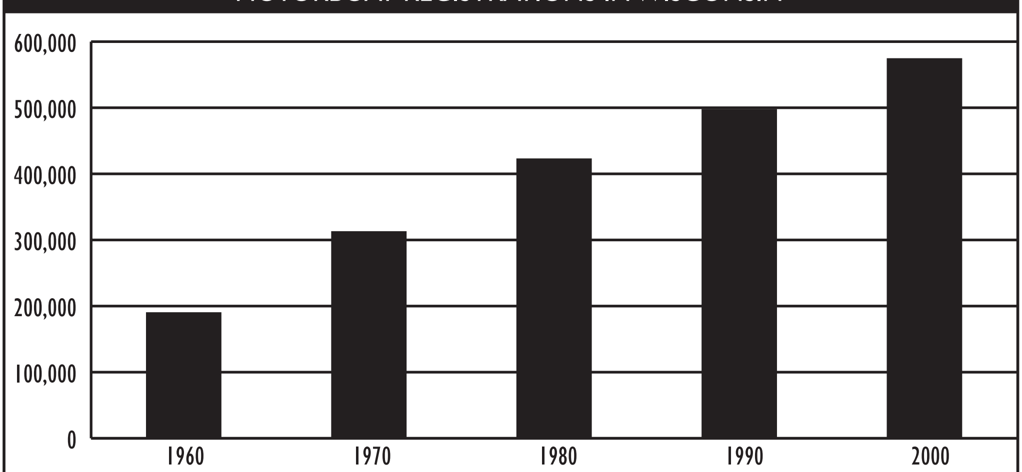


Figure 17

WDNR

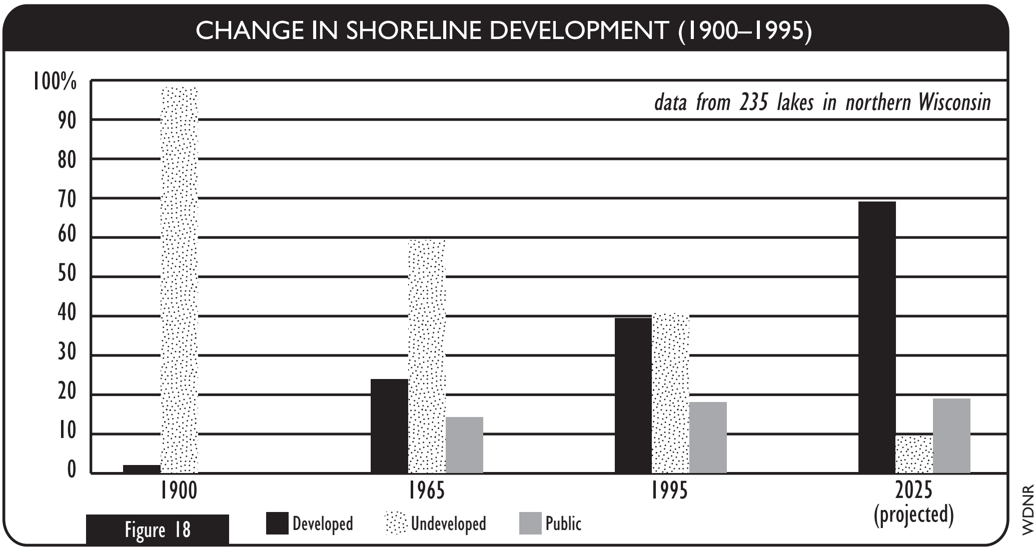


Figure 18

Hydrologic Alteration

Over the last 150 years Wisconsin's hydrologic cycle has been altered extensively. These alterations include

- damming of rivers and smaller streams for timber driving, hydroelectric power generation, flood and erosion control, creation of recreational lakes, and (on the Mississippi River) transportation;
- dredging, straightening, and leveeing of rivers for navigation and flood control;
- management of lake levels through construction of locks and dams;
- filling and draining of wetlands for farming and building construction;
- conversion and development of Wisconsin's native upland prairie, savannah, and forest communities;
- paving of land and construction of human infrastructure, much of which consists of impermeable surfaces, decreasing natural infiltration to groundwater and increasing discharge to waterways;
- construction of sewer and water treatment systems, which also decreases natural infiltration to groundwater and increases discharge to waterways; and
- installation of deep and shallow wells to tap groundwater for commercial, residential, agricultural, and industrial uses.

Hydrologic alterations provide an array of human benefits, from employment and transportation to power generation and recreational opportunities. They can also impose costs through economic loss, loss of ecosystem products and services, and impaired functioning of aquatic ecosystems. Specifically, hydrologic alterations have resulted in

- loss of the water filtration capacity;
- loss of natural flood protection through reduced water storage capacity;
- increased incidence of flooding in urban areas;
- loss of infiltration and thus replenishment of groundwater supplies;
- loss of groundwater discharge to streams in urban areas;
- changes in water temperature;
- disruption of river and stream habitats through altered flow patterns, which shorten flood periods, yet increase flood intensities;
- longer duration of low flow periods;
- loss of the ecosystem connectivity between rivers and their floodplains, with the consequent loss of ecosystem services (such as denitrification) and functions (such as fish migration); and
- decline or loss of some forms of aquatic biodiversity.

Few of these hydrologic alterations are sufficiently understood or inventoried. The U.S. Geological Survey has identified how changes in land cover have significantly modified stream morphology and the flood plain of the Fish Creek drainage system in Bayfield County. The structural changes decreased available habitats and had detrimental impacts on the aquatic ecosystem (Fitzpatrick et al. 1999). By contrast, studies of the Coon Creek watershed near La Crosse have documented impressive changes in what was once a badly degraded stream. Conservation practices adopted and maintained by landowners since the 1930s allowed Coon Creek to recover, and to become a blue-ribbon trout stream (Potter 1991; Anderson 2002). More recently, restoration projects and alternative water management approaches have sought to regain some of the ecosystem services lost as a result of hydrologic alterations.

STORMWATER

Management of stormwater is an issue of increasing concern, especially in urban areas of southeastern Wisconsin. Precipitation that would have infiltrated to the groundwater now runs off because impervious surfaces, such as streets, parking lots, and roofs, have changed natural flow regimes. The water now flows either directly into surface waters or into detention basins that typically discharge into lakes or streams.

The increase in stormwater runoff adversely affects lakes and streams. Increased peak flows contribute to increased potential for flooding. The loss of infiltration reduces base flow to streams; base flow is especially critical in maintaining stream flows during dry seasons with low flow. Erosion increases as water runs off faster and in greater volume. Increased runoff also mobilizes non–point source pollutants, reducing water quality and degrading aquatic and riparian habitats.

Suburban development and the expansion of highway infrastructure have increased the extent of impervious surfaces statewide. Fish communities and base flow are severely impacted when the amount of land in connected impervious surface within a watershed reaches a threshold of between 8 and 12% of the total watershed (Wang et al. 2001).

WETLAND DRAINAGE

The importance of wetlands for wildlife habitat, flood prevention, and water filtration has been increasingly appreciated over the years. After losing almost 50% of the state's wetlands to hydrologic alteration, Wisconsinites became early leaders in wetland restoration. Efforts to restore wetlands date at least to the late 1920s, when conservationists and sportsmen worked to restore Horicon Marsh. Reflooding of drained wetlands in Wisconsin's Central Sand Plains began during the dry mid-1930s. Passage of the 1972 Clean Water Act afforded additional protection to some wetlands.

Wisconsin is still losing wetlands. A DNR review of permitting data compiled by the U.S. Army Corps of Engineers showed that losses averaged 1,440 acres per year between 1982 and 1991. This rate dropped to 312 acres per year between 1991 and 1998 (WDNR 1998). The decrease in permits to fill wetlands is attributed to 1991 legislation that adopted state water quality standards for wetlands (NR103) and gave the DNR authority to apply the standards to regulatory decisions. These estimates are for permits only and do not reflect losses from illegal filling and drainage of wetlands.

Since the 1970s, a number of new wetland restoration programs have been developed. These include state and federal programs administered by the U.S. Department of Agriculture, the U.S. Fish and Wildlife Service, and the Wisconsin DNR. Private organizations such as Ducks Unlimited, the Wisconsin Waterfowl Association, and the Wisconsin Wetlands Association also administer wetland restoration programs (Thompson and Luthin 2000). The Wisconsin Steering Committee of the Upper Mississippi and Great Lakes Region Joint Venture estimates that these groups, working in partnership, have restored an estimated 70,000 acres of wetlands since 1991 (Lippincott pers. comm.).

DAMS

More than 3,500 dams are in place across Wisconsin's streams and rivers (figure 19) (WDNR 2000a). About 400 are producing hydroelectric power or are involved in flood control or commercial navigation. Many of the small dams were built to facilitate logging drives, to support milldams and cranberry operations, and to create flowages. Often these dams no longer serve their original purposes. Impacts of dams on Wisconsin's rivers include alteration of natural flow regimes, changes in sediment and nutrient passage, modification of stream habitat, and disruption of fish migratory patterns (Stanley and Doyle 2002).

Conflicts often occur when the dams are considered for deconstruction. The dams have been around a long time, and some property owners and communities consider the impoundments to be a valuable attribute. Other users would prefer a free-flowing river. Often, repair and maintenance of dams is cost prohibitive and dam removal is a cheaper alternative. Dam removal can result in substantial environmental and economic gains, including increased fish migration, restoration of riparian habitat, and new recreational opportunities.

DAM LOCATIONS IN WISCONSIN

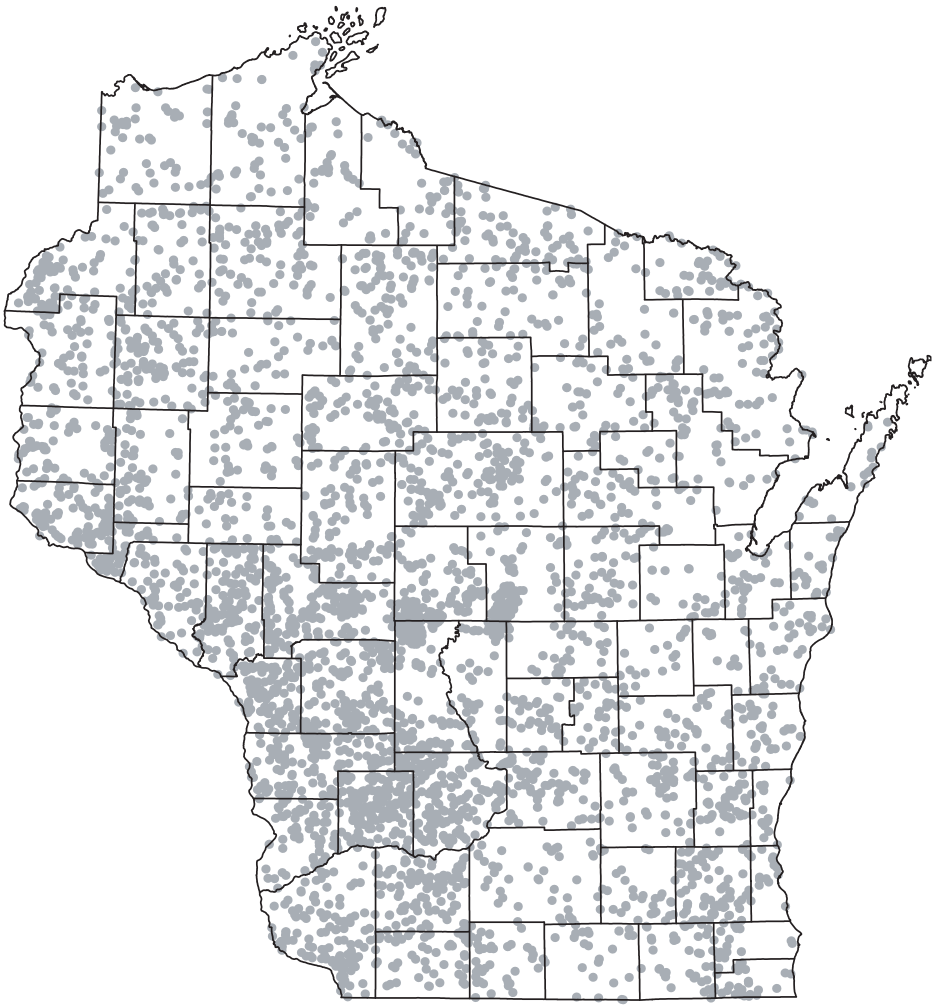


Figure 19

WDNR

Removal, however, is not without potential costs, such as the release of sediments and the facilitation of invasive species dispersal (Stanley and Doyle 2002).

Wisconsin has become one of the nation's leaders in dam removal, with more than 50 dams having been removed since 1967 (Born et al. 1998). Since 1997, four dams have been removed from the Baraboo River, making its 115 miles the longest stretch of restored flowing water in the United States. Interest in dam removal has increased in recent years and is likely to continue growing as obsolete dams continue to age.

Aquatic Ecosystems and Biodiversity

Trends affecting Wisconsin's aquatic ecosystems are discussed throughout this chapter. Changes in climate, water quality and quantity, hydrologic processes, and various human uses have affected the functioning of aquatic ecosystems and the biological diversity they support. Eutrophication, for example, is the response of aquatic ecosystems to the increased levels of nutrient input. Some lakes are naturally more eutrophic, but human activities artificially raise the nutrient levels, changing the food webs within the water body. Similarly, species naturally disperse, colonize, and go extinct, but the natural "background rates" of biodiversity change have been greatly accelerated as a result of human activity.

It is easiest to understand trends in biodiversity at the species level. Two processes directly affect the species diversity of Wisconsin's waters: extinction (the global loss of a species) or extirpation (loss of a species from Wisconsin, although it may still be found beyond the state); and species introductions and invasions, especially the invasion of harmful exotic species (species not previously present in a lake, stream, or wetland).

The potential loss of a species native to Wisconsin is a serious enough matter that special status has been provided for threatened and endangered species. The concern about species loss is real enough; we do not need to travel to tropical forests or coral reefs to chronicle extinctions and extirpations. Of Wisconsin's 147 native fishes, six have been extirpated: the deepwater cisco, blackfin cisco, and shortnose cisco from the Great Lakes, and the ghost shiner, iron color shiner, and creek chubsucker from our inland lakes and streams (Lyons et al. 2000). Many other species have been lost from individual lakes and streams. The problem has not faded away. Lake and wetland species that the State of Wisconsin lists as endangered or threatened include 21 fishes, 7 amphibians and reptiles, 18 birds, and 36 invertebrates (of which 19 are mussels) (WDNR 1997b; WDNR 1999c). About 130 species of aquatic/wetland vascular plants are listed as endangered, threatened, or of special concern on the Wisconsin Natural Heritage Working List (Anderson pers. comm.). At least one plant species, the knotted spike-rush, is considered extirpated (Wetter et al. 2001).

The factors that contributed to earlier extirpations and that continue to threaten aquatic biodiversity include many of the water problems discussed elsewhere in this chapter:

- *Habitat loss and degradation.* Dams, channelization, shoreline development, wetland drainage and conversion, as well as changes in uplands and watersheds generally, have been major factors in altering aquatic ecosystems and biodiversity (WDNR 1995; Prince 1997).
- *Pollution.* Increased development pressures affect nearby surface waters through the addition of both point and nonpoint pollutants; atmospheric pollutants that end up in Wisconsin's waters further impact the welfare of aquatic systems.
- *Overfishing.* Historically, overfishing contributed to significant changes in aquatic ecosystems and their fish fauna, especially in Lakes Michigan and Superior (Bogue 2000).
- *Overharvesting.* Other aquatic organisms were heavily exploited historically, including furbearing mammals, waterfowl, and freshwater clams (Bogue 1990).
- *Invasive exotic species.* Interaction with invasive species is a major threat to native aquatic species (see sidebar).
- *Disease.* New diseases are entering the state fish populations with unknown future impacts. Recently documented diseases include the largemouth bass virus (LMBV), affecting several species in the Mississippi River; a microsporidian parasite in yellow perch near Eagle River; and bacterial kidney disease (BKD) in Lake Michigan salmonids.

• *Climate change.* The impacts of climate change on aquatic biodiversity are also potentially profound (see chapter 3).

Often, biodiversity is lost as a result of the combination of several threats. For example, lake trout populations in the Great Lakes were nearly extirpated due to the combination of invasion of predatory sea lampreys, pollution, and overharvesting (Bogue 2000).

Invasive species constitute one of the primary threats to the diversity of Wisconsin's waters (see sidebar). Invasive exotics originate outside of the particular lake, stream, or wetland being invaded and are often (though not always) of distant origin. Unwanted exotics can transform an aquatic ecosystem through the loss of one or more existing species — species that we have likely taken for granted in terms of the goods and services they provide. Once introduced, intentionally or accidentally, into environments where their natural population checks are absent, invasive exotics experience dramatic population growth and range expansion, outcompeting native species for food or critical habitats. Such transformations can challenge our sense of how that water body was and how it "should be." It is usually extremely difficult, if not impossible, to eliminate invasive species. The side effects of removal or treatment techniques (e.g., using poisons that are not species selective) are often undesirable or unacceptable.

Trends in diversity at other levels of biological organization – genetic, population, and community – are shaped by the same factors that affect diversity at the species level, but in general are less well understood. Many aquatic communities have been so thoroughly disturbed, fragmented, or transformed that they are no longer available for study, and restoration may not be possible. Where restoration is possible, biodiversity can to some degree recover. Dams, for example, impede fish movement within streams and between lakes and tributaries, leading to the loss of diversity within fish populations and communities; dam removal, conversely, can allow diversity to recover relatively quickly.

Loss of genetic diversity is of special concern in fisheries management. Fish genetic diversity in the Great Lakes and other Wisconsin waters has diminished due to overfishing, habitat loss and degradation, hydrologic alteration, pollution, artificial propagation, and the introduction of exotic species (Koonce 1995). While most of Wisconsin's native fish species survive, genetic diversity within species and populations has diminished. Lakes Superior and Michigan, for example, formerly supported several hundred distinctive lake trout stocks. By the early 1950s the lake trout was extirpated in Lake Michigan; the species survives in Lake Superior, but many stocks (especially the river-spawning populations) have been lost. The net result of the trends at all levels of biological diversity is that our aquatic floras and faunas have tended to become simplified and homogenized over time (Rahel 2002).

Because water acts as a medium for toxic contaminants and species invasions, aquatic biodiversity often serves as the "canary in the coalmine" in understanding environmental impacts of special concern. For example:

• Plants, insects, and other invertebrates are important indicators of change in water quality. The impacts of soil erosion and sedimentation, excessive nutrient loads, habitat loss, and

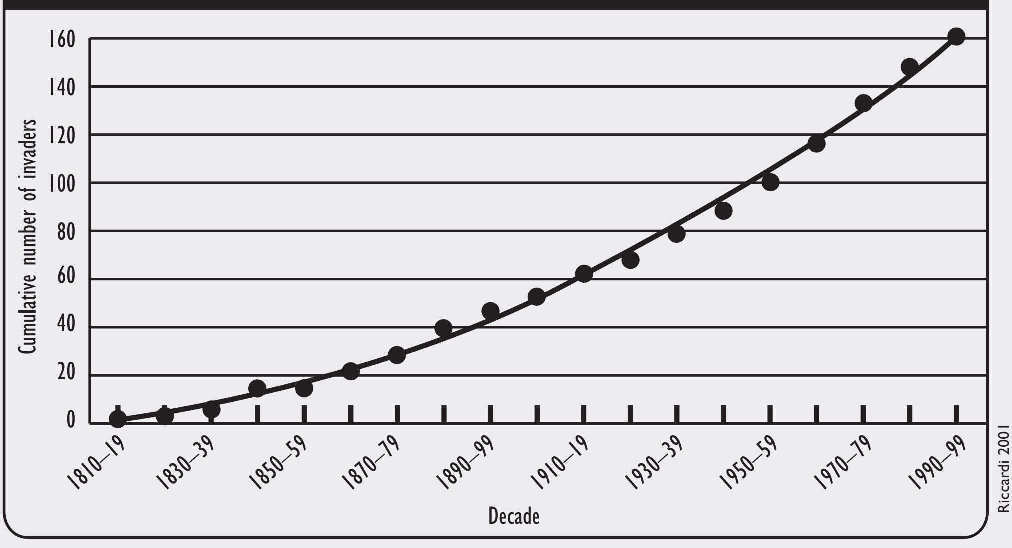
INVASIVE SPECIES IN WISCONSIN'S WATERS

Invasive species are a preeminent threat to the quality and integrity of aquatic ecosystems in Wisconsin (WDNR in prep.). Because populations of nuisance species can rapidly grow in their new aquatic environments, simply stopping the problem at the point of entry is not as effective a solution as it is for chemical contaminants and nutrients. In most cases we have had to learn to live with invasive species. This is not so difficult if the species is in some ways beneficial, but invaders are often detrimental to environmental quality and degrade important ecosystem services. They do so by displacing native species and transforming, through their high numbers, the structure of the food webs in the invaded lake, stream, or wetland.

Invasive species can be native species, but most often they are exotic species (that is, species arriving from far beyond their historic range). The Laurentian Great Lakes now have 161 exotic species, ranging in size from unicellular algae and zooplankton to mollusks and crustaceans, to the alewife and sea lamprey (Martin and Horns 2001). Expansion of the global economy and international trade has placed growing pressure on ecological integrity as international shipping has allowed invasive aquatic species to be exchanged between North America and the rest of the world. (And we, in turn, have exported aquatic species that have become problems elsewhere in the world.)

The rate at which new exotic species are arriving in Wisconsin's waters continues to increase (see figure below). The species are often stowaways from Europe, Asia, or the Atlantic Coast, arriving in the ballast waters of oceangoing tankers. Efforts to address the problem and stem the spread of invasive species westward to Lakes Superior and Michigan have been largely ineffective. Once a species has arrived, the Great Lakes serve as a source for exotics to colonize the inland waters. A notorious nuisance species that has recently entered our inland waters through the Great Lakes is the zebra mussel from Europe. Many exotic species (for example, the round goby) have moved into the Illinois and Mississippi River basins through the Chicago River diversion canal

INCREASE IN GREAT LAKES INVASIVE SPECIES



in Illinois. That same canal serves as a potential corridor for exotics in the Illinois River to enter the Great Lakes (the Asian carp is an especially worrisome recent example).

Other exotic species arrive from less distant waters, but whether from Asia, Europe, the Ohio Valley, or other lakes and streams within Wisconsin, the potential for nuisance levels of abundance exist. The nuisance exotics include animals, plants, and disease-causing microorganisms, and they can be problematic in all our aquatic ecosystems. Zebra mussels are not only causing the extirpation of native mussels in the Mississippi and St. Croix Rivers, but also disrupting navigation and recreation and interfering with water intake structures. Purple loosestrife and reed canary grass are crowding out and simplifying the plant communities in our shallower wetlands. Rusty crayfish are transforming the ecological structure of inland lakes in northern Wisconsin. Rainbow smelt are causing the extirpation of cisco and preventing successful recruitment of walleye and perch in the northern lakes. The spiny water flea, a small predaceous crustacean, is present in all the Great Lakes, where it competes with young fish for food.

Invasive species are spread both accidentally and intentionally. Eurasian water milfoil is a submerged rooted aquatic plant that flourishes in the shallow waters of lakes and crowds out native plants, frequently interfering with boating and swimming. It is often moved unintentionally to new lakes on the frames of boat trailers and outboard motors. Water milfoil hanging from boat trailers is also a vehicle for young zebra mussels to spread; they are attached to the plants and arrive with them to new waters. Other species are spread when well-intended fishers dump their bait buckets. Rusty crayfish, for example, have been introduced from bait buckets — by lakeshore owners who want them to remove rooted plants, in one case by a teacher who wished to increase the biodiversity of a closed lake, and likely by other means as well.

Regardless of the method of introduction, the negative effects are the same and influence all who use the invaded waters. Reed canary grass was planted in wetlands, beginning in the 1800s, as a forage plant, when native grasses might have been used. The Eurasian carp was introduced as a food fish to Wisconsin's waters before 1900. The carp has muddied our waters, wiped out aquatic plant communities, and increased resuspension of nutrients from the bottoms of lakes. Purple loosestrife was introduced as an ornamental plant and escaped into nearby wetlands. Our history with exotics provides many examples of purposeful introductions — mistakes that many wish we could take back.

Some fishes not native to Wisconsin are used in fish management, and populations of desired native fishes are commonly supplemented by stocking. In many cases these have been considered successes, as with the Pacific salmon in the Great Lakes or the brown trout in our trout streams. In supplemental stocking, the issue of genetic adaptation of particular strains of common fishes to specific waters has received little attention in Wisconsin. These are important issues throughout the Pacific Northwest, and especially the Columbia River basin, where individual strains can be protected as "ecologically significant units" under the Endangered Species Act. Concerns about specifically adapted stocks are just beginning to be considered in Wisconsin — for example, with lake trout. Also of concern to fish management and health are new diseases that are showing up in state fish populations, with unknown future impacts.

watershed degradation are readily apparent in aquatic plant and invertebrate communities. Conversely, the success of restoration projects may be measured by their impact on these components of aquatic ecosystems.

- Fish species allow us to understand changes in water chemistry arising from point source discharges, polluted runoff, and atmospheric deposition of pollutants. For example, we track changes in the impact of acid rain and mercury on lakes in part by examining their fish populations (Watras et al. 2000).
- Amphibian species are especially sensitive to environmental change. In the last decade, declines in amphibian populations and deformities in frogs and other amphibians have become concerns in Wisconsin, as well as nationally and globally. Annual frog and toad survey data indicate that, since 1984, populations of eight of Wisconsin's 12 species are increasing or stable. These tend to be species of open water or forested environments, and their status may reflect the extensive (and increasing) amount of forest cover in the state. Of the declining species, three (Cope's gray treefrog, northern leopard frog, and western chorus frog) are more open-country species whose decline may reflect degradation of their aquatic and upland habitats (Hay pers. comm.; Mossman pers. comm.). The other declining species is the pickerel frog, a species that is especially sensitive to decline in water quality (Vogt 1981).
- Reports of deformities in frogs and other amphibians rapidly increased beginning in the mid-1990s. Deformities have been reported in 52 of Wisconsin's 72 counties. Researchers here and elsewhere have tested a number of possible causal factors, including high levels of ultraviolet radiation, pesticides, and other contaminants, and epidemic parasitic infections. It has been suggested that these factors (and others not yet identified) may interact and are exacerbated by human alteration of habitats (Hayes et al. 2000; Blaustein and Johnson 2003; Casper pers. comm.)
- Bird and mammal species have been especially important to our understanding of the impact of DDT, PCBs, and other persistent toxic contaminants. Fish predators such as cormorants, bald eagles, and herring gulls have been important indicators of the accumulation and gradual reduction of toxic contaminants within aquatic food webs (Koonce 1995).

These examples suggest a critical point. By historical standards, Wisconsin's aquatic biodiversity remains degraded, and sobering threats continue to emerge; yet history also offers us many examples of positive change in recent decades. In all these ways, trends in aquatic ecosystems and biodiversity reflect trends in the way we live with and use our waters. With that basic connection in mind, we may step back and try to consider the state of the waters in general.

THE STATE OF THE WATERS: A SUMMARY VIEW

Wisconsin's waters are changing in complex ways. The geological foundations of our waters — the formations that hold our groundwater, the position of surface waters in the landscape — have remained more or less constant since the retreat of the glaciers. But the hydrology, ecology, human uses, and quality of water are in a state of constant flux. To live sustainably with all our waters, we need to understand how they are changing, and respond appropriately.

Change occurs at varied scales of time and space. Climate change, for example, occurs over large areas and long periods. Such changes can be especially difficult to discern. Other changes, such as toxic spills or dam removal, occur locally and immediately. Some types of change can be summarized at the state level but vary widely within Wisconsin, according to geology, topography, human population, land use, and the type of water body. Other changes occur at the local level of a particular lake, stream, or watershed. The causes and consequences of change are connected in intricate ways. For example, increasing concentrations of arsenic in some of Wisconsin's groundwater are the result of a lowered groundwater table, which in turn reflects growth in the human population, increased water demand and consumption, and reduced groundwater recharge.

We have found it useful to organize trends into four categories: (1) trends that demonstrate the positive results of water protection and restoration efforts; (2) trends that are of continuing concern; (3) trends related to the increased demand for water and water-related services; and (4) emerging trends and potential problems.

Positive trends. Wisconsinites can point with pride to important gains in the protection and restoration of the state's waters over the last several generations.

- Programs for conserving Wisconsin's outstanding and exceptional waters have given special protected status to the jewels of our waterscape. We no longer take for granted the tremendous value of these pristine waters.
- Since the 1930s, adoption of basic soil and water conservation practices has allowed the hydrologic functions of many watersheds to stabilize, allowing in turn for the recovery of their surface water ecosystems. The rampant watershed degradation of the past has in most places been checked and reversed.
- Over the last 30 years, many of the primary point sources of pollution have been identified and controlled, and most industrial users are meeting, and many surpassing, water quality standards. This holds true for both the Great Lakes and inland waters. The results (for example, in the recovery of the Fox River walleye fishery) have been dramatic.
- Over the last 20 years, efforts to control the atmospheric transport and deposition of pollutants have reduced the impact of acid precipitation and the amount of mercury entering Wisconsin's waters. Some lakes are showing signs of recovery.
- Appreciation of the value of wetlands has grown tremendously in recent decades, and Wisconsin has established itself as a national leader in wetland protection and restoration.
- Wisconsin is recognized as a leader in the removal of small dams and the restoration of our flowing waters.
- As aquatic ecosystems have recovered from past declines and disturbances, many wildlife species — including trout, otters, beaver, and bald eagles — have recovered with them. Other extirpated species, such as trumpeter swans and whooping cranes, have benefited from reintroduction programs.

- Wisconsin has adopted runoff rules that bode well for statewide collaborative efforts to meet the challenges posed by non–point source pollution.
- Citizen awareness of water-related issues has grown and participation in stewardship activities expanded, especially through the growth of local watershed organizations, lake associations and lake districts, land trusts and conservancies, and public-private partnerships. Citizens increasingly appreciate the importance of groundwater management issues that were little noticed until just a few years ago.
- Our ability to monitor and understand water trends has benefited from new technologies and from investments in programs such as the National Science Foundation's Long Term Ecological Research system and the USGS Upper Mississippi River Long Term Resource Monitoring Program.

These and other positive changes have come in response to well-recognized water-related problems. They provide evidence that we can respond effectively to emerging water problems. Moreover, positive changes in one area (for example, in protecting outstanding waters and restoring degraded watersheds) often have positive consequences in other areas (for example, in preserving aquatic biodiversity and improving recreational opportunities). These positive changes cannot be taken for granted. Programs and practices that have yielded these results, in both the public and private sectors, must be continually supported, monitored, and refined.

Continuing concerns. Some water trends are well recognized, but the long-term effectiveness of our responses is still unclear, suggesting the strong need for continued diligence.

- The long-term quality of our drinking water is not ensured. Water-borne pathogens; volatile organic compounds; naturally occurring radioactivity; and nitrate, pesticide, and arsenic concentrations in our water require constant and continued attention.
- Although much progress has been made in reducing point source pollutants, there is still room for improvement. Permitted discharges in some areas are running up against the assimilative capacity of the receiving waters. Illegal dumping, accidental spills, leaking storage tanks and landfills, poorly maintained septic systems, and abandoned wells constitute continuing threats to water quality, although programs have been put into place to address some of these problems. PCBs and other residual pollutants from old discharges remain in surface water sediments and in aquatic food webs.
- The control of polluted runoff is essential to continued improvement in water quality. Much attention has focused on agricultural nonpoint sources. The adoption of sustainable agricultural practices has helped to reduce or control sediment loads and some nutrients; high phosphorus levels, however, are of increasing concern. More attention is now being given to runoff from construction sites and to urban/suburban stormwater. Of particular concern for the future are impacts resulting from increases in impermeable surface area and potential changes in the intensity of storm events.
- Mercury, oxides of sulfur and nitrogen, pesticides, and other airborne contaminants continue to affect water quality and the health and reproductive success of fish and wildlife.

- The diversity of life in Wisconsin's aquatic ecosystems remains vulnerable to a suite of threats, including habitat degradation, invasive species, and climate change. The effects of polluted runoff and hydrologic alteration on aquatic life continue to be significant. Loss and degradation of shoreline and near-shore habitats is increasing rapidly. Illegal filling and drainage of wetlands still occurs, while development pressures continue to affect wetlands both directly and indirectly. The overall trend suggests that, without ongoing and concerted action to protect and restore our lakes, rivers, wetlands, and groundwater, we will leave future generations a much simplified and more homogenous aquatic flora and fauna.
- Alteration of hydrologic functions and regimes reflects long-term patterns of land and water resource development in Wisconsin and will likely be with us for generations. Many of these changes are essentially irreversible. Others can be at least partially mitigated through conservation and restoration practices. For example, creative management of water levels on the Upper Mississippi River offers opportunities to regain some of the ecosystem benefits lost as the river was developed.

Many of these continuing concerns have been targeted through specific regulations, incentives, and water stewardship and management programs. In some cases, the problems have been slow in building, and improvements are slow to come even after corrective actions are taken. In other cases, treatments have been applied only recently, and information on their effectiveness is not yet available. To address these and other persistent problems, existing programs must be fully implemented and fine-tuned through continual monitoring and adaptive management.

Demand-driven trends. A variety of demand-driven trends present significant long-term challenges to Wisconsin's waters. These trends involve the amount of available water and its capacity to meet human needs and provide services on a sustainable basis.

- The demand on groundwater supplies is increasing across Wisconsin and in some places is increasing dramatically. In areas where groundwater remains ample, and where Great Lakes waters seem readily available, the sustainability of groundwater supplies may seem like a remote concern. However, the expanding human population and economy, especially in the southern and eastern parts of the state, are making the sustainability of groundwater supplies critical to our future.
- Regional, national, and global demands for freshwater will continue to increase, bringing greater attention to both groundwater and surface water in Wisconsin. The Great Lakes, in particular, will be viewed as a source of freshwater both within and beyond the basin, and proposals for transfer and withdrawal will increase.
- The assimilative capacity of Wisconsin's surface waters is likely to become a more significant limiting factor. More Wisconsin communities will need to address this constraint directly and proactively. The challenge will be compounded if flows in rivers and streams decline as a result of reduced groundwater discharge and predicted impacts of climate change.
- Recreational demands on our waters are increasing, in terms of both numbers of recreationists

using the waters and the total cumulative impact of recreational activity. Some demands, such as lakeshore development for second homes, are ultimately limited by the available space; others, such as motorized recreation, face limits involving public safety, user conflicts, and environmental impacts.

- Competing demands for available water are exacerbated during drought. Yet, Wisconsin lacks fully developed preparation and response plans that encourage water conservation during times of normal precipitation and that prioritize and allocate uses during times of drought.

MONITORING THE HYDROLOGIC CYCLE: GOALS, STATUS, AND NEEDS

To understand how the human body functions, we weigh ourselves, take our pulse and temperature, measure our blood pressure. If a health crisis occurs, we can pinpoint causes and track the success of treatment through a variety of observations and tests. To understand the changing status of Wisconsin's waters, we similarly employ a variety of sensors: gauges that measure stream flow, wells that indicate groundwater levels, samples to test for contaminants and pollutants, observations of water-related phenomena from the seasonal extent of ice cover to the nesting success of loons to the spread of invasive zebra mussels and purple loosestrife.

Are we successfully measuring the things we need to measure to understand the health of our waters? Is our monitoring system able to provide citizens and decision makers with the information they need? In 1996 a team of water scientists from universities, government agencies, and the private sector gathered to assess the state of water monitoring in Wisconsin. The team focused on our monitoring of hydrologic properties, motivated by several concerns: declines in the number of stream flow gauging stations, water quality monitoring stations, and groundwater observation wells in the state; poor definition of goals for monitoring the quality and quantity of both surface waters and groundwater; and insufficient knowledge about Wisconsin's long-term water data needs. The team's tasks were to identify long-term needs; describe the dimensions of a fully effective monitoring network; and determine how such a network could be maintained, financially and institutionally.

In its report, cooperatively published by the Wisconsin Water Resources Center and the U.S. Geological Survey, the team reached the following conclusion: "Reduction in Wisconsin's water-monitoring networks will cause serious risk to the residents of Wisconsin by increasing the uncertainty of water-resources plans and decisions, and ultimately increasing the costs for construction of water-related facilities and damage from extreme events…. Present water data networks in Wisconsin are less than optimum for most state and federal agencies to make decisions and probably are not adequate for the specific needs of many local government units, industry, utilities, and recreational users" (TEWWMN 1998).

The team provided a series of specific recommendations to strengthen the state's water monitoring network, to coordinate data collection and management, and to distribute the costs of

Demands for water continue to increase. Responding to demand-driven trends requires a higher level of awareness, among the public and decision makers, of the importance of efficient water use and conservation and of the capacity of our waters to absorb a variety of human uses. Our demands, as they grow, will increasingly compete with each other. Although we have the luxury of abundant waters in Wisconsin, our choices will become increasingly difficult without planning based on good information and a strong public commitment to sustainability.

Emerging concerns and potential problems. For some water trends, the available information is sufficient to suggest important problems ahead, but responses — through regulation, incentive programs, or stewardship practices — are not fully developed.

monitoring. Partners in the Waters of Wisconsin initiative reviewed and updated these findings (Krohelski 2002). In summary:

- Wisconsin's groundwater observation well network needs to be expanded to all of the state's water-bearing formations and better targeted in areas of intensive groundwater development. Observation wells need to be better designed so that they tap a single aquifer (rather than a composite of aquifers), and better distributed around the state. In addition, the well network should be adapted to include groundwater quality monitoring.
- The stream-gauging network needs to be expanded and better distributed. Eighty-five percent of Wisconsin's 115 long-term stream-gauging stations are sited on medium or large rivers. An additional 25 stations would permit better coverage across Wisconsin, especially on midsize streams.
- We do not have a consistently implemented long-term water quality monitoring network. In general, the existing network would benefit from a thorough review. It should include both chemical and biological monitoring and should include lake and beach sampling.
- We do not have a coordinated lake level monitoring network. A system to monitor groundwater flow through different types of lakes should be established. Four lakes (Lake Winnebago, Devil's Lake in Sauk County, Lakes Mendota and Monona in Dane County) have a long record of consistent monitoring and can form the foundation of a statewide network. In addition, Lake Districts and Lake Associations should be encouraged to maintain lake level measurements on a continuous basis.

Attention to these needs would go a long way toward ensuring that we have the best available information on the hydrology of Wisconsin's waters. Other dimensions of water monitoring — including monitoring of climate change, aquatic biology and ecology, human water uses and impacts, and the effects of restoration activities — are (or should be) reviewed regularly as well. By improving our system of "sensors," and using new technologies to gather, coordinate, analyze, and disseminate water information, we can be confident that the health of our waters is being well watched.

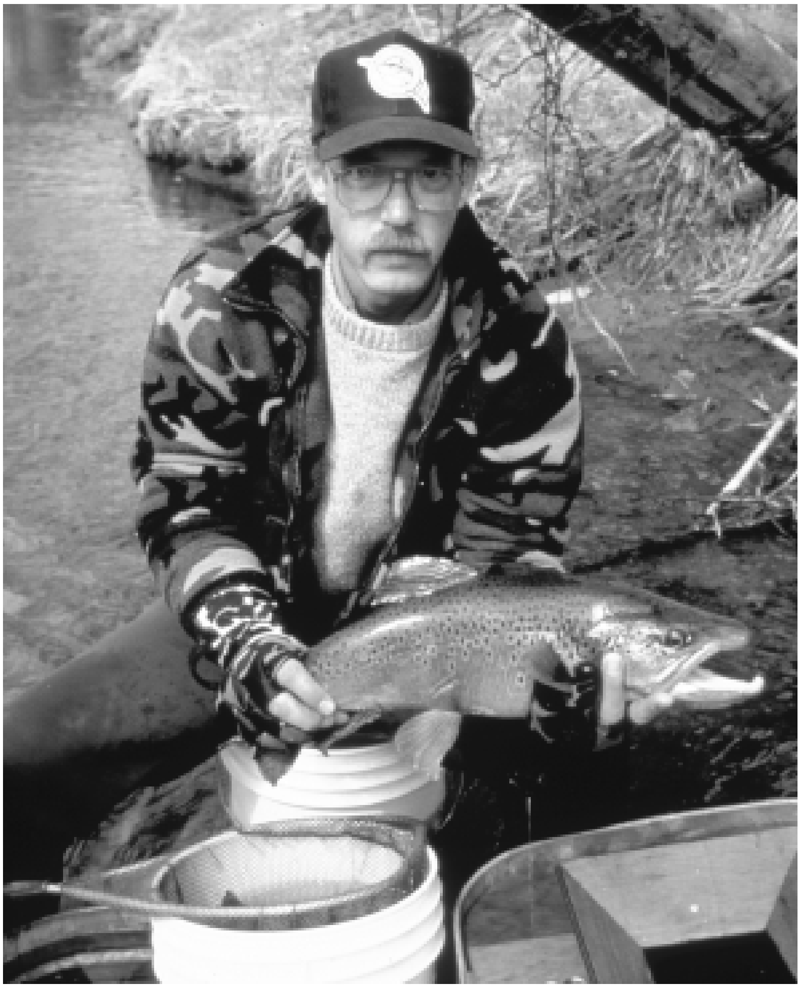
- While debate on the extent and cause of climate change continues, the weight of evidence suggests that Wisconsin's waters will experience significant impacts over the next century, and that it would be wise to develop strategies to deal with these impacts. Some of the predicted changes in precipitation, temperature, ice cover, lake levels, stream flows, and soil moisture we may well have to learn to live with. Others we can mitigate in part through adaptive changes in our land and water use. Long-term planning of water needs, uses, and ecosystem impacts must include consideration of adaptations to climate change and variability.
- The spreading of aquatic invasive species is evident to anyone who spends time on or near Wisconsin's waters. Historically, we have responded on a case-by-case basis; indeed, we have intentionally introduced many species that then became problems (Eurasian carp, for example). The public and resource management agencies have awoken to the full dimensions of the threat to Wisconsin's aquatic ecosystems. Controlling the spread of invasive species is an overwhelming challenge, and it is likely to remain so as new invasive species continue to arrive on our shores and in our waters.

These and other early warning trends are especially challenging, in terms of both policy and environmental management. Evidence of the problems is conclusive enough to warrant response, yet options for action are not developed fully. Policies to address the trends are not in place, and building public awareness and consensus around them is often difficult. Yet, these are the very trends that require new policies.

Other changes in our waters are poorly studied or understood. We know, for example, that hormones, antibiotics, and other pharmaceuticals move into and through our water supply, but we have little understanding of their effects — alone or in combination — on human health or aquatic ecosystems. Still other potential threats to the sustainability of our waters are all but impossible to anticipate. For example, ensuring the security of our water supply is an emerging issue with potentially profound repercussions. Other social and technological trends are obviously difficult to anticipate but will have a variety of impacts on our waters. While population pressures are likely to grow, we may also anticipate that technological trends (for example, in monitoring tools) will allow us to greatly improve our understanding of the state of our waters.

The high level of uncertainty surrounding such considerations should not deter us from thinking about them, and speculating on research needs and policy responses. Some of these involve mainly the hydrologic and biological aspects of water and water use; others involve the social and economic dimensions. A critical understanding of hydrologic systems and a working set of sustainability principles are especially important in trying to grapple with such unknowns.

That Wisconsin's waters will continue to change is a given; how we understand and respond to these changes is uncertain. In the past, we have tended to take action only after water-related problems have developed. The key question for the future is whether we can better predict problems, shorten our response time, and take action before negative effects become obvious and widespread. This is especially important — and difficult — for problems whose causes are complex and whose consequences are long-term or irreversible.


WDNR

FUTURE CONSIDERATIONS: WATCHING OUR WATERS

Waters of Wisconsin participants have sought to understand not only the status and trends of our waters, but also the state of our capacity in water research and monitoring and in data collection, management, and analysis. As we have noted, Wisconsin is fortunate to have a remarkably strong set of institutions involved in water research, and these institutions have long collaborated in bringing knowledge of our waters into the management and policy arenas.

Nonetheless, there are important gaps and weaknesses in our capacity to watch well over our waters (see sidebar). We lack sufficient understanding in many key areas of water science. For example, we do not have an effective system of accounting for water use in Wisconsin, and we do not adequately understand the effects of changes in groundwater hydrology on surface water ecology. The “feedback loops” in our water assessment system — the connection between emerging trends and management responses — are too often weak or lacking. Funding for effective water monitoring programs and networks is at risk.

A strengthened system should include reference areas where we can gather baseline data and a monitoring network that takes into account spatial and temporal scales of interest (TEWWMN

1998; Alley et al. 2002). The frequency of measurement should be geared to the dynamics of the processes, events, or conditions we are interested in. Both technical monitoring programs and voluntary citizen efforts can and should contribute to a more effective water monitoring system.

Although there are weaknesses in our monitoring and assessment system, we have at the same time tremendous opportunities to use existing information more effectively. New and emerging research, monitoring, and data management technologies can allow us to make water information more accessible and available to Wisconsin citizens and decision makers. Chapter 6 of this report offers a series of recommendations for meeting these needs and taking advantage of these opportunities. In summary, the WOW committee recommends the following:

- that the state of Wisconsin — working in partnership with federal, tribal, and local governments, the private sector, and nonprofit organizations — maintain the state's long-term commitment to, and capacity for, effective water monitoring;
- that the state of Wisconsin, in partnership with relevant state and federal entities, explore options for improving coordination of water information within the state and identifying key research and monitoring needs;
- that the state of Wisconsin help make information on Wisconsin's waters more available and useful to citizens, local officials, state legislators, and other decision makers, by coordinating preparation of a regular "State of Wisconsin's Waters" report; and
- that institutions engaged in gathering and analyzing information on Wisconsin's waters collaborate in developing a web-based, interactive repository of documented water status and trend data.

Dependable information on status and trends is essential if we are to understand changes in demands on our waters, detect warning signs, reverse negative trends, and evaluate the effectiveness of water management and policy actions. Making that information more available and accessible is essential if we are to ensure that the public and decision makers are engaged and informed. Acting on these recommendations will keep our capacity for information gathering, analysis, and communication strong.

Water decisions have long-term consequences. To make wise decisions, we need clear links between water information and water management. We cannot measure everything, everywhere, all of the time; thus the need for a robust water monitoring and assessment system. We need policies and administrative structures that address various trends together and respond to them in a more integrated and comprehensive fashion. We need to encourage practices that recognize water-related trends and contribute to sustainable water management. In the next chapter, we address one further need: an ability to use our knowledge of trends to think creatively about changes and decisions that will shape our water future.

WDNR

CHAPTER 3

LOOKING FORWARD: ENVISIONING WISCONSIN'S WATER FUTURE

Knowing what we know — and what we *don't* know — about Wisconsin's waters, what can we say about the future? How will our aquatic ecosystems change? What forces will determine the quality and quantity of water one generation, or seven generations, hence? What effect will this generation's decisions and policies have on that future? With what level of confidence can we see ahead? How far? Participants in the Waters of Wisconsin initiative have tried to examine these questions in ways that open our imaginations, combine varied perspectives on water, and shed light on current needs and opportunities. Although we cannot know the future, we can think about it in ways that help us to better understand our choices.

This is more than just an exercise for the imagination. The preceding chapter of this report provided a "report card" on water status and trends: how Wisconsin's waters are doing, and where we appear to be heading in the near term. Yet, even if we had complete and accurate scientific information, the future would remain to some degree unknowable. The next chapter will outline a series of principles to help guide decisions in the face of that uncertainty, and later in this report we will consider how Wisconsin citizens, as an informed public, can develop policies that take long-term concerns into account. Here we provide a rationale for how and why Wisconsin citizens and policy makers should think about the long-term future; offer a series of story lines as examples of how future thinking can highlight key issues, forces, and relationships that affect water; and suggest ways to improve the adaptive capacity of our communities, institutions, and policies.

THINKING ABOUT THE FUTURE

Why think about the future? Since we cannot know the future with certainty, what value is there in the effort? How can we think about the future more productively?

In fact, we think about the future all the time. Our decisions, in everything from personal choices about our children's future to broad questions of national and international policy, reflect that thinking. We base our decisions on available information, the values we bring to the discussion, our understanding of options, our consideration of costs and benefits, our assumptions about outcomes, our personal preferences.

Our focus here is on private and public decisions that will determine the future status of Wisconsin's waters. The obvious dilemma is that we cannot predict the future, but we still must make decisions — often major decisions — that will shape it. In most cases, we will not know for decades whether our decision was wise or proper. Good decisions and strategies are those that foresee the fullest range of possible and plausible consequences while meeting shared objectives across several possible futures. Ensuring that any given decision will be the best one is not possible, but we can improve the odds.

We begin with several basic points.

Uncertainty is a given. Decisions are always made in an environment of uncertainty. The future — whatever else it may be — is uncertain. Our society will continue to evolve in response to cultural developments, demographic trends, economic transformations, technological changes, and political shifts within and beyond our borders. Ecosystems and landscapes will continue to change, as they always have — but with human impacts increasingly blurring the boundary between natural and anthropogenic rates of change.

Uncertainty can and should be taken into account. Uncertainty may be inevitable, but it can be factored into and, to some degree, reduced in the decision-making process. Although we act in the absence of complete information, we can make better use of the existing information. We can bound the uncertainty as we make decisions and direct research and resources to help clarify the consequences of our actions.

Not all decisions are the same. Decisions vary by type. Some are made by individuals on the personal level; others by governments at the community, county, state, tribal, and federal levels; others by private institutions, businesses, and organizations. Some decisions are primarily economic; others concern environmental, administrative, policy, public health, or resource management goals. Some are external, others internal; that is, some are imposed from beyond, and others are self-imposed. Wisconsin's national leadership in protecting so-called isolated wetlands is an example of a recent internal response to an external decision (see sidebar).

All actions have consequences. Although we act with incomplete information, decisions will be made and they will have consequences. Even the decision to do nothing has consequences. Short-term decisions can have long-term consequences. The impacts of some decisions are local, others are widespread. Decisions have consequences both within and beyond our state's borders. Wisconsin's water uses, for example, affect the entirety of the Great Lakes watershed and the hypoxic waters in the Gulf of Mexico (Rabalais et al. 1996).

Consequences accumulate. Decisions and their consequences do not occur in isolation. An action taken in one part of a watershed, or affecting one part of the hydrologic cycle, will have consequences in other parts, and these can and will accumulate over time. Cumulative impacts are often the most difficult to predict, to detect, and to address, but they cannot be ignored.

Consequences vary in their degree of reversibility. Some consequences of our decisions are easily managed, others not. Some, with time and effort, can be substantially reversed. Some respond quickly, some slowly, to corrective action. Recent successes in small dam removal in Wisconsin are an example of a reversible action (Stanley and Doyle 2002). Other consequences, such as species extinctions, are by definition irreversible.

Trend is not destiny. The past is not a simple guide to the future, because the type and rate of changes are themselves subject to change. Consider, for example, the explosive growth in the number of websites on the internet in just the last 10 years. In the water arena, we can see many trends — both positive and negative — that have changed dramatically. By 1925, for example, poor farming practices had severely degraded streams and watersheds throughout the driftless area of southwestern Wisconsin. Few would have predicted the successes we have since had in restoring stability and vitality to many of the region's waterways (Potter 1991; Anderson 2002).

These premises lead to the conclusion that the future can be either well considered or poorly considered. Because we do think about the future, because we act on what we think, and because our actions have consequences, we are obligated to make decisions with as much knowledge and imagination as we can muster.

WHICH WISCONSIN? LOOKING TO THE FUTURE

Wisconsin's waters are changing constantly. Their current state is the result of countless decisions made over the last 150 years. Some decisions consciously took into account the future; others did not. Building dams and removing dams; draining wetlands and restoring wetlands; introducing non-native carp and reed canary grass and protecting native species; dumping effluent into public waterways and passing pollution control measures; plowing fields up-and-down or along the contour; drawing drinking water from deep aquifers, shallow aquifers, or surface waters — these and a thousand other actions have been based on calculations of public

PROTECTING WISCONSIN'S ISOLATED WETLANDS

In the spring of 2001, the citizens and elected officials in Wisconsin took swift action to protect our state's rich and diverse wetland heritage from significant adverse impacts. The effort to safeguard isolated wetlands stands as an exemplary success story of citizens positively influencing water policy in Wisconsin.

On January 8, 2001, the U.S. Supreme Court handed down a decision affecting millions of acres of wetlands across the country. The court case involved the Solid Waste Agency of Northern Cook County (SWANCC), a group of municipalities in northeastern Illinois, and the U.S. Army Corps of Engineers, the federal agency with authority to regulate filling of wetlands under the 1972 federal Clean Water Act. By a 5-4 vote, the court determined that the Corps does *not* have regulatory jurisdiction over "isolated, non-navigable, intrastate" wetlands under the Clean Water Act and the subsequent Migratory Bird Rule of 1986. The Corps had argued that the ponds and gravel quarry were important habitat to migratory birds, especially waterfowl. The Supreme Court ruled that these "isolated" wetlands — those not somehow directly connected to a navigable waterway — were not protected under our federal laws.

In Wisconsin, the DNR estimated that the SWANCC decision rendered more than a million acres of wetlands vulnerable to filling and development, since the state's jurisdiction was directly tied to federal jurisdiction. The affected wetlands include kettles and prairie ponds, depressional wetlands in the Lake Michigan swell and swale region, and many of our northern bogs. The impact of the court's decision would soon be felt on the ground. On March 19, the first wetland loss resulting from the SWANCC decision occurred: 0.7 acres were filled to construct a new store in Peshtigo. Over the next six weeks, the state lost on average a wetland a day due to the regulatory gap created by the Supreme Court.

Recognizing the gravity of the situation, conservationists responded quickly. Efforts to plug the gap through state legislation began. Within weeks of the court's decision, the Wisconsin State Senate passed on a strongly bipartisan basis a simple but effective status quo wetland protection bill. As the bill moved into the State Assembly, wetland protection quickly became a "front burner" conservation issue. Thousands of citizens communicated with their legislators and with the governor's office. Eventually more than 70 national, state, and local organizations, with a and private good, with long-term consequences that were sometimes anticipated, sometimes unexpected.

Likewise, actions taken today will determine the future state of Wisconsin's waters, whether or not we take the time to consider their effects. Our actions on land are reflected in the water. The future of the waters will reveal our ability to address multiple forces, understand hydrologic processes, gather and use the best scientific information, build in a safe margin of error, and respond flexibly to change as it occurs.

If we think about how Wisconsin's waters have changed, and continue to change, we can appreciate the complexity that forecasting entails. An observer of Wisconsin's waters in 1925 would have seen more than the badly eroded stream banks of the driftless area. She would have noticed degradation of the lakes and streams in the cutover lands of the north; decline in the

combined statewide membership of over 320,000, signed a letter calling upon the legislature to pass SB 37 to restore wetlands. Support for the bill was wide and diverse, bringing together hunters and anglers, environmental organizations, biking and hiking groups, Native American communities, and church congregations. Significant support came during the Wisconsin Conservation Congress spring hearings held around the state in early April. A strongly worded wetland protection resolution passed in 58 of 60 counties where it was introduced, with a favorable vote of more than 91%.

Then–Lieutenant Governor Scott McCallum had issued a statement in January expressing his concern over the loss of protection for the wetlands of the state. As the outpouring of public support increased, Governor McCallum created a team with representatives from the Wisconsin Realtors Association, the Wisconsin Wetlands Association, and the governor's staff to develop language for a bill. Simultaneously, state legislative leaders met independently to develop a compromise bill. Eventually, a bill was crafted that met with the approval of realtors, the DNR, legislators from both houses and parties, and the conservation and environmental community. The final version of the wetlands bill passed unanimously in the Senate on May 1, and unanimously in the Assembly two days later. On Monday, May 7, Governor McCallum signed "2001 Wisconsin Act 6," the new wetland protection law for Wisconsin. The law became effective at midnight that night.

Wisconsin thus became the first state in the nation to pass a wetland protection law in response to the SWANCC decision, exactly four months to the day following the Supreme Court ruling. The upshot of the new law is that jurisdiction over isolated wetlands, which had been held by the federal government, now rests with the state of Wisconsin. The Corps retains jurisdiction over all other (nonisolated) wetlands. The new law restored protection to all wetlands in the state; every wetland fill project is still reviewed by the DNR under NR 103, which establishes the water quality standards for wetlands. The speedy passage of this law demonstrated that the citizens of Wisconsin hold their wetland heritage dear, and that the democratic process can work when that heritage is at risk. Wisconsin remains the only state to have adopted this new wetland protection legislation.

commercial fisheries of Lake Michigan; rapid drainage of wetlands, especially in the Central Sands; unconstrained pollution in core industrial areas in the Mississippi, Wisconsin, Fox, and Menomonee River valleys; and the earliest signs of automobile-dependent suburban development, with all its impacts on water use. Simple extrapolation of the trends would have yielded a grim prospect not only for water, but for Wisconsin's air, soils, water, and biological resources generally. It would have failed to account for positive changes owing to conservation measures and for negative changes yet to emerge.

Likewise, the dynamic state of our waters, and of the relationship between people and ecosystems, makes simple extrapolation problematic. An observer in 2075 may look back on our forecasting efforts and ask: Which threats to water grew and emerged? Which threats faded? How did changes in scientific knowledge and public attitudes shape decisions? How did public policies, economic incentives, and other interventions work — or not work — to sustain the health of Wisconsin's waters? Which Wisconsin did they foresee and plan for in 2003?

A VIEW INTO THE FUTURE

Forecasters use a variety of tools and techniques to peer into the future, each with different strengths. Trend analyses allow particular factors to be drawn out and elaborated. Simulation models integrate multiple factors to create forecasts. Computer models can distill and synthesize massive amounts of quantitative information at various scales. Delphi techniques use a structured process of questions and responses to gain the collective judgment of experts in a given field (Flader 1983). Here we consider some dimensions of the future of our waters using another future-thinking technique: scenarios.

Scenarios are stories about the future. They explain how the future might unfold under feasible circumstances. As stories, they are intended to evoke contemplation and discussion, to play "what if" on a long-term scale. They are grounded in the real world and thus depict credible outcomes, but are not predictive or prescriptive. Rather, the goal in creating scenarios is to help us think more clearly and creatively about things that we might not have thought about otherwise. They are intended to stimulate discussion of the longer-term results of current decisions (Hammond 1998; Tellus Institute 2001; Peterson et al. in press).

Scenarios are not simply made up. They try to capture the dynamic forces shaping the future, and so they are built according to certain methods and assumptions. Effective scenarios consider key driving forces, including technology, economics, politics, demographics, societal values, and ecological conditions. These drivers shape the environment in which decisions are made. In creating scenarios, certain givens (or uncontrollables) hold for all scenarios. Around the drivers and givens, various uncertainties are combined to create the range of alternate scenarios.

Many scenarios identify key decision points or policy choices (controllables) that occur en route to the future. In a democratic society, with its often conflicting interests, scenarios should reflect a wide variety of goals and objectives, reflective of the diversity in the body politic. Because values are embedded within any story of the future, and because values vary, useful scenarios will present a spectrum of plausible futures.

While scenarios may not lead directly to consensus, compromise, legislative initiatives, or behavioral changes, they can clarify how various choices might influence change. They can draw attention to early-warning signs — signals that particular scenarios may, in fact, be beginning to unfold. They can show certain key decisions to be robust, with positive consequences that hold up under a wide range of assumptions about future states. Finally, by telling stories about ourselves and our shared future, scenarios can bring otherwise opposing perspectives into closer communication.

THE WOW SCENARIOS

As a part of the Waters of Wisconsin effort, a working group convened regularly to develop several story lines about the future of Wisconsin's water. The group focused on a limited set of issues of concern to WOW: the health of Wisconsin's aquatic ecosystems, our ability to meet changing societal demands for water, and recognition of the many competing uses for water in Wisconsin and beyond. In creating the scenarios presented in this chapter, the working group operated according to several assumptions and wrestled with several dilemmas.

- Given the constraints on WOW's work, the scenarios build on the work of others and are largely nonquantitative.
- To comprehend the many factors affecting Wisconsin water resources, we needed a general set of impact indicators or stressors pertinent to water. To meet this need, the working group incorporated much of the framework developed by the "status and trends" working group (see chapter 2).
- The working group had to confront the issue of appropriate scale for even preliminary scenarios. To effectively describe alternative futures for Wisconsin, should the focus be on the state level? On subregions, such as the northern lakes or the Upper Mississippi? On the larger context of our waters (e.g., the Great Lakes and Mississippi River systems)? On cross-boundary and global factors such as atmospheric deposition, climate change, and international security? The group ultimately chose to focus on several key factors (or drivers) around which to integrate water impacts at various scales.
- What is the most useful time frame for scenarios? Several decades? A human lifetime? Seven generations? The group finally chose to focus on scenarios that looked out some 50 to 75 years.

Obviously, many factors will shape the future of water in Wisconsin. An incomplete list would include changes in climate and precipitation patterns; demographics (our population size and distribution); land use development patterns; agriculture, food processing, and food distribution systems; global water supplies and the current trend toward privatization of municipal water systems; macroeconomic forces, including international trade and economic disparities; state-level economic incentives, including the promotion of "new economy," high-tech enterprises; energy production and consumption patterns; conservation and restoration practices; communication and information technologies; and changes in our social structure and means of governance.

These and other factors will certainly have profound impacts on Wisconsin's waters. And yet, in looking ahead everything seems to depend on everything else. Critical trends do not operate in isolation, and the complexity can be paralyzing. How, in creating scenarios, can the large number of variables be reduced, without gross oversimplification of important connections and interdependencies? To deal with this dilemma, the working group chose to tell stories about the future using four organizing themes: agriculture, land use and urbanization, climate change, and development in the Northern Highlands lakes region.

WDNR

STORY LINE 1: WATER AND AGRICULTURE IN WISCONSIN

Since Wisconsin achieved statehood, agriculture has provided the underpinning of its economy and driven development of its landscape and culture. Agriculture has also had far-reaching impacts on the state's waters. Rapid conversion of Wisconsin's native wetlands, prairies, savannahs, and forests altered surface hydrology while adding inputs of sediment and, later, fertilizers and pesticides. In some regions of the state, the introduction and expansion of irrigated agriculture has changed groundwater/surface water dynamics. Agriculture, however, is itself a dynamic system and subject to constant change, innovation, and market-driven preferences. Many detrimental farming practices have been abandoned or modified in ways that have greatly improved the state's waters. In the following discussion, we consider plausible ways in which agriculture might affect water in the future.

Agriculture in Historical and Global Context

Water is essential to any agricultural operation. Because Wisconsin has abundant water, rich soils, and a temperate climate, agriculture has long formed the foundation of its culture and economy. For centuries before the arrival of Europeans, Wisconsin's indigenous people engaged in traditional subsistence agriculture, concentrated especially along the water bodies in the southern half of what became Wisconsin. The agricultural potential of the area was the leading factor in drawing European immigrants during the 19th century; the realization of that potential transformed the native landscape, and the waters within it.

Agriculture in Wisconsin has evolved over the last century and a half, in part in response to the limitations and opportunities afforded by water. In southern Wisconsin, the early wheat farming economy proved unsustainable, in part because the climate was less favorable than in lands farther west. The transition to dairy farming, with permanent pasture and mixed crops, was well suited to the climate and to the prevalence of small landholdings. In central Wisconsin, sandy soils and extensive wetlands prevented intensive agricultural development until mechanized drainage equipment began to open up this new agricultural frontier in the late 1800s and early 1900s. (An exception was the cranberry industry that developed in the region, taking advantage of the area's unique wetland hydrology.) In the north, Wisconsin's rivers and Lakes Superior and Michigan provided the initial means of transport for the immense cut of pine timber through the late 1800s. Farms were intended to follow the axe, and efforts to bring farmers to the cutover were widely promoted, but in much of the north, the soils and climate proved unsuitable for agriculture.

As we try to think about the future of agriculture in our state, and its economic, environmental, and food system impacts, we might look back over the last 75 years to gain both insight and humility. Who was prescient enough to foresee the consequences of the tractor or the milking machine; the growing industrialization of the poultry and livestock industries; the development of irrigation technologies, new crop varieties, new agrichemicals, and new production systems that would transform central Wisconsin into a major potato and vegetable growing region; or the dominant role of government in the economic and environmental functioning of the agricultural sector?

We also need to see Wisconsin agriculture in the larger context of two global crises — ecological degradation and extreme poverty. As summarized by Brown (2001):

> Expanding food production to feed the world's growing numbers will be far more difficult during this half-century than it was over the last. During the last half of the twentieth century, the world's farmers nearly tripled grain production.… Impressive though this achievement was, most of the progress was canceled by population growth. Today, 1.1 billion ... people are still undernourished.… Eradicating the hunger that exists today and feeding those to be added tomorrow is a worthy challenge, one made all the more difficult because two of the world's three food systems — rangelands and oceanic fisheries — are already being pushed to or even beyond their sustainable yields. The output of croplands has not yet reached its limit, but the rise in cropland productivity has slowed over the last decade.

Hammond (1998) summarizes the situation this way: "As the growing ranks of the poor struggle to survive, they are forced to farm more erodible land, cut down more forests, and crowd more livestock onto overburdened pastures, leading to degradation, still greater scarcity, and deeper poverty."

Changes in Wisconsin agriculture do not occur in isolation. Increasingly, national and global market forces have altered the structure of Wisconsin agriculture, especially since World War II. Although the state retains a higher percentage of smaller owner-operated farms than many areas of the United States, the trend is toward fewer and larger operations. Global economic pressures are playing out on Wisconsin's landscape with the continuing loss of the traditional small farm, ever-higher capital investments, and intensified promotion and adoption of biotechnology.

As the 21st century began, net farm income of $350 million was at its lowest level since 1955. This income included more than $600 million in direct government payments under various farm income-support programs. What are the future prospects for the state's dairy industry, where milk sales account for more than half of farm cash receipts? Income has fallen significantly in the past few years, and cow numbers (now at 1.28 million head) are declining. The future of corn and soybean production in the state is strongly influenced by government policy and the market environment. About 2.75 million acres are presently planted to corn, and 1.7 million acres to soybeans. One can envision significant changes to the state's rural landscape depending on future national and international market conditions for corn and soybeans (Jesse 2002).

Clearly, changes in agriculture will profoundly affect Wisconsin's water resources and aquatic ecosystems. As we ask ourselves what kind of water future we as a state can expect and would like to work toward, we must ask simultaneously what kind of agricultural future we envision and would like to encourage through our policies (Tilman et al. 2001; Nassauer et al. 2002). From the universe of possible agricultural futures, consider the following two contrasting scenarios.

Benign Corporate Agroindustrial Farming

During the first two decades of the 21st century, the U.S. economy's role in global markets continues to grow and to intensify. Family farms, especially Midwestern dairy farms, largely succumb to the inexorable forces of the marketplace. Farm commodity price supports are eliminated by 2020, and smaller units of production are unable to stay competitive. At the same time, the public's demand for clean water and healthy ecosystems has led to the adoption of binding rules for the conduct of agricultural operations — the Code of Best Agricultural Practices. Farm operators are mandated to internalize the costs of production in ways that do not compromise the health of the environment, the viability of soils, or the quality of ground and surface waters.

These events require commercial agriculture to be technologically advanced, large-scale, capital intensive, internationally competitive, market-driven, and compliant with governmental environmental regulations. Consolidation and corporatization of the Wisconsin farm economy has moved ahead rapidly because industrialized operations are able to produce at lower per-unit costs. The new large enterprises are able to access capital markets and disperse ownership to avoid the intergenerational financing and cash-flow problems that plagued the traditional family farm. The industrial farms are able to capitalize on scientific agricultural breakthroughs and carefully manage agrochemical usage and intensive production practices within the bounds of the Code of Best Agricultural Practices. Energy efficiency is achieved through greater economies of scale, fully computer-monitored applications of purchased fertilizers and pesticides, and new generations of farm equipment utilizing emerging fuel cell technologies.

Large confined-animal operations are able to overcome the costs and challenges of bringing in forage and moving waste from thousands of animals through innovative regional forage production and waste management systems adapted from Europe. The inefficiencies that once made smaller farms major contributors of nutrients to the state's waterways have been eliminated. Water quality in rural Wisconsin's lakes, streams, and groundwater improves dramatically, meeting state standards. The corporate farms, in an effort to respond to community values and social responsibility, undertake environmental restoration efforts on their lands, restoring fish and wildlife habitat on marginally productive lands. They establish expanded public access opportunities for diverse recreational activities on their holdings. There is little public nostalgia for the family farm of a bygone era.

The Renaissance of Sustainable Farming

The desirability of expanding industrial agricultural and livestock operations, taken for granted in the first two decades of the 21st century, are hotly debated in both rural and urbanizing Wisconsin. Despite assurances that corporate farming operations have greater economic means to be good stewards of the land and waters, individuals and localities across the state are now encountering widespread contamination of streams and groundwater, as well as noxious odors and health-endangering gases from concentrated livestock operations. Permit violations are commonplace, the Wisconsin Department of the Environment contends that it lacks sufficient resources to enforce the laws, and protests occur in numerous rural communities.

International trade has expanded dramatically, but trade policies were modified in 2020 to protect environment quality and the rights of the local labor force. This has worked to the benefit of those smaller, owner-operated farms that remained economically viable through the early decades of the century. Government continues to move toward a full agricultural market economy, eliminating petroleum subsidies, transportation and water subsidies, and various commodity price supports and dramatically altering agricultural production incentives to favor smaller, less agrochemical-intensive farm units. Consumers, spurred on by continuing news stories about pesticides in foods and antibiotics in meat, a growing organic food industry, and a desire to support local agriculture, increasingly favor the economics and community benefits of smaller owner-operated farms.

These events, coupled with recurrent water shortages in the Western states, have led to the revitalization of moderate-scale agricultural operations across rural Wisconsin. Many are locally owned, multifamily partnerships, with roots in the Badger state going back more than two centuries to the mid-1800s. Rotational grazing practices are widely employed in the state's dairy regions, and farm operations are less capital intensive and more environmentally benign. The University of Wisconsin agricultural research and extension system places priority on the health of the land and sustainable local economies and helping smaller units of agriculture adapt to technological, environmental, and socioeconomic changes.

The proliferation of relatively small owner-operated farms revitalizes rural Wisconsin. Creative governmental programs based on private-public collaboration have brought together the goals of preserving farmland, protecting and restoring critical environments, improving water quality, and providing open space in ways that provide added revenue sources to agricultural land stewards. As revealed by internet polls throughout the mid-2000s, the public strongly believes that the family farm is the best alternative for a healthy environment, safe food, and successful rural communities and landscapes. In short, Wisconsin farmers have weathered the transformation of markets and the initial onslaught of large-scale industrialized agriculture and are now pursuing a sustainable mode and size of production.

STORY LINE 2: WATER, LAND USE, AND URBANIZATION IN WISCONSIN

As agriculture's role in Wisconsin's culture and economy has changed, so have alternative land uses. The growth of industry, then later of technological, service-based, and information-based economic activities, has led to widespread conversion not only of agricultural land, but also of undeveloped land throughout Wisconsin. Industrial, commercial, residential, and infrastructural development has placed pressures on water that were relatively minor when our population was smaller and agriculture dominated local landscapes. Only recently have we begun to wrestle with the impacts of changing land uses on water, including increased groundwater withdrawals, increased runoff from impermeable surfaces, loss of stream and shoreline habitats, and rising recreational demands (see sidebar). The following scenario describes a plausible future for southeastern Wisconsin focused on these factors.

As the baby boom generation reaches retirement age, aging boomers begin to relocate, just as their parents' generation did years earlier. In southeast Wisconsin the boomers, freed from the constraints of commuting, are attracted to inexpensive farmland in Waukesha, Washington, Sheboygan, Walworth, Dodge, and Jefferson Counties. This trend is further fueled by the continuing decline of agriculture, which has made large tracts of land available at a relative bargain for home building. However, land in western Racine and Kenosha Counties is becoming more and more expensive because of its proximity to Chicago.

For Wisconsinites still in their working and saving years (Gen-Xers and the rest), the exodus of retiring baby boomers creates a glut of "McMansions" dating from the 1980s and 1990s in Waukesha and Ozaukee Counties. Younger workers snatch up big suburban houses at low prices. As a result, the amount of land consumed by housing per person continues to rise for the first two decades of the century.

Much of the new residential development is on lakefront and riverfront property. Despite efforts to encourage (or require) waterfront landowners to retain natural vegetation buffers along shorelines, many homeowners continue to plant, mow, and fertilize their lawns right up to the water's edge. Despite this additional stress on water quality, the reduction in farming in these counties actually results in a decrease in the nutrients applied to the land. In addition, as farmland is converted to residential uses, homeowners plant trees, resulting in modest reforestation of areas that had been largely treeless cropland since the mid-1800s.

Overall impacts on water quality are variable, however, depending substantially on local regulations. In towns where much of the new development takes place, zoning regulations dating from the 1960s continue to promote development on five-acre lots. Runoff from home sites is comparable to the runoff from agricultural land, while the increased road network required to serve these dispersed homesites results in increased runoff from the street to the nearest ditch. Many ditches empty directly into small streams flowing into Wisconsin's rivers. Much of the pollution ultimately reaches Illinois and the Mississippi River. While sedimentation and organic nutrients decline somewhat with the decline in agriculture, the impacts of salt, thermal pollution, and toxic contaminants increase. By 2020, the impacts downstream are significant. The state of Illinois sues all Wisconsin communities that have retained five-acre zoning without instituting other controls to protect waters from street runoff. The case languishes in court for almost a decade, but eventually Illinois wins. Local governments are faced with a massive reengineering of stormwater controls along local streets and highways.

After the verdict in the Illinois case, other communities that had adopted stringent requirements for controlling runoff from streets and other impervious surfaces congratulate themselves on their foresight — not to mention the millions of dollars saved by engineering stormwater controls when the streets were first constructed rather than needing to retrofit decades later.

As the boomers retire, labor shortages create pressure to ease restrictions on immigration. Unlike the immigration boom of the 1980–2000 period, the Midwest becomes a favored destination of newly arrived immigrants. As the Southwest and Southeast experience extreme water shortages beginning in the 2010s, local governments in those regions are forced to limit population growth by placing restrictions on new home building. Homes there become increasingly expensive. Newcomers to the United States, along with many native-born citizens, are attracted by Wisconsin's relatively moderate home prices, its quality of life, and its diverse economy. Like immigrants of earlier generations, most new arrivals make their first homes in the centers of larger cities. Milwaukee's population returns to its 1970 level by 2040. Moreover, between 2020 and 2050, Wisconsin's population grows at twice the rate at which it grew between 1970 and 2000, bringing Wisconsin's total population to 9 million by 2050.

WISCONSIN'S WATERS AND LAND USE: MAKING THE CONNECTION

Wise management of Wisconsin's water requires an appreciation of the fundamental link between land use and water resources. Residential, commercial, industrial, recreational, and agricultural uses of the land can affect — for ill or for good — surface and groundwater supply and quality.

Imagine the land surface as a leaky roof on a house. Some precipitation runs off, but some falls on the roof and passes through and under it. Wisconsin's landscape behaves like a giant roof, whether the surface is a farm field, a woodlot, a meadow, a residential yard, a commercial parking lot, an industrial disposal area, or a city street. Rainwater, snow, and ice eventually reach the land surface and run off into nearby wetlands, streams, and lakes, or filter into the groundwater. Water is transported via natural waterways in rural settings or via stormwater drain systems in urban/industrial settings. This is where the link between the atmospheric water, the land surface, surface waters, and groundwater is made.

The land surface is never perfectly clean. Once falling precipitation reaches the surface, it carries whatever is on the land, including soil, nutrients, leaves, grass, and other organic debris; lead, mercury, and other chemicals and metals; and grease, oil, and other petrochemicals that are spilled or dripped from users of the land. The link between the land surface and water supply is clearly evidenced in the condition of community water systems, private wells, and sanitary waste systems, and areawide wastewater treatment facilities. A leaky landfill can contaminate groundwater needed for human consumption. Gasoline can leak from a failed storage container or spill out during careless refueling efforts. Fertilizers and pesticides improperly applied may likewise run off or infiltrate into the groundwater or recreational surface waters.

The key to safeguarding the quality and quantity of surface water and groundwater is to keep the land surface free of contaminants or pollutants. And the key to wise land use and management is good planning. Planning aims to determine which uses of land are appropriate in different parts of a community, and which uses will best balance the economic and environmental needs of cities, towns, and villages.

Wisconsin's comprehensive planning law (often referred to as the Smart Growth law) prescribes that each town, village, and city will by 2010 have a plan to guide its future development. After the plan is in place, decisions regarding zoning, subdivisions, annexations, and public utility siting must be consistent with these plans. The state government provides matching planning grants to participating communities and will reward qualifying communities whose plans reduce sprawl.

The increase in the central city population is further augmented by aging baby boomers, who by 2025 reach the age when they are no longer willing or able to drive as much as their exurban locations require. While a renewed market for housing in the larger cities eases the development pressure in rural areas in general, demand for waterfront homesites does not abate. Virtually all of the land on the lakes of the Kettle Moraine, Dane County, and the Fox Valley, along with most private river frontage in the state, is built up by 2050. With population pressure mounting throughout the decades of the 2030s and 2040s, cities farther north — Stevens Point, Wausau,

The new planning law should not only help curb sprawl in Wisconsin, but also provide communities with unprecedented opportunities to determine their economic and environmental future — including the future of their surface water and groundwater supplies.

Each comprehensive plan must address a series of plan elements (see below). In the planning process, citizens and communities can ask critical questions involving the link between land, water quality, and water quantity. For example:

Issues and Opportunities: Is there a need in our community for a wellhead protection plan?
Housing: Will most new homes be served with public sewers or private on-site wastewater disposal systems?
Transportation: How and where will new roads be built, and how will runoff from these roads be managed?
Utilities/Facilities: Should there be public investment in new or improved water and sewer systems, and how will their locations influence future growth?
Agricultural/Natural Resources: What safeguards are needed to assure that high-capacity wells will not lower the groundwater table or degrade surface water systems?
Economic Development: Will the plan ensure that high-quality water supplies of sufficient quantity are available for future businesses?
Intergovernmental Cooperation: Is our community ready, willing, and able to address water supply and surface water management issues collectively with neighboring governmental units?
Land Use: Given the range of potential uses of the land in our community, which types of uses will have the least detrimental effect on available water resources? Which can have a positive impact?
Implementation: Is a proper combination of incentives and regulations being considered to provide for sustainable use and restoration of water resources and aquatic ecosystems in the community for generations to come?

By asking such questions, we can make the connection between sustainable land use and water use, and promote healthy waters and healthy communities simultaneously.

and Eau Claire — grow at astounding rates. The increasing population within an easy two-hour drive of Wisconsin's northern lakes puts additional development pressure on those resources.

Although improved site design and building technology reduces many of the negative impacts on Wisconsin's waters, unabated development of Wisconsin's lakeshores and riverfronts wreaks serious damage on Wisconsin's surface waters. By 2075, the essential ecosystem links between land and water are almost completely obliterated in 90% of Wisconsin's major water bodies. Recognizing the impending ecological crisis, Wisconsin enacts a major land purchase program to buy back lakefront properties that can serve as ecological corridors for plants and animals. The vision of a statewide network of open spaces serving both people and nature — proposed decades ago — finally wins sufficient support for passage. The cost of the buyback, planners estimate, is at least 10 times what it would have cost to buy the land for preservation *before* it was developed for homesites.

The pace of conversion of land from agriculture to residential use has continued, but adoption of water-saver regulations during the first decade of the century achieves real results in reducing the consumption of groundwater and the amount of runoff from residential properties. The first water-saver regulations are adopted in southeastern Wisconsin, west of the subcontinental divide, to mitigate the negative impacts of development on the quantity and quality of groundwater available for use by homeowners and public water supply systems. These regulations require the adoption of new plumbing codes that allow the reuse of gray water and other conservation measures. The codes require rainwater to be either used directly or infiltrated to the groundwater to recharge that precious resource. Many a basement rec room and home gym is torn out to make room for a cistern to collect and hold water from showers, the laundry, and rainwater, which is then reused for flushing toilets and irrigating gardens. Some homeowners also install small treatment systems that can remove the small amounts of soap and oils found in gray water.

In counties that have experienced severe groundwater shortages, a moratorium on new wells is imposed in 2010. This rule severely reduces demand for new development in those areas. Even so, some homebuyers are willing to build new homes in areas with no public water supply, despite the ban on new private wells. Instead, these homebuyers have contracted with water hauling firms to deliver water in bulk to buried storage tanks on site. In real estate listings, "on water" takes on a new meaning. No longer does the phrase mean that the home is on a lake or river. Rather, it means that the home is connected to a public water supply.

Water-saver regulations achieve some notable success in using less water and protecting the quality of water. Nonetheless, the continued outward expansion of urban development, including a trend toward larger lot sizes despite the best efforts of Smart Growth planning, exacerbates the problem of stormwater runoff from roads and other impermeable surfaces. More dispersed residential development increases the number of road miles, the number of road stream crossings, and the amount of roadway de-icing materials used in the winter. In southeast Wisconsin, these impacts are felt earlier and are finally resolved through Illinois's successful lawsuit. In the rest of the state, however, change comes slowly.

Finally, by 2060, new Department of Transportation standards are adopted, forcing effective stormwater runoff management from any roadway segment with a pavement width greater than

35 feet. The department estimates that when all roads have been reconstructed to meet this requirement in 2130, Wisconsin roadways will no longer deposit pollutants and silt into Wisconsin waterways. Real progress will be achieved in meeting the 150-year-old goal of achieving “fishable and swimmable” waters throughout the state.

STORY LINE 3: WATER AND CLIMATE CHANGE IN WISCONSIN

Climate change is likely to have a major impact on Wisconsin’s water. The data are telling us that the climate is changing (Houghton et al. 2001). Air temperatures have increased around the northern hemisphere over the last century. In the United States, the 1900s were the warmest century in the last 1,000 years and the 1990s were the warmest decade in the 1900s (Trenberth 2001). Over the last 150 years, the duration of ice cover on lakes has decreased in Wisconsin and around the northern hemisphere (Magnuson et al. 2000). Changes in ice cover have been more rapid in the last 20 to 30 years than over the last 150 years (Magnuson et al. in press). The percentage of rain falling during extreme events has increased since 1910. These are some of the observed changes, and they are well documented. How might changes in Wisconsin’s climate affect our waters?

Setting the Stage: The Climate in Flux

Climate models, driven by increases in the concentration of greenhouse gases such as CO_2 from the burning of fossil fuels, have generated a range of possible future climates. The model scenarios suggest that the Great Lakes region will experience a warming climate over the next century (see chapter 2). Nighttime temperatures are expected to warm more than daytime temperatures. Warm extremes are expected to be more common. Stream base flows are expected to decrease and water levels are expected to fall in most lakes (Sousounis and Bisanz 2000;

Lofgren et al. 2002). Such changes would obviously influence our waters, as well as the options and strategies we might adopt to manage and conserve water.

What scenarios should we create to highlight the critical role of climate change in Wisconsin's water future? If, because of uncertainties in the models and in future energy policies, we were to choose a risk-prone future, we might build scenarios around the least degree of change: "Why do anything in water management because climate change may not occur or may be minimal?" If, because of the same uncertainties, we were to choose a risk-averse future, we might create scenarios around the greatest degree of change: "Why not prepare for the worst in management of our waters because it may happen?" Alternatively, we might prefer an intermediate approach to the future and assume degrees of change and risk somewhere between the extremes.

As we consider the future, we can either plan or not plan for change. Climate scenarios indicate that in the century ahead we will move toward a warmer and drier climate. Thus, decisions about climate and its effect on Wisconsin's waters will fall into at least two categories: (1) changes in energy use and policy from the local to the global scale, and (2) adaptations in the way we use water resources and conserve aquatic ecosystems to achieve a sustainable future. The scenarios that follow describe two futures: one in which we adapt to climate change and its attendant effects on water, and one in which we do not. In the "without adaptation" scenario, society would cope as effectively as possible with changes after they occur, but with some time lag. Decisions on waters would be based on the observed climate, perhaps over the previous 10 years. In the "with adaptation" scenario, society would undertake planning and design of water use and management to anticipate changes in hydrology and aquatic ecosystems.

To provide a broad margin of interpretation, the design climate for both scenarios falls on the more dramatic side of potential future climates. Under these climate conditions, the air temperature warms, rainfall amounts stay about the same, evapotranspiration increases, more of the rainfall occurs in extreme events, and a greater proportion of winter precipitation occurs as rain rather than snow. This has widespread consequences for the goods and services provided by water and for the quality of aquatic ecosystems. Of course, many such consequences could be explored; the impact, for example, of reduced ice and snow on ice fishing, snowmobiling, skiing, and other forms of winter recreation, or the potential influence of climate change on the eutrophication of lakes. Here we focus on two dimensions of water: flooding and drought, and fish biodiversity and fishing in inland waters.

Flooding and Drought

Climate change alters the hydrologic functions and characteristics of Wisconsin's waters. Flooding from extreme rain events becomes more common. Base flow in streams decreases, owing both to increases in evapotranspiration in the warmer climate and to increased runoff and less infiltration during extreme events.

Without Adaptation

Without adaptation to these hydrologic changes, flood damage to shoreline areas of Wisconsin's inland lakes and streams increases. Homes become increasingly susceptible to damage. Under the state's Smart Growth provisions, rain gardens are promoted in urban areas in the effort to maintain infiltration and reduce flooding. These, however, prove insufficient under the new climate. Managers of water levels and flows attempt to increase the control of floodwaters by dredging and channelization, and by building more dikes and dams (including reconstruction of dams at sites where they were removed in the first decade of the new century). River and river floodplain ecosystems are further degraded, and the ecosystem services they provide are reduced. Affected ecosystem services include the biogeochemical cycling of nitrogen, fish and wildlife habitat, and water for recreation.

Water extraction from surface waters for sewage treatment and for drinking water proves insufficient in the new climate, even though plans were designed to anticipate population growth and urban development. Consequently, downstream flows are even further reduced. The drying up of medium-sized rivers becomes more common and longer in duration, especially in drier years during the summer. Water levels of most lakes decline, in response to increased evaporation and reduced base flow. Water extraction increases and becomes a significant component in the water budget of large lakes. In the Great Lakes, the drop in water level is sufficient to cause cities to rebuild shoreline infrastructure for water supply and harbors. The dredging of harbors and interlake channels intensifies progressively to maintain shipping channels and boat access. There is fear that with further declines, shipping on the Great Lakes may cease altogether.

With Adaptation

Adapting to the expected hydrologic changes, planners and developers anticipate increased flooding from extreme rain events and reduction in the base flow of streams. A conscious decision is made to delineate areas that will become increasingly flood prone under the new climate conditions and to incorporate this knowledge in planning and development. Zoning is taken much more seriously as a means of preventing development in flood-prone areas. Mechanisms are developed to deliberately relocate people already in flood-prone areas to higher ground.

The effects of climate change are incorporated into Smart Growth plans. A program of outreach education, regulation, and incentives is implemented to promote better choices of home and development sites. Residential and commercial developments are no longer in harm's way. Rain gardens are incorporated and retrofitted into building designs in the attempt to maintain infiltration and reduce flooding. Managers of water levels and flows attempt to hold water higher in the drainage system and to increase infiltration to maintain base flows. River and floodplain ecosystems are less degraded, and ecosystem services are better maintained. Water extraction from surface waters for sewage treatment and drinking water is designed to include the response of drainage systems to climate change.

Wisconsin's land cover moves toward more drought-resistant landscaping in urban neighborhoods, drought-adapted crops in agriculture, and the restoration of drought-tolerant native prairie and savannah communities. Consequently, downstream flows are better maintained. The drying of medium-sized rivers remains uncommon. Water extraction from lakes and streams and from groundwater systems is reduced as stringent water conservation measures are adopted. The water level in most lakes still declines, owing to increased evaporation and reduced base flow. In the Great Lakes, the costs of adaptation to lower lake levels are anticipated and less of a surprise. In general, the costs of adapting to climate change are acknowledged, and opportunities for benefits in the new climate are sought.

Fish Biodiversity and Inland Fishing

Again, climate change has altered the hydrologic functions and characteristics of Wisconsin's waters. Water temperatures rise in lakes, streams, and groundwater. Infiltration decreases and base flow decreases; minimum instream flow decreases; winter runoff increases; and flooding increases. The lakes and streams have shorter periods of ice cover. Lake waters mix earlier in the spring and later in the fall, effectively remaining thermally stratified through a longer summer.

These changes, in turn, have significant impacts on Wisconsin's aquatic ecosystems, and hence on fish habitat, distribution, and populations. Habitat with temperatures suitable for stream trout and for coldwater fishes (trout, whitefish, and lake herring) in inland lakes decreases. Habitat with temperatures suitable for coolwater fishes (walleye, perch, northern pike, suckers) decreases in most streams and shallow inland lakes. Habitat suitable for warm-water fishes (bass, bluegill, carp) increases in streams and inland lakes, at least through 2050.

In contrast to the inland waters, thermal habitat increases for cold-, cool-, and warmwater fishes in the Great Lakes as the fish move down to thermal refugia in deep water (Magnuson et al. 1990). Growth rates in the warmer waters increase where the production of fish prey is sufficient to provide food to fuel the higher metabolic rates at the warmer temperatures (Hill and Magnuson 1990). Commercial aquaculture decreases for coldwater fishes and increases for warmwater fishes such as channel catfish. The southern distribution boundary for cold- and coolwater fishes moves northward 300 miles with a doubling of heat-trapping gases in the atmosphere.

Invasions of warmwater fishes become common in connected waters as populations disperse northward. In inland lakes, increased predation by and competition with warmer-water fishes further degrades waters for the coolwater and even coldwater fishes such as lake trout (Vander Zanden et al. 1999). Invasive warmwater organisms other than fishes increase, causing dramatic changes to the community structure of lakes and streams. The winterkill of fishes decreases as the shorter period of ice cover reduces the likelihood of complete oxygen loss under the ice. The summerkill of coldwater fishes in inland lakes increases as the longer period of summer stratification results in greater declines in oxygen in deep water. Increased flooding and higher erosion rates cause more siltation, while increases in winter rains and runoff increase nutrient inputs from agricultural fields to lakes and streams.

Without Adaptation

People cope by changing the species they fish for. Trout fishing in inland waters experiences the greatest decline. Other popular inland water fisheries — walleye, northern pike, muskellunge, perch — also decline. Opportunities for Native American spearfishing for walleye decline in the north with warming and the introduction of additional warmwater species.

There are changes to the image of Wisconsin — and even the state's "sense of place" — as a northern mecca for recreational fishing and as the source of rich Native American cultures. Fishing opportunities come to resemble those of more southerly states. Fishing for warmwater fish such as smallmouth and largemouth bass increases as these species become more common and as fishers pursue available recreational fishing opportunities. Recreational fishers begin to target the warmwater-loving carp as they become more abundant.

The transport and planting of live fish from one lake to another are permitted only with the approval of the Wisconsin Department of Natural Resources, but as fishing declines, illegal introductions become common. Individual fishers and landowners transport warmwater fishes northward into their lakes without any planning or control, haphazardly hastening the decline of the cooler-water species in the region. Fishers also notice that game fish attain lower weights because of the higher metabolism rates that warmer temperatures entail. Fishers respond by introducing warmer-water prey species. In many lakes, these introductions significantly reduce the relative abundance of native fishes.

With Adaptation

Many of the trends in fish populations and fishing behavior are unavoidable, but active response allows us to determine to some degree the rate of change and the amount of suitable habitat for different fisheries.

On many Wisconsin streams, temperatures are maintained for trout over more stream miles for longer periods. This occurs as landowners, both private and public, increase shoreline shading and thus reduce solar heating of the stream. They increase water infiltration rates in the watershed through changes in upland land use and land cover, gradually allowing greater quantities of groundwater to accumulate and discharge into the streams. Communities and landowners have also removed dams from trout streams, reducing the amount of impounded water, which warms more rapidly than stream reaches. Better shoreline and watershed management on both public and private lands decreases the negative effects of increased runoff and associated flooding on siltation and nutrient inputs. These behavioral shifts reduce the rate of loss of coldwater stream fisheries.

On Wisconsin's lakes, regional plans are developed to sustain coolwater fishes in the face of global warming and increased predation and competition from warmwater fishes. These plans include the identification of lakes in the state where walleye and other coolwater species are most likely to persist. This is especially important in the areas where Wisconsin's tribal members spear walleye. Following triage methodology, other lakes are managed for warmwater fishes with little or no attempt to sustain coolwater fish populations. Climate models are developed to estimate future temperature structure of candidate lakes for coolwater fishes. Those with the greatest potential are placed in a class managed for sustaining coolwater fishes. In these waters, new warmwater species are not introduced and supplemental stocking is not used to augment existing warmwater fish populations. Where necessary, special fishing regulations (e.g., allowing only catch-and-release fishing for walleye and other coolwater species) are considered to sustain the coolwater fishes. Similar approaches are used to increase the likelihood that populations of non–game species or threatened and endangered coolwater fishes can persist.

STORY LINE 4: WATER AND WISCONSIN'S NORTHERN LAKES

*Ten thousand years ago when, the continental glaciers melted back out of what is now Wisconsin, they left behind the gift of the northern lakes and streams. The following scenarios describe possible futures for one portion of northern Wisconsin: the Northern Highlands lake district. This area includes Oneida and Vilas Counties and portions of Forest, Iron, and Price Counties. It is now changing from a region of relatively sparse settlement to one with a denser human population. As in the other story lines in this chapter, this transition will be shaped by many complex variables, including changes in climate, species invasions, human migration patterns, land use regulation, technology, and business activity.**

Varied external forces are transforming the lakes of Wisconsin's northern highlands. Preeminent among these is the migration of people into the region. Climate change, mercury deposition, and the invasion of exotic species are also expected to play a role. Climate change is expected to warm the region and bring increased rainfall over the next century, although the degree of future change is uncertain. Mercury from the burning of fossil fuels outside the region

* The Northern Highlands Lake District scenarios presented here are adapted from Peterson, G. D., T. D. Beard Jr., B. E. Beisner, E. M. Bennett, S. R. Carpenter, G. S. Cumming, C. L. Dent, and T. D. Havlicek. 2003. Assessing future ecosystem services: A case study of the Northern Highlands Lake District, Wisconsin. *Conservation Ecology* 7(3): 1 (available online at http://www.consecol.org/vol7/iss3/art1). The WOW committee thanks our colleagues for permission to draw upon their work.

continues to accumulate within the region's ecosystems. The ever-increasing global movement of materials inadvertently relocates species, occasionally with substantial effects on their receiving environments. Although the arrival of new species in the region is to be expected, the consequences of their arrival are difficult to predict. The three scenarios that follow are defined using two key uncertainties: human migration patterns and ecological vulnerability.

Walleye Commons

In the 2000s, national and global economic growth accelerate as a result of reforms in energy policy, expanding globalization, and peaceful international relations. As wealth spreads worldwide, many regional conflicts are resolved. Terrorist threats decline, and international travel increases sharply. The expansion of high-speed wireless networks increases the ability of people to telecommute and greatly increases the flexibility of the traditional workweek. People use more disposable income than previous generations and have more time for leisure activities. Global travel becomes easy, cheap, and common.

Life in Wisconsin's northern highlands, however, has taken a turn for the worse. Climate change has brought longer summers and milder weather. As expected, warming reduces opportunities for snowmobiling, cross-country skiing, and other winter sports. At the same time, and quite unexpectedly, climate warming also contributes to the spread of disease. A deadly walleye pathogen, which was amplified in hatcheries, quickly spreads and forces the closure of several valuable walleye fisheries. Even worse, a water-borne protozoan introduced from South America creates a new human health hazard in the region. The protozoan easily moves from lake water through open cuts to infect the human nervous system. Over a period of years, victims of protozoan infection suffer gradual and debilitating nervous system disorders. Although the disease is usually not lethal, the quality of life of those infected is severely reduced during the multiyear recovery period.

The coincidence of easy global travel, substantial disposable income, limited fishing opportunities, and fear of disease has a major impact on life in the lake district. People from urban centers who had once flocked to the region because of its accessibility, charming beauty, and relaxed atmosphere now choose to vacation or retire to other, safer locations. The decline in tourism and the sale of many second homes, along with the fear of living with a mysterious and dangerous disease, lead many local business owners to follow their former customers to other regions. These initial emigrations set in motion a downward spiral. Declining property values, bankrupt businesses, and school closures lead more people to leave the area and accelerate the decline. Small towns lose almost all of their businesses. Larger towns, such as Minocqua and Eagle River, become small, poor, and dilapidated. When they cannot be sold, many summer homes and cabins are seldom visited or simply boarded up and abandoned.

During this emigration, however, few people leave Lac du Flambeau. Despite unemployment and declines in casino revenue, people begin to take advantage of low land prices to purchase land. With the construction of new casinos in southern Wisconsin, the Lac du Flambeau Band in cooperation with a consortium of other Native American groups is able to purchase land in northern Wisconsin. The state of Wisconsin and The Nature Conservancy also take advantage of cheap land to expand existing nature reserves. The net result is an increase in the size of protected areas and tribal lands and a decrease in the amount of land held in small private plots.

Ecologically, this series of events has both predictable and surprising consequences. Wetlands greatly expand as riparian vegetation reclaims once-manicured lawns. Wildlife proliferates as a result of reduced exploitation and increased available habitat. The reduction in fishing and boating slows the spread of invasive species, especially into small isolated lakes. Reduced human activity increases overall water quality and improved fish populations in the region. However, erosion from poorly maintained roads and lawns increases turbidity in a number of lakes. Size and age distributions of fish populations shift toward older, bigger fish, that is, those typically targeted by anglers. In lakes affected by the hatchery-borne walleye disease, the walleye do not recover, but other fishes such as smallmouth bass and muskellunge establish robust stocks. A few larger lakes become eutrophic as the septic systems of abandoned lakefront homes fail and leak. However, there is less pollution in the area in general, and the increase in wetland area provides more filtering and buffering capacity for the pollutants that remain.

Surprisingly, mercury pollution in lakes becomes an increasingly severe problem. Coal burning upwind of the area continues to deposit mercury across the region, and the increased wetland area exacerbates the bioaccumulation of mercury. The increase in wetlands causes an increase in anoxia and dissolved organic carbon in lakes. Increased anoxia increases the generation of methylmercury, and increased dissolved organic carbon reduces the ability of light to degrade methylmercury. The presence of large, old fish, which bioaccumulate more mercury than do the smaller fish lower on the food chain, in combination with the increased amounts of methlymercury, leads to high levels of mercury in many fish. For Native Americans heavily dependent on spearfishing walleye, which selects for larger, more mercury-laden fish, this presents a health risk, but an innovative system that combines lake rotation with pulsed harvesting is invented to reduce mercury exposure.

In 2025, roughly 12,000 people are living in the lake district, representing a fourfold population decline from 2000 to near 1900 levels. However, the Native American population has grown from less than 10% of the population to roughly 40%. People living in the area are not much better off than they were in 2000 and relatively much worse off than in Wisconsin as a whole. With the exception of walleye, fish populations are healthy. The lakes look good, but the water is dangerous. However, the people in the area now say that the wealth they receive from nature more than compensates for their low incomes. Those who disagree left long ago.

Northwoods.com

In the 2000s, concerned that the robust growth of the U.S. economy would leave Wisconsin behind, the state government, business leaders, academics, and community groups create statewide economic and community development plans that allows Wisconsin to thrive in the 21st century. A program that combines venture capital with university and community partnerships leads to the development of a large University of Wisconsin campus and business park in Rhinelander. The goal of this expanded campus is to retain young people in Wisconsin. The university emphasizes local community and business development. With the establishment of the university campus and the influx of faculty, staff, and students, the regional economy gradually diversifies away from tourism toward an economy that includes a number of branch offices for a wide variety of businesses. Some initial local successes, combined with the high quality of life, leads to the rapid expansion of these branch offices.

Young people are drawn to the area by the low cost of living and the high quality of life in the northwoods. Companies find the area attractive because they can recruit talented people for relatively low wages. Some companies even argue that the residents of the lake district receive two paychecks: one from their jobs and the other from life in a region that offers remarkable opportunities for outdoor recreation. As young people remain in the region, the Rhinelander and Minocqua areas begin to urbanize. The young residents tend to cluster near the social life of the university. As the area develops and property values rise, this area gradually expands along the Wisconsin River from Rhinelander to Merrill.

The fresh waters in the Wisconsin River corridor from Eagle River to Merrill become highly urbanized and heavily used. The lakes closest to this corridor sustain major ecological impacts from urban development and heavy human recreation. Most nearby wetlands are drained for lakeshore development, more pollutants enter these lakes from the watershed, blue lakes turn green from increased nutrient runoff, increased fishing pressure causes fish stocks to decline, boat traffic accelerates the dispersal of invading species, and concentrations of aromatic hydrocarbons increase 100-fold in the lakes.

A series of fish kills in the Wisconsin River causes widespread concern about the costs of development. Economic growth around Rhinelander increases the tax base of cities and towns, which increases the relative political power of urban residents. These fish kills mobilize the urban residents to protect the aquatic resources of the surrounding areas. City governments and then county governments and businesses all support new land use policies to appeal to their new constituents. However, businesspeople prefer market-based policies to strict regulation and, in cooperation with University of Wisconsin faculty, they create an innovative and profitable market for quality riparian habitats and a variety of ecosystem services provided by pristine lakes. Acquiring conservation lands becomes a major goal of the local government. Zoning ordinances and conservation easement plans, funded by a steep horsepower tax on boat motors and riparian development, are enacted to preserve the lakes in the surrounding region.

Although many landowners profit from these policies, other residents grow angry as development costs for lakefront property soar, as does the cost of utilities, wells, and fishing. Some rural constituents take advantage of the cost-sharing programs and capitalize on the increased value of their property for tourism, whereas some urban residents still want to use large motorboats on pristine lakes. However, regardless of this opposition, the majority agrees that, if the inhabitants want to degrade ecosystem services, they must pay to replace them.

Although the Lac du Flambeau casino does not do as well as hoped, an influx of new job and training opportunities into the area greatly improves job, educational, and cultural opportunities for Native Americans. In two decades, they go from having a per capita income less than half that of other northern residents to one as high as the state mean. Despite some conflicts with the new town-oriented environmental regulations, these regulations increase the value of much of the Lac du Flambeau land. The tribe, controversially, limits access to a number of reservation lakes to produce highly profitable, high-quality fishing lakes.

By 2025, the population of the region has grown to nearly 65,000 people, a 50% increase over the population in 2000. Most of the population growth occurs near the Wisconsin River. Household income in the region is now about equal to that of Wisconsin as a whole. Rather than being older than the rest of Wisconsin, the population of the region is slightly younger. In general, conservation policies cause most of the lakes in the region, especially those farther away from the urban corridor, to improve in quality. Overall, the region provides more ecosystem services than in the past. More riparian habitat improves fish recruitment and growth, and more trophy fish are caught. Lakes that had previously experienced a lot of motorboat activity and associated pollution improve in water quality. Wetland area increases, adding to the improvement of the water quality in many lakes. Increased wetland area also increases dissolved organic carbon inputs to some lakes and, through methylation-light penetration feedback, mercury problems are exacerbated in some areas. For tribal members, whose diet and cultural traditions depend heavily on fish consumption, this is a serious health problem.

Lake Mosaic

Economic growth in the late 20th and early 21st centuries creates many wealthy baby boomers. Despite a generally robust economy, international tensions, terrorism, and warfare greatly reduce international travel. Their ready cash and reluctance to travel lead many families to consider either buying a vacation home in, or retiring to, northern Wisconsin. Furthermore, the milder climate resulting from global warming makes the region a more desirable location to live in year-round. These changes, combined with expansion of high-speed wireless networking, increase the number of people who alternate their lives between two homes. All these factors increase the number of households deciding to move, full- or part-time, to the northern highlands. Most of these new residents want lakeshore property and homes in the woods away from the hustle and bustle of city life.

Lakeshore development proceeds rapidly. The residents, most of whom move to the area because of a love of the outdoors, spend lots of time on lakes or in the nearby wooded areas. Consequently, they choose locations that were not highly developed. As the number of cabins on an individual lake begins to climb, that lake becomes less attractive to new arrivals, and new developments begin on other, less developed lakes. As a result, almost all lakes in the region become moderately developed.

Most residents are very attached to their lakes. Often people are attracted to a particular lake because of its features and the attitudes of the other people living around it. These people frequently organize themselves into lake associations. Many existing lake associations become powerful and implement a variety of activities intended to improve life around their lakes. However, the scope and ultimate goals of these activities varies. Some people improve their lakes by removing all hazards to boat navigation and importing sand for beaches, whereas others try to improve fishing; still others add woody debris to their lakes in an effort to return them to a former wild state.

The great variability among lakes and the diverse interests of the people settling around them lead to considerable variety in lakeshore development patterns. Some lake associations advocate the rights of residents to build "dockominiums," modify habitat, and intensify boating activity. Other lake associations work to ban personal watercraft, severely restrict loss of habitat, limit access, and improve fishing.

With the increased population of the region, fishing quality generally declines despite ever-stricter regulation by the Wisconsin Department of Natural Resources. This leads several groups of people, including some fishing clubs, to purchase the entire perimeter of a lake to provide high-quality fishing. On these lakes and a few lakes in government-maintained wilderness areas with "trophy-only" regulations, fishing quality is excellent. Some private landowners are able to profit handsomely by selling extraordinary fishing opportunities at premium prices. However, in most lakes accessible to the public, fishing quality continues to decline because of increased fishing pressure and the continual removal of the larger individual fish. Whenever one lake has a particularly good year, mobile anglers quickly descend on it and reduce the quality of its fishing to the level of the other lakes in the region.

The decline in public fishing opportunities, combined with the improvement in private fishing, is only one of many initially subtle, but increasingly open conflicts among people living on different lakes. Resort operators complain about how the new residents, through overfishing, limit their ability to attract tourists. Lake residents are often unfriendly to outsiders, and conflicts over noisy boats, roads, land use, and the deterioration in water quality sometimes lead to nasty and long-running feuds. Ecological management decisions are frequently court-mandated. There are many irate letters to the editors of local papers, more intense influence peddling, more acrimonious county board meetings, and increasingly frequent acts of vandalism.

This gradual spread of low-density residential development across the landscape has variable and lake-specific ecological effects. These depend on the preferences of the lakeshore owners and the characteristics of the individual lakes. For example, a "swimming lake" may have less coarse woody debris, better or at least stabilized water quality, and decreased motorboat traffic. In other lakes, especially small lakes or lakes with only a few property owners, habitat, water quality, and fishing quality remain high.

In 2025, the population of the Northern Highlands is 55,000 people, a population increase of 25% from 2000. The region's inhabitants are generally older and richer than in Wisconsin as a whole. However, there is a lot of inequality. Whereas a number of rich people own huge homes that they occupy for only a few weeks a year, many local residents earn minimum wages for cleaning and security companies. Everyone agrees, however, that the northwoods have become more like the suburban environments found commonly throughout the United States. There are many suburban features, ranging from extensive lawns to strip malls. Local politics are more contentious and divisive. Although many people are unhappy with the ways that the area has changed, there are conflicts that prevent effective organization to improve the situation. There is a sense of quiet resignation that the northwoods will inevitably follow the path of suburbanized counties "down south." Some long-term residents even sell their homes to relocate to quiet, wild, undeveloped lakes in Canada.

TODAY'S CHOICES, TOMORROW'S WISCONSIN

These scenarios illustrate only a few plausible futures. They are intended to trigger conversations about the future and about public and private choices that will have significant long-term consequences for Wisconsin's waters. As noted, the basis upon which we make choices constantly changes, reflecting advances in scientific understanding, emerging environmental concerns, shifting public perceptions and attitudes, and reevaluations of economic costs and benefits.

A century ago, the choices were simpler, and more poorly informed. We knew little about the way water worked within the Wisconsin landscape, or through its continental and global hydrologic connections. The economic and ethical dimensions of our water uses were seemingly straightforward, less burdened than they are now by an appreciation of trade-offs and unintended consequences. The cultural context of our water decisions was narrow, providing scant room for consideration of prior generations of Native American stewardship, or of the stake of future generations in productive, healthy, self-renewing aquatic ecosystems.

Our choices are more difficult now, and better informed. We know more about water. The waters themselves are subject to increasing pressures and competing needs and desires. The cultural and ethical dimensions of water use, protection, and management are central to the discussion. The global context of water decisions is unavoidable.

Despite the changes of the last century, there is a constant. One hundred years ago Wisconsin helped in important ways to give birth to the national conservation movement, which emphasized the need for commitment to the public interest in managing natural resources. In the past, that commitment has allowed Wisconsin to be a leader in conservation policy and practice. The future can build on that past. The results will be reflected in the waters.

For most of us, thinking far into the future does not come easily or naturally. The goal in this chapter has been to ask how we might consider the future more seriously as we make decisions. To anticipate growing water problems and to secure healthy aquatic ecosystems and water resources, we need to evoke a sense of obligation to the future among different sectors and constituencies in Wisconsin. And to do that, we need to push the time frame of our thinking forward.

As we look ahead, the main thing we see is widespread uncertainty and complexity. To chart a course that sustains our waters, we will need to think broadly over the long term and integrate multiple factors in our planning. We will need to avoid, as much as possible, decisions whose consequences foreclose future options. We will need to invent new decision-making processes that ensure fair, informed, and open public participation. And even as we try to prevent further degradation of our waters, we will need to encourage actions that restore them.

We can improve our ability to anticipate and adapt to change. Building that adaptive capacity is a task for citizens, institutions, and decision makers in all sectors. Our culture is characterized by short-term thinking. We will need consciously to support and reward efforts to think long-term about water use, water policy, and water economics. We will need to make allowance for learning — and for failure — in the process. We will need to identify and gather the information necessary to manage our waters more effectively and, we hope, to mark our progress.

Given the complexity and uncertainty on the path ahead, we need to define principles that can help guide our decisions. Such principles can help to reduce our vulnerability and encourage conservation (in the broad sense) of our waters. The next section of this report attempts to provide such a set of principles.

CHAPTER 4

SUSTAINING WISCONSIN'S WATERS

Harold E. Malde, courtesy of The Nature Conservancy

The Waters of Wisconsin initiative has sought to encourage long-term thinking about the fate of all Wisconsin's waters. This is not to discount the critical importance of the many specific water-related challenges we face now and in the immediate future. Rather, it reflects the need, and obligation, to look forward and plan ahead if we are to avoid short-term crises and chronic degradation of our waters.

Solutions to contemporary problems, and assurances of the long-term health of Wisconsin's waters, must be based on a shared set of values, accurate information, sound and responsive policies, and citizen commitment. Water has a strong capacity to renew and restore itself. However, that capacity is not unlimited and has been tested severely in many places. Water is subject to new pressures as human demands grow and change. To better protect Wisconsin's water resources and aquatic ecosystems over the long run, we need to think about water in new ways — ways that avoid the shortcomings and misconceptions that have compromised Wisconsin's waters in the past.

The concept of *sustainability* has emerged as a way of addressing the interrelated needs of people and ecosystems. Although definitions of sustainability vary, most share a basic trait: they recognize the need to connect the well-being of human communities, economies, and institutions to the quality and resilience of the ecosystems in which they are embedded. Sustainability allows us to consider simultaneously our social, economic, and environmental needs and the long-term consequences of our actions (NRC 1999b; Hawken et al. 1999; Baron et al. 2002; Holland et al. 2003).

What does sustainability mean when applied to a particular aspect of the ecosystem: *water*, in a particular place: *Wisconsin*? Participants in the Waters of Wisconsin initiative have considered this question. Our goal in these discussions was to develop a general statement of principles upon which more effective water policies, conservation actions, and stewardship investments might be based. We hope that such a statement will prove useful to those who make decisions involving water in Wisconsin.

Of course, all Wisconsin's citizens make daily decisions that affect water. Perhaps no single statement can address all the values, realities, requirements, and concerns involving water in Wisconsin. However, the WOW participants believe that this statement, prepared in the spirit of Wisconsin's long-standing conservation ethic, can help strengthen the foundation for a sustainable water future.

A STATEMENT OF PRINCIPLES

People in Wisconsin, and throughout the world, are coming to realize that water cannot be taken for granted. Increasingly we appreciate that degradation of water bodies and watersheds, excessive drawdown of aquifers, disruption of hydrologic processes, loss of aquatic biodiversity, and varied forms of water pollution pose serious threats to human health, the quality of life, a thriving economy, and vital aquatic ecosystems. We are awakening to the strong links between water and our progress toward a more peaceful, prosperous, secure, and socially just world (Leopold 1990; Postel 1999; Gleick et al. 2002).

Wisconsin, though only a small part of that world, has been and should continue to be a leader in this effort. Wisconsin's bounty of freshwater and the variety of its aquatic ecosystems are assets of global significance. However, our waters face diverse short- and long-term challenges to their integrity, beauty, and abundance. In striving to address these challenges, Wisconsin's citizens can again assert the commitment to conservation that binds our generations together over time and across our landscape.

For the purposes of this report, sustainability implies *a commitment to protecting, managing, restoring, and using Wisconsin's waters in a manner that ensures the health of our aquatic ecosystems while securing their cultural, economic, and public health benefits for future generations.* In Wisconsin, the sustainability of our waters is closely connected to our understanding of water as a shared resource. Our state has a strong cultural and legal tradition that recognizes the public interest in all the waters of the state (Kent and Dudiak 2001). We also recognize that Wisconsin's waters are part of larger hydrologic cycles and systems, and that our actions affect human and natural communities elsewhere. These facts imply that we have responsibilities both within and beyond our boundaries.

The well-being of Wisconsin's citizens and the state's community of life require a firm commitment to understanding the impact of our activities — current and expected, positive and negative — well into the future. With this knowledge we will be better able to shape that future, rather than merely react to changes. As we envision a healthy future for the waters of Wisconsin, and all that depends on them, we may begin by defining foundations for that future. These foundations include consideration of the value of water, the connections that characterize water, the water policies that we as a state abide by, and the approach that we take as stewards of the waters.

Water Values

Wisconsin's waters are of **value** for the biological diversity and ecosystem functions they support; for the spiritual, aesthetic, cultural, health, and economic benefits they provide; and for the essential human goods and services they provide.

Wisconsin's waters do not belong to any one generation. The relationship between Wisconsin's waters and its people extends to both **past and future generations.**

Wisconsin's land ethic embraces all its waters. Our citizens recognize a **personal obligation** to safeguard our waters and to use them with care and respect.

All Wisconsin citizens have **rights and responsibilities** in relation to water. Fair and equitable **access to water** of sufficient quality and quantity, for basic uses and enjoyment, by the people of Wisconsin shall be assured.

With this assurance comes a **responsibility to avoid water uses that cause excessive, unreasonable, or irreparable harm** to other people, to future generations, and to other forms of life dependent on Wisconsin's waters.

The well-being of Wisconsin's waters requires the active **involvement, participation, and leadership of citizens in decision making** at the local community and watershed level.

Decisions involving Wisconsin's waters respect the values and traditions of the state's **diverse cultural groups**, while recognizing the common interest in healthy waters.

Water Connections

Wisconsin's waters are **connected to larger ecologic and hydrologic systems and cycles,** and contribute importantly to their healthy functioning.

Atmospheric water, surface water, and groundwater together constitute **an integrated hydrologic system.**

Wisconsin's **aquatic and terrestrial ecosystems are bound together in watersheds,** and these connections shall be recognized in all protection, management, and restoration plans and actions.

The healthy functioning and biological diversity of aquatic ecosystems are best supported when **natural hydrologic connections,** especially in our flowing waters, are maintained, enhanced, and restored to the fullest possible extent.

Wisconsin's waters form **a dynamic medium** in which aquatic organisms, materials, and compounds are commingled and transported.

Issues of **water quality and water quantity** shall be considered together.

Wisconsin's atmospheric, surface, and underground waters move between and across wild, semiwild, agricultural, rural, suburban, and urban lands, and their health depends on stewardship actions **across the full spectrum of landscape types.**

Wisconsin's waters — and responsibility for them — are shared across state and national boundaries. Wisconsin shall thus manage its waters in a spirit of **mutual cooperation and benefit with our neighbors.**

Water Policies

Wisconsin's water, in all of its forms, is essential to the well-being of the people as a whole. Water policies in Wisconsin shall be in accordance with the state's **public trust doctrine** and shall guide management of all the state's waters, carefully balancing the public interest with private rights.

Policies to direct the management, use, restoration, and conservation of Wisconsin's waters shall be **comprehensive, coordinated, and appropriately scaled.**

Water policies necessarily involve **coordination across jurisdictional boundaries and among different levels of government,** and shall aim to enhance cooperation among all governmental entities.

Sound water policies are built upon **interdisciplinary knowledge and integrated approaches** to entire water systems.

Policies shall be based on **consistent and responsible use of the most reliable scientific information and knowledge available** on the status and trends that characterize Wisconsin's water resources and aquatic ecosystems, while acknowledging the role of uncertainty in the use of scientific data.

Water policies shall recognize the **market and nonmarket values of water** and strive to acknowledge the full costs and benefits of varied water uses.

Water policies shall seek to **address and correct economic forces** that deter conservation efforts and that encourage wasteful or harmful use.

Water policies shall, through appropriate rewards and incentives, **encourage and support actions** that conserve water, improve water quality, and protect and restore the state's aquatic ecosystems.

Conversely, water policies shall, through appropriate penalties and disincentives, **discourage actions** that result in the inefficient use of water, decline in water quality, and degradation of aquatic ecosystems.

Water policies shall recognize that there are **no "one size fits all" responses** to our multiple water challenges and should encourage innovative solutions.

Water Management and Stewardship

A **commitment to water education,** involving all Wisconsin citizens, is fundamental to effective stewardship of the state's waters.

Citizens, organizations, and institutions should have **access to information** about water, the source and destination of the waters they use, and the changes that may occur in the process of using them.

Because **the size of our human population, our consumption habits, and our patterns of land use** have critical impacts on the status of Wisconsin's waters, these factors should be considered in any long-term efforts to attain water stewardship goals.

Long-term challenges to the health and ecological integrity of Wisconsin's waters are easier to address before they become acute problems; policies should therefore strive to be **proactive rather than reactive.**

Wisconsin's **waters ought to be conserved at all times,** and not just in times of emergency, to maximize our flexibility in managing demand.

In the face of uncertainty, management policies and actions should support **cautious and conservative use** of Wisconsin's waters and seek to prevent irreversible damage to, or the addition of dangerous inputs into, the waters.

In order to reduce uncertainty and improve our ability to make wise management decisions, water managers in all sectors should seek constantly to **identify and meet new water information needs.**

Watershed and water basin approaches should be an inherent part of all water management and planning.

Management of Wisconsin's waters should strive to protect and where possible restore natural **hydrologic functions, native biological diversity, and ecological integrity.**

Management of Wisconsin's waters should be **flexible and adaptive** in responding to advances in scientific knowledge as well as challenges resulting from unexpected and potential changes in climate, hydrologic systems, ecological interactions, and social and economic conditions. This should not be misconstrued to allow for inequitable use or additional degradation to knowingly occur.

Continuous water monitoring and assessment is essential to sound management of Wisconsin's waters and must be adequately supported in both public and private sectors.

Management policies should encourage the **continual development and adoption of innovative technologies** to improve water conservation, education, monitoring, remediation, and restoration.

TESTING THE PRINCIPLES

To test these principles — to see what happens when the "rubber" of sustainability principles meets the "road" of reality — participants in the Waters of Wisconsin initiative applied them to a series of case studies around the state. Appendix D contains summaries of five case studies: managing water levels on the Upper Mississippi River; cleanup in the Fox-Wolf River basin; high-capacity well law reform; stormwater source control and management; and rehabilitation of the coaster brook trout on Lake Superior. These case studies provided opportunities to review the principles, assess their usefulness, and determine whether their adoption would in fact have made any difference in these situations.

In applying the principles to actual decision-making circumstances, we learned several things. Because we lack complete information about Wisconsin's water, our capacity to use or incorporate some principles is limited. In using the principles, decision makers need to identify those that relate most directly to the decision at hand. Some principles are more relevant in the early phases of a decision, and others in the implementation phase. The case studies suggest that sustainability should not be thought of as a simple state that we might soon "achieve." Rather, it is an ongoing process of adaptation that reflects progress toward a closer harmony between human needs and environmental quality, between inherited realities and long-term goals and aspirations.

There is, however, a bottom line. In all these case studies, Wisconsin's water users, managers, researchers, and advocates face difficult trade-offs and choices, under great fiscal and political constraints. These constraints are likely to intensify with increasing water demands, *especially in* *the absence of concern for sustainability.* Despite these constraints, varied interests in all of the cases examined have begun to explore new ways to correct past blunders, minimize future damage, assess the full complexity of water-related decisions, and incorporate into their decision-making process an awareness of water's inherent dynamism. In some cases it has taken many years and even decades to arrive at this point. It is cause for optimism that, as of 2003, we are beginning to realize the full dimensions of our water challenges. That is a first and necessary step toward meeting them.

USING THE PRINCIPLES

This statement of principles is not intended to serve as a set of inflexible rules. Rather, it summarizes considerations that ought to be weighed in decisions that affect the long-term viability of Wisconsin's water resources and aquatic ecosystems. Many of these principles have long been reflected in Wisconsin's state constitution, statutes, administrative rules, and legal decisions. Many are reflected less formally in the ways people interact with water in the private sector and in their private lives. Other principles are still poorly recognized and not reflected in legislation or in daily practice.

In developing this statement, WOW participants have sought to frame the principles in a way that is useful to varied audiences: an elected official facing a legislative decision, a land manager dealing with a threat to the public's waters, an advocate assessing the impact of a land use proposal, a businessperson developing a business plan, or a private landowner weighing options on his or her property. The principles are intended to provide guidance, raise questions, stimulate discussions, and identify future directions in policy. They suggest a checklist that decision makers at all levels, in all sectors, can consult in determining whether that decision contributes to, or undermines, the long-term health of Wisconsin's waters (see sidebar).

Waters of Wisconsin participants proposed a variety of other ways in which these principles might be used.

- Educators could use them to evaluate existing water education programs and develop curricula that focus on local waters while combining science, history, literature, and other subjects.
- Key water user groups could use them to evaluate long-term needs and opportunities for improved water management.
- Legislators and administrators could use them as the basis for evaluating the effectiveness of existing or proposed statutes.
- Nonprofit organizations, businesses, agencies, and local governments could use them to develop a variety of more specific tools for implementation (e.g., consumers' guides, websites, workshops, training materials).
- Planners could use them as criteria in informing local planning decisions.
- Media outlets might make them widely available to the general public as part of the Year of Water activities.

A COMMITMENT TO THE FUTURE

Those involved in the Waters of Wisconsin initiative hope that these principles will be widely disseminated, tested, and embraced. The principles have been formulated in an open and participatory manner, reviewed widely by water professionals and citizens alike, and revised so as to reflect a wide spectrum of perspectives while still retaining "teeth." We encourage others to use these principles and to continue public discussion of them.

Sustainability is an abstract concept that can sometimes seem far removed from the rain and snow, rivers and lakes, wetlands and springs and groundwaters that circulate over, under, and around Wisconsin. But behind the concept lies a basic reality: the fate of Wisconsin's waters and the fate of its human communities are interdependent. To ensure long-term economic health, community well-being, and environmental integrity, those connections need to be understood and respected.

Ultimately, the label of sustainability is not so important as the commitment to the future that it implies. The final test of these principles will be whether they help to inspire actions that will ensure the safety, abundance, and vitality of Wisconsin's waters. Will we invest in our capacity to measure and monitor our waters and all that they support? Will we effectively enforce water protection laws, even as we seek new ways to recognize and reward effective conservation practices? Will we modify our personal choices and decisions in ways that contribute to the overall quality of our watersheds and aquatic ecosystems? How will we respond to global economic forces that affect the status of Wisconsin's water? Will we look beyond our jurisdictional boundaries to treat our waters as the interconnected system that they are?

Although sustainability cannot be easily quantified, it can be defined and tested, and it can be *sought*. Certain actions can be taken immediately, and without cost; others will come only if and when priorities changes and values shift. Wisconsin achieved its reputation as a conservation leader when, early in the 20th century, its citizens acted on the realization that natural resources can in fact be exhausted through human misuse. As we look ahead into the 21st century, we are challenged again to act. We must do so based on accurate information, more integrated approaches to resource management, and a shared commitment to the future.

SUSTAINING WISCONSIN'S WATERS: A CHECKLIST

If we are to sustain our waters, Wisconsin's citizens and decision makers must build an understanding of and concern for our waters into our individual and institutional behaviors as well as our public policies. As we face the challenge of making informed decisions, stewarding our waters, and choosing among competing water needs, we may ask ourselves if our actions reflect a coherent set of principles. Do our water-related decisions achieve the following:

Water Values

- ❑ Recognize the value of Wisconsin's waters for the biological diversity and ecosystems they support; the spiritual, aesthetic, cultural, health, and economic benefits they provide; and the human goods and services they yield?
- ❑ Recognize that the connection between Wisconsin's waters and its people extends across generations?
- ❑ Reflect an ethical commitment to and personal responsibility for the health of our waters on the part of Wisconsin's citizens?
- ❑ Ensure fair and equitable access to water of sufficient quality and quantity for basic uses and enjoyment?
- ❑ Reflect a responsibility to avoid water uses that cause excessive, unreasonable, or irreparable harm to other people, future generations, and other forms of life?
- ❑ Encourage and support the active involvement, participation, and leadership of Wisconsin citizens at the local community and watershed level?
- ❑ Respect the values and traditions of the state's diverse cultural groups while recognizing their common interest in healthy waters?

Water Connections

- ❑ Recognize that Wisconsin's waters are connected to larger ecological systems and cycles and contribute importantly to their healthy functioning?
- ❑ Recognize and address connections between Wisconsin's aquatic and terrestrial ecosystems and between Wisconsin's atmospheric waters, surface waters, and groundwater?
- ❑ Demonstrate awareness of the basic importance of watersheds and water basins?
- ❑ Conserve the diversity and function of aquatic ecosystems by maintaining, enhancing, and restoring the natural hydrologic connections of our waters to the fullest extent possible?
- ❑ Treat Wisconsin's waters as a dynamic medium in which aquatic organisms, materials, and compounds are commingled and transported?
- ❑ Address the connections between issues of water quality and water quantity?
- ❑ Ensure the health of Wisconsin's waters across the full spectrum of landscape types as they flow between wild, semiwild, agricultural, rural, suburban, and urban areas?
- ❑ Recognize Wisconsin's important contributions to the healthy functioning of ecosystems and watersheds beyond our state boundaries?

Water Policies

❑ Accord with Wisconsin's traditional public trust doctrine and appropriately balance the public interest in the state's waters with private rights?

❑ Reflect a comprehensive, coordinated, and appropriately scaled approach to the management, use, restoration, and conservation of Wisconsin's waters?

❑ Achieve better coordination across jurisdictional boundaries and among different levels of government?

❑ Rest upon a foundation of interdisciplinary knowledge and integrated approaches to entire water systems?

❑ Draw on the most reliable scientific information and knowledge available on water status and trends?

❑ Recognize both the market and nonmarket values of water and strive to acknowledge the full costs and benefits of varied water uses?

❑ Address and correct economic forces that externalize costs and encourage wasteful or harmful use?

❑ Encourage, support, and reward actions that conserve water and protect and restore the state's aquatic ecosystems?

❑ Discourage inefficient use of water and the degradation of aquatic ecosystems?

❑ Recognize that there is no "one size fits all" policy response to our water challenges and instead encourage innovative adaptations?

Water Management and Stewardship

❑ Support water education opportunities?

❑ Use available information on water, the source and destination of the waters we use, and changes that may occur in the process of using them?

❑ Take into account the impact on our water of the size of our human population, our consumption habits, and our patterns of land use?

❑ Strive to be proactive rather than reactive, responding to long-term challenges to the health, integrity, and diversity of Wisconsin's waters before they become acute problems?

❑ Promote water conservation at all times, and not just during times of water shortage?

❑ Encourage, in the face of uncertainty, cautious and conservative use of Wisconsin's waters?

❑ Seek constantly to identify and meet new water information needs in order to reduce uncertainty and improve our ability to make wise management decisions?

❑ Adopt watershed and water basin approaches in water management and planning?

❑ Strive to protect and where possible restore natural hydrologic functions, native biological diversity, and ecological integrity?

❑ Encourage flexible and adaptive management of Wisconsin's waters in order to respond to unpredictable changes in climate, ecological interactions, and social and economic conditions?

❑ Promote and provide for continuous water monitoring and assessment?

❑ Encourage the continual development and adoption of innovative technologies to improve water conservation, education, monitoring, remediation, and restoration?

CHAPTER 5

WATER POLICIES FOR WISCONSIN'S FUTURE

Photo by Gerald H. Emmerich, Jr. courtesy of The Nature Conservancy

Public awareness of strengths and weaknesses in Wisconsin's current water policies has grown in response to recent headline issues: the Cryptosporidium outbreak in Milwaukee's water supply; beach closings along the Lake Michigan shore; proposals to bottle and sell groundwater from environmentally sensitive watersheds; cleaning up PCBs in the lower Fox River and Green Bay; new legislation to ensure protection of the state's isolated wetlands; the long-standing proposal to mine metallic ore deposits in the Wolf River basin near Crandon; proposed interbasin transfers of Great Lakes waters — and many others. Such issues demonstrate how our policies have historically served mainly to address a particular use, activity, or impact, or one part of the hydrologic system, rather than to manage for the overall health of Wisconsin's watersheds and water resources.

Meanwhile, larger-scale water issues — from climate change to national and global water shortages, from the hypoxic zone in the Gulf of Mexico to the future governance of the Great Lakes — remind us that Wisconsin's waters are not isolated, and that the impacts of our decisions ripple well beyond our borders. Our water policies are not ours alone, and policies originating elsewhere affect us directly. As effective as many of Wisconsin's policies may have been in the past, we face new and complex water challenges. We understand more fully than we did in the past the interdependencies, functions, and limits of our hydrologic systems. This suggests the need for coordinated policies that reflect accurate scientific information, recognize and respect the hydrologic cycle and water resource connections, embody our water values, and anticipate the needs of future generations.

The Waters of Wisconsin initiative has sought to address this need in all aspects of its work. By examining the current status and trends of our waters, we can better understand how past decisions and policies have affected them, for better or worse. By considering the consequences of today's decisions more carefully, we deepen our understanding of the long-term impacts of those decisions. By developing a working set of sustainability principles, we can advance our shared commitment to healthy water resources and aquatic ecosystems as well as healthy communities and economies. Together, these provide the foundation for a more productive and forward-looking discussion of policy needs and directions.

DEFINING WISCONSIN'S WATER POLICY

What do we mean by policy? In general, policy can be defined as a statement intended to influence actions and guide decisions. Although we tend to think about policies first in terms of statutory laws, policy in fact comes in many forms. In the case of Wisconsin's water, for example, we may find policy in the language of the state constitution; in the accumulation of state and federal court decisions; in executive orders; in a patchwork of state statutes, programs, administrative rules, and agency management guidelines; in the decisions of local governments across the state; and in many applicable federal laws. Wisconsin's waters are affected by day-to-day decisions made at many levels by many players, including individual water users, landowners, communities, local governments, businesses, organizations, Native American tribes, elected officials, and agencies.

Governmental decisions about Wisconsin's water are made at several levels, under various jurisdictions and mandates, according to different areas of responsibility and authority, and in pursuit of varied goals. Wisconsin's 11 Native American tribes and bands have sovereign standing, under which they maintain nation-to-nation relationships with the United States and are afforded sovereign rights and privileges. Federal law (especially the 1972 Clean Water Act) and various international and regional Great Lakes agreements and institutions involve the state of Wisconsin in larger-scale decision-making processes. Counties, townships, and municipalities affect water significantly through their local decisions involving, for example, water supply and treatment, wastewater management, land use, and economic development. Governmental policies cannot, and should not, dictate the fate of every drop of water that falls upon and flows through the state. However, government policies help create the social and political environment in which decisions are rewarded or discouraged, and those decisions have long-term consequences, intended and unintended, for the future of water.

Although there are various kinds of policy regarding the many types and uses of water in Wisconsin, we do not have an explicit Wisconsin water policy to bring coherence and consistency to the many dimensions of water management and governance. Few states do. The federal Clean Water Act is not state-specific; its approach is national. Other states, especially those with more limited water resources than Wisconsin, have adopted explicit state goals for water quality and quantity. These vary in the degree to which they take into account the entire hydrologic cycle, the functioning of watersheds and aquatic ecosystems, the full range of human uses and impacts, and the broad scope of issues that affect water quality and quantity. The basic realities of water — where it is distributed, how it moves, how we use it, who has jurisdiction over it — underlie the complex challenge of devising policies to fully sustain it (White 1999; NRC 1999a).

To better meet that challenge, we can begin with some basic premises *about* water policy.

Water policy is expressed in many ways. As noted previously, policy comes in many forms. We tend to think of policy rather narrowly, as the body of laws enacted by the legislature, or the positions held by the executive office, or the administrative rules and priorities carried out by state agencies. Water policy includes these and much more. Different governmental entities are empowered to use different tools in the policy "tool kit." The key questions are whether different entities work together or at cross-purposes, toward what ends, and with what results.

Water policy changes over time. Over the last century and a half, water policy in Wisconsin has continually evolved. These adjustments have come in response to constant changes in Wisconsin's aquatic ecosystems; in the values society attaches to water; in the human demands on water; in our scientific understanding of water and the environmental impacts of our actions; in methods for both exploiting and protecting our waters; and in our social, political, and educational institutions. Consider, for example, the dramatic shift away from wetland drainage and toward protection and restoration; away from destructive farming practices and toward the widespread adoption of soil and water conservation practices; away from the discharging of raw sewage and pollutants into our waterways and toward the adoption of water quality protection measures. Water policy, in short, is dynamic.

Water policy does not exist in isolation. We tend to think of water policy as being the responsibility of a particular agency (largely, in Wisconsin's case, the Department of Natural

Resources). But policies that affect water originate in, and are executed by, other agencies of the state government; the state legislature; and national, tribal, and local governments as well. More broadly, the status of Wisconsin's water reflects decisions and actions made in other policy arenas: energy and land use, transportation and agriculture, public health and education, state budgeting and economic development, electoral politics and campaigns.

Water policy can ignore complexity but cannot avoid it. No water policy, or set of policies, can succeed in the long run without taking water's complexity into account. For policies to succeed, they must make allowance for varying scales of time and space, the connections inherent in hydrologic systems, and the diversity of often competing water interests, rights, and users. If policies do not recognize these realities, the problems do not go away. They accumulate and become even more difficult for those who inherit them.

Today we live with the consequences of past water policies (White 1999). We have inherited both the substantial benefits and the costs of policies designed to develop, use, protect, conserve, manage, and restore Wisconsin's waters. *Participants in the Waters of Wisconsin initiative believe that we have clearly reached an important juncture in our history. If we are to ensure a secure water future for the state, the incremental and often reactive policies of the past must be updated and better integrated, and key gaps must be filled.* Before focusing on the future, however, we need to examine more closely the existing framework of water policy.

WISCONSIN'S CURRENT WATER POLICY FRAMEWORK

Although Wisconsin does not have an explicit state water policy, we do have an aggregation of individual policies pertaining to many water uses, water types, water bodies, and water-related activities. In this sense, it can be said that we have a *de facto* water policy. This de facto policy comprises the statutes that are on the books and the administrative rules and guidelines used to implement them. A full review of existing policies was beyond the scope of the WOW initiative, but in the course of our discussions, WOW participants did ask several fundamental questions: What are the main elements of our water statutes and administrative policies? In what areas pertaining to water do we have explicit policy? Where do we lack explicit policy? Do our current laws reflect emerging principles of sustainability? Do existing policies conflict? Where, in short, are we at this point in our efforts to fit water policy to long-term water needs and realities?

To answer those questions, we should first recall Wisconsin's unique water qualities and circumstances. Wisconsin is water rich in that we have thousands of inland lakes and streams, extensive marshes and wetland complexes, borders on the Great Lakes and the St. Croix–Mississippi Rivers, and a vast supply of groundwater. However, we are also very water dependent, relying on these abundant but vulnerable resources for drinking water, residential needs, industrial and agricultural uses, energy generation, commerce, recreation, and tourism. Over time that dependency has resulted in a variety of responses by local, state, tribal, and federal governments to ensure that these uses are managed to meet certain objectives.

As noted earlier, these responses emerged and developed as changes in water uses, demands, and management practices caused discrete water problems for our society. As a result, our water policies have too often been reactive and fragmented, designed to address problems associated with particular uses or activities. This can be illustrated by several examples.

Floodplain zoning. Each county in Wisconsin is required by state law to adopt zoning practices that restrict building in floodplains. These zoning guidelines and restrictions are intended to prevent damages to property or loss of life at the site or upstream or downstream from the site. This policy was developed not to manage the water resource itself (for example, through coordinated efforts to minimize flood risk through improved land use), but rather to manage the impact of high flows on buildings.

Effluent limitations for sewage treatment plants. State policy has evolved in such a way that any sewage treatment plant has the opportunity to utilize rivers and streams for wastewater assimilation. This opportunity is allocated on a first come, first served basis. A margin of safety is built into permit allowances, but there is otherwise no provision for reserving capacity for future users, for changing needs, or for addressing cumulative impacts.

Fragmented management. A municipality may use groundwater for its public water supply. It is treated and ultimately discharged to a surface water body. Stormwater runoff from the same municipality may be transported as rapidly as possible to the same surface water body to minimize flooding in the urban area. Each of these issues — groundwater extraction, wastewater treatment, and stormwater management — may be independently addressed through separate policies, as if these actions were not interrelated. Management of the water is not connected or coordinated. There is no balancing of groundwater usage, stormwater volume management, and surface water discharge of wastewater, because there is no policy or agency responsible for managing the whole hydrologic cycle.

Fish and wildlife consumption advisories. Contaminants released through atmospheric discharge, polluted runoff, and disturbance of sediments enter the food chain, leading to the imposition of fish and wildlife consumption advisories. Yet there is no state policy that establishes specific procedures or deadlines to attain fish or wildlife edibility standards.

Drought and usage priorities. If a drought affects Wisconsin to the point where competing demands exceed supplies, what is the protocol for rationing, assigning priority uses, allocating use rights, and restricting uses? Over the last three decades, officials from Wisconsin's emergency planning, water management, and agriculture offices have intermittently tried to develop an emergency drought plan. Legislation drafted in response to extreme drought in the late 1980s would have established priority uses for times of scarcity. After the rains returned, however, interest faded and the legislation was never enacted.

Lakes and lakeshore development. In 1965, Wisconsin adopted the first lake shoreland protection legislation in the United States. Because of the limited scope and inadequate enforcement of the legislation, it has not succeeded in preventing rapid lakeshore development and degradation of lakeshore habitat and lake ecosystems. The legislation did not focus on maintaining and restoring healthy lakes, gave scant attention to general watershed conditions, and failed to anticipate or address such problems as invasive species.

Unique resource protection. The Brule River in northern Wisconsin is protected from navigational impediments. The Pine, Pike, and Popple rivers are designated State Wild Rivers. Class 1 trout waters have been granted special status that protects them from wastewater discharge impacts. However, none of these designations require or encourage watershed management activities to sustain these uniquely valuable water resources. Can we then say with confidence that our present policies adequately protect Wisconsin's special waters?

These are examples of the status quo: Although many policies have been established and enacted in Wisconsin to manage *specific* activities or resources, we have no comprehensive policies designed to enhance our capacity to fully protect, use, enjoy, and replenish our water resources into the future. The de facto policy has worked well to handle many aspects of water management in the state, establishing Wisconsin as a national leader in the management of water resources. The question for the future, however, is whether the de facto approach will suffice as water demands increase, water uses change and intensify, and discrete impacts accumulate and interact.

We now face challenges that could not have been imagined when the conservation movement emerged a century ago: rapid growth of our human population, extensive urban and suburban development, the spread of invasive exotic species, the emergence of synthetic pesticides and other chemicals, and the accumulation of greenhouse gases in the atmosphere, to name a few. Past policies have helped us to address seemingly intractable water resource problems. We enjoy today, for example, significant improvements brought about by soil and water conservation practices introduced in the 1930s and by the water quality provisions of the Clean Water Act of 1972. The challenges of the future will, however, demand that we address not just discrete water problems, but the overarching problem of sustaining all of our waters, for all that we value them for.

In sum, we do not have a comprehensive Wisconsin water policy; instead we have a patchwork policy that is strong in many areas, weak in some areas, and silent in still other areas. Among our strengths: basic human needs for water in Wisconsin are met; water remains a vital economic asset for the state; we have slowed and even reversed many destructive trends; our level of technical expertise is high; and because of our abundant waters, the margin for error — and for adaptation — is relatively broad. Wisconsin's people and elected officials have historically been quick to respond to both immediate and long-term threats to the quality of our surface waters, and increasingly to our great groundwater resources. This public commitment is reflected in the pieces of water policy that have accumulated over the decades.

However, that which may have served us well in the past may not suffice in the future. Demands upon our water are growing and changing, and new concerns are emerging. We are faced with issues that extend far beyond Wisconsin's boundaries: future protection and governance of the Great Lakes; the hypoxic zone at the mouth of the Mississippi River; increasing conflicts involving the privatization of water resources and many water management functions (see sidebar); national and global water shortages and growing pressures on freshwater supplies. Water quantity issues have become more evident, and thus increasingly important. We are much more aware of growing threats to, and the critical role of, our buried treasure of groundwater (see sidebar). Competing demands of growing numbers of people, along with the cumulative and synergistic impacts of human activities, will demand new approaches to managing water quantity and ensuring water quality, and a firm commitment to ongoing research and monitoring.

The need to understand and respect the interconnections within the entire hydrologic cycle will require broader citizen awareness and participation in water basin management, as well as more comprehensive and integrated approaches to water resources. In short, we need to reframe the fragmented management approach to water resources and aquatic ecosystems that has characterized the past and find ways to bring all the pieces together.

FOUNDATIONS OF FUTURE POLICY

There is no easy path toward a more coherent state water policy, but there are definite steps we can take in that direction. In some areas, we have already begun to take such actions. Recent efforts to reform the state's high-capacity-well laws, to protect isolated wetlands, to define future options for improving groundwater policy, and to work with other states and provinces on more holistic approaches to protection and management of the Great Lakes waters all signify a greater appreciation of hydrologic connections in water management, and a widespread commitment to the protection of all our waters (Born et al. 2000; Luthin 2002; WGCC 2002; GQWG in prep.). Change will not come without broad support, but recent signs do point to growing public awareness of the need.

In considering the framework for a comprehensive state water policy, we should remind ourselves of the renewable, but finite, nature of water resources. Water circulates and cycles within the global hydrologic system. The occurrence of water can change as a result of shifts in short- and long-term weather patterns. Its distribution can be altered by human activity,

WISCONSIN'S WATER: PRIVATE ASSETS AND THE PUBLIC GOOD

Water is a precious and scarce resource, so why isn't it, and the right to it, bought and sold on the open market? Increasingly, it is. For example, the sale of bottled water is a large and growing business. The number of units of bottled water sold in the United States has doubled since 1997, and we pay more per gallon for it than we do for gasoline (Fulmer 2002). But we buy and sell water in other forms (beer and soda, for example). Water courses through our economy much as it courses through our landscape.

That fact raises complex economic, political, and ethical issues. In Wisconsin, the legal and economic status of water has been brought to the surface in recent years through such high-profile issues as periodic proposals to withdraw or divert Great Lakes waters and the Perrier Company's proposal to bottle groundwater from south-central Wisconsin. New international trade agreements may affect the governance and legal status of water in unprecedented ways. These and other issues raise profound questions about society's role in conserving and managing water resources, and about the relationship between public and private interests in water.

Discussion of these questions often revolves around the terms *privatization* and *commodification*. In the water context, *privatization* refers primarily to efforts to transfer the administration of public water supply and treatment systems to the private sector. The private sector is increasingly involved in supplying and treating water, a responsibility that, in the U.S., has historically belonged to over 50,000 community water utilities. Two patterns are emerging. First, private companies are contracting to assume management of municipal waterworks. Second, companies are buying water utilities and selling the water to their customers.

These trends are evident both nationally and globally. The nation's largest private water firm, the American Water Works Company, serves 9 million people in 22 states. The largest international firms are two French companies, Suez Lyonnaise des Eaux and Vivendi SA. Together they own water companies in 130 countries serving more than 100 million people. In 2000, Suez Lyonnaise des Eaux acquired United Water, the United States' second-largest waterworks contract operator. The net result of these changes is that the highly decentralized pattern that historically characterized local water supplies is changing, raising concerns about the accountability of large private companies to the local communities being served.

The privatization trend is occurring as local and regional water utilities face daunting financial prospects. The U.S. Environmental Protection Agency estimates that by 2019 over $138 billion will be needed to improve water systems owing to aging infrastructure, increasing population growth, higher per capita water use, and federal water quality requirements (other estimates are as high as $650 billion) (Revkin 2002; Jehl 2003). Obviously, it will be difficult to secure such huge sums of money. Municipalities are likely to respond by exploring consolidation to achieve economies of scale, or by contracting with large, experienced firms in the private sector that can provide access to capital and provide improved operational efficiency.

Privatization of water supply and treatment raises essential questions whose answers remain unclear. For example, will private water companies want to buy or become operating partners with municipal systems that require large capital investments to improve infrastructure? How shall the tension between providing an essential public service and generating a profit be reconciled? How can incentives to conserve water and sustain aquatic ecosystems be built into a privatized water management regime? In short, there are unlikely to be quick and cheap technological fixes to the problem of deteriorating water purification, delivery, and treatment systems.

Commodification refers to efforts (primarily in the private sector, but also among governments) to purchase, produce, process, market, and distribute water. As concern over the global supply of water has grown, so has interest in water as a tradable good. This can entail plans (such as Perrier's) to withdraw and bottle groundwater, as well as large-scale efforts to move water in bulk (as has occasionally been proposed for Great Lakes waters). Commodification raises fundamental questions: To whom does water belong? Who has the right to sell it?

In Wisconsin, the state's public trust doctrine holds that the navigable surface waters of the state belong to all the citizens of the state and are managed by the state government in the public interest (Scott 1965; Kent and Dudiak 2001). The public trust doctrine protects citizens' rights to use the waters for commercial or recreational navigation, fishing and hunting, swimming, and enjoyment of scenic beauty. Riparian landowners have use rights to these surface waters for domestic, agricultural, or industrial purposes and can even bottle it and sell it, as long as such use is reasonable and doesn't harm neighbors or other water users.

Meanwhile, the groundwaters that feed, and are fed by, the surface waters are subject to a different set of legal standards and conditions, as developed through common law. In the common law, use of groundwater is part of the bundle of rights that property owners enjoy (while remaining subject to the regulatory responsibilities of the state government). Even in cases where the impact on surface water is indirect, Wisconsin common law limits a landowner's use of groundwater to the reasonable use standard.

Reconciling these different legal traditions — with each other, and with our increasing scientific understanding of water's connectivity — will be a basic challenge in Wisconsin's water future. We face a wide range of complicated issues that will force us to confront our basic conception of water and its role in our lives, in our legal tradition, and in our economy. Water is unarguably becoming a more significant part of our commercial economy, but it is not an optional resource for which substitutes can be found. Every living thing, ourselves included, must have it to survive. That fact takes the discussion beyond the realm of law, science, economics, and public policy and into the realm of ethics.

allowing the quality and quantity of water supplies to be modified on large regional scales. However, the water resource itself remains finite.

The question then becomes one of choices and consequences. We can build a pipeline from Lake Superior to Phoenix, but should we? What if the need were in Wausau? We may be able to support exurban growth in our northern lakes region, but can it happen in a manner that retains the character of the lake resources? We may be able to divert stormwater away from a property in a safe manner, but have we accounted for the resulting surge in peak flow and its impact on downstream habitats, aquatic life, landowners, and communities? A coherent water policy ought to consider — and connect — our choices to their consequences.

WDNR

FRAMING THE FUTURE

The principles outlined in chapter 4 of this report provide a starting point for framing future water policy. They suggest a number of areas in which we might examine existing statutes and identify areas for improvement. We can pose these as questions. In moving toward a comprehensive state policy:

- Should there be a statement in our statutes about the importance of water as an element essential to public health and well-being, the beauty and diversity of aquatic ecosystems, and the prosperity and quality of life in the state of Wisconsin?
- How shall future policy reconcile the state's traditional commitment to protecting water as a shared resource under the public trust doctrine with the existing right to use water, and with increasing commercial interest in water as a commodity subject to market forces?
- Should state policy prohibit activities that would deplete our water resources and irreversibly degrade aquatic ecosystems?
- Should Wisconsin prevent, limit, or discourage the diversion of water from one basin or aquifer to another?
- Should the interconnection of all water, including the scientifically recognized interrelationship between surface water and groundwater, be recognized in the statutes?
- Shall Smart Growth comprehensive planning requirements give greater attention to the connections between land use, surface water, and groundwater and ensure that they are fully considered?
- Should there be integrated policies in place to encourage the restoration and management of riparian corridors on a landscape scale?
- Should Wisconsin establish a priority system that establishes preferences for the use of water when conflicts arise over available water? Which uses should be given priority: human drinking water, other domestic uses, agriculture, ecosystem services, commercial and industrial operations?
- Should Wisconsin revisit its existing drought-preparedness plans? In times of water scarcity, should state water policy first mandate water conservation measures, before water allocation decisions are made?
- Should Wisconsin develop plans for adapting to the water-related consequences of climate change?
- Is our understanding of trends in water withdrawal and use sufficient? Do we have adequate and accurate information on various water uses?
- Is our definition of water quality consistent and sufficient? Does it adequately address the quality of aquatic habitats and ecosystems and protect them from degradation?
- Should Wisconsin establish state water quality goals that would be used to design policy, direct programs, and establish water quality standards? Do we want to attain a minimum level of water quality so that designated uses are not impaired, or should we set a higher goal?
- Should Wisconsin have a formal, ecologically informed policy on the introduction of exotic species into our waters?
- Should there be a new policy to limit the modification of water resources in ways that alter their natural function? What about dams or other changes that affect natural conditions?

- How shall we address changing recreational demands, especially conflicts arising from increasing incompatible uses? How shall the state mediate conflicts between growing recreational demands and the health of aquatic systems?
- Should Wisconsin establish a policy to create more consistent and transparent decision-making processes, so that the ground rules are clear to all stakeholders?
- Has Wisconsin begun to address issues of water security adequately?

SHARING THE BURIED TREASURE: COMING TOGETHER OVER GROUNDWATER

Natural resource management issues tend not to make the newspaper headlines and evening news until a crisis hits or a conflict arises. So has it been with Wisconsin's buried treasure of groundwater. As concerns have grown over the use of groundwater for domestic, agricultural, and industrial purposes and awareness of the connections between surface waters and groundwater has increased, the news stories have become more common:

- The Perrier company proposes to locate a private bottling plant in south-central Wisconsin.
- High levels of arsenic appear in well waters in the Fox River Valley as a result of intensive groundwater pumping and rapid residential development.
- Declining water tables threaten access to usable water supplies in southeast Wisconsin, Green Bay, and Fond du Lac.
- Springs, wetlands, and trout streams run low as a result of excessive pumping in Dane County and the Central Sands.

In response to these and lesser known concerns, the Wisconsin Groundwater Coordinating Council (WGCC) initiated an effort to evaluate the state's role in protecting and managing groundwater resources and to identify educational, research, planning, and policy needs for the future. The WGCC is an interagency body established by the state legislature in 1984 to better coordinate the activities of state agencies involved in groundwater management. In 2000, the WGCC proposed that a Wisconsin Groundwater Summit be organized to take the pulse of groundwater management activities, to gather input from key stakeholders, and to facilitate the exchange of diverse viewpoints on groundwater issues.

The summit, held in Waukesha in October 2001, attracted 135 people with a wide array of interests and viewpoints on the future of groundwater management. Participants included groundwater scientists, elected officials, and agricultural users as well as representatives from state, local, and tribal agencies, water utilities, environmental and conservation organizations, business and industry groups, and the University of Wisconsin Extension system. The summit provided a unique opportunity for conversation among people who do not usually discuss groundwater priorities.

A comprehensive state water policy would seek to address these and other issues. Many of these points obviously have broad ramifications; others are narrower in scope. Some have precedence in existing policy; others are only now emerging as components of a more comprehensive policy. None can be fully or effectively addressed as separate issues. The picture that emerges with such questions is complex, but by framing the issues in this way, we are seeking, for the first time in our history, to consider water in all its dimensions.

NEXT STEPS IN WATER POLICY DEVELOPMENT

Although actual development of a state water policy was beyond the scope of the Waters of Wisconsin initiative, WOW participants discussed, and can recommend, broad directions for

Summit participants heard presentations on basic groundwater science, groundwater quality and quantity problems, the history of groundwater policy in Wisconsin, and current groundwater management activities. A panel of representatives from key user groups offered perspectives on pressing groundwater issues and management needs. All participants had opportunities to express views and opinions on future groundwater management needs.

Most of the summit attendees agreed that the leading issue in the coming decade will be managing groundwater quantity as well as quality. Participants identified other key themes: the importance of long-term monitoring; water conservation; regional approaches; public education; groundwater protection; the hydrologic connections between surface and groundwater; and continued management of water quality. Together, these themes suggested the basic need for a comprehensive, science-based approach to groundwater management that is equitable to all users. However, no consensus emerged on how best to accomplish this or which approach would best suit Wisconsin. The summit provided no easy answer but did serve as a starting point for further discussion about the future of groundwater management in Wisconsin.

The key themes and strategies identified at the groundwater summit are summarized in a report entitled *Sharing Our Buried Treasure* (http://www.dnr.state.wi.us/org/water/dwg/gcc/SOBT.pdf). The WGCC continues to encourage agencies and organizations to use *Sharing Our Buried Treasure* to evaluate their current groundwater management activities and to take action to achieve the goals and needs identified at the summit. That will mean different things for different organizations and institutions. For some it may mean defining new research priorities or guiding agency planning; for others it may mean finding collaborative solutions or implementing water conservation practices. The goal of the WGCC in its summit and report is to provide a common framework within which these varied actions can take place.

For more information on the WGCC and the groundwater summit, please visit the website http://www.dnr.state.wi.us/org/water/dwg/gcc/.

water and related policy in Wisconsin. We suggest that *the goal of Wisconsin's water policy should be to assure for this generation and future generations a safe and plentiful supply of water to meet essential human needs; to strive toward efficient use and environmentally responsible management of our waters; and to ensure the resilience, viability, and beauty of Wisconsin's watersheds and aquatic ecosystems.* With this as a starting point, Wisconsin's citizens, leaders, and decision makers may explore the policy needs and opportunities we face.

A comprehensive state water policy would explicitly recognize the connections between the various activities and agencies of state and local governments and water users across the state. Stated another way, the goal is not to define a "Wisconsin Department of Natural Resources Water Policy," or even a state government policy, but a *Wisconsin* water policy that reflects and represents the broad public interest in healthy water resources and aquatic ecosystems in the state. State water policy cannot be compartmentalized under any one agency or authority; rather, it must be linked coherently across agency and jurisdictional boundaries, be given higher priority within all agencies, and involve the nongovernmental and private sectors in its development.

A concrete next step toward improved state water policy would be to take a fresh look at the mandates of the agencies of the state government, their relevant water-related responsibilities, and the various sectors in which they are active. This would include consideration of the connections between water and public health, transportation, agriculture, energy, commerce, research, education, and land use. The effort to review and better link state efforts in the water arena would entail little or no cost and would pay long-term dividends through improved coordination — and through the improved condition of the waters themselves.

Such a review should seek specifically to identify

- perverse incentives that encourage degradation of our waters;
- ways to strengthen incentives to encourage improved water use and conservation;
- existing policies that are not now being implemented;
- areas of shared responsibility and liability; and
- key areas requiring more research.

All agencies and sectors can and must contribute to the sustainability of our waters. We need to begin with a clear assessment of current rules, roles, and responsibilities.

The process by which we achieve a more comprehensive water policy is as important as the product itself. That process must be as transparent, inclusive, and interactive as possible. It must involve all levels of government in a meaningful way and draw upon the expertise of water scientists and varied water users. It must be solidly based in scientific understanding of the hydrologic cycle, aquatic ecosystems, and human water uses and impacts. The Waters of Wisconsin initiative has sought to build such expertise, transparency, and public participation into its work, illustrating how Wisconsin can proceed with the task of developing forward-looking state water policy.

As a next step, the Waters of Wisconsin initiative recommends that the governor and state legislature formally establish a Wisconsin Water Policy Task Force to develop a comprehensive state water policy (see chapter 6). The task force should be charged with several tasks:

- Conducting a full inventory, review, and assessment of Wisconsin's existing water policies;
- Identifying key gaps, conflicts, duplications, and weaknesses in existing policy;
- Identifying scientific data, sources, and additional information needs on which Wisconsin can base effective water policy;
- Providing a clear statement of future directions and a general framework for policy change;
- Making recommendations for the modification of statutes and other needed reforms; and
- Assessing needs associated with water education, water resource information and monitoring needs, and water-related research.

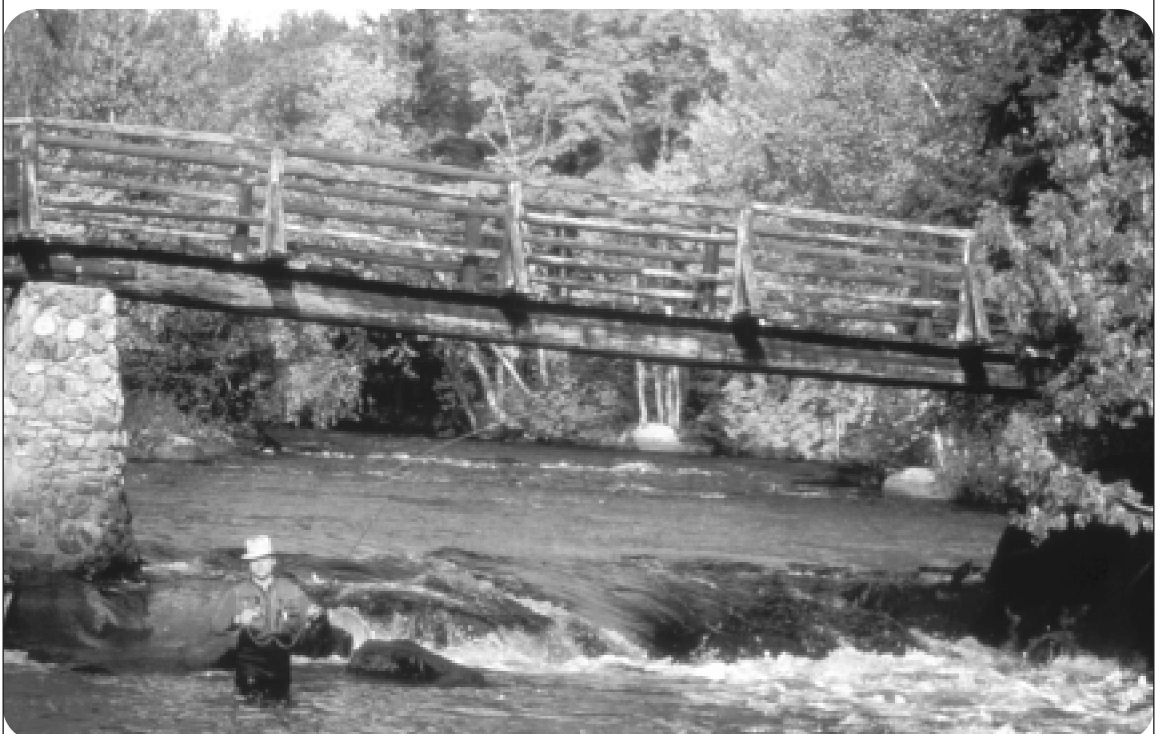
SEIZING OUR OPPORTUNITY

Wisconsin needs a coherent state water policy, based on shared values and principles, to guide protection and use of its vital water resources and aquatic ecosystems. In the absence of such a policy, the various water issues we face will become only more difficult to address in the long run. The sobering news is that this will require unprecedented commitment on the part of our citizens and leadership to overcome obstacles to better policy. The positive news is that we have the opportunity to be ahead of the curve — to work toward consensus and act while growing pressures and emerging issues are relatively manageable.

Wisconsin can take advantage of its strong base of scientific knowledge, its highly capable water-related institutions, and the increasing interest that exists, in all sectors, in safeguarding our inheritance of water. Above all, we have Wisconsin's traditionally strong conservation ethic to build upon. Wisconsin has every right to be proud of past efforts that established our state as a national leader in environmental protection and water management. We now have the opportunity to demonstrate such leadership again through development of a forward-looking, more integrated state policy to sustain our vital water resources and safeguard our aquatic ecosystems.

CHAPTER 6

FINDINGS AND RECOMMENDATIONS



WDNR

In coming to its conclusions and recommendations, the Waters of Wisconsin committee focused its attention on actions that will enable Wisconsin's citizens and institutions to sustain safe and abundant water resources for our communities and economy and healthy aquatic ecosystems over the long term. The following recommendations reflect the vital interconnections within the hydrologic cycle and among air, land, water, and people. They are organized here under four main categories: water policy; public education and civic participation; water science and assessment; and sustainable water management. Although the recommendations reflect long-term goals, they also point toward immediate steps that can begin to move us toward a healthier and more secure water future.

TOWARD A WISCONSIN WATER POLICY

Wisconsin's waters are at once abundant and precious, renewable and limited, resilient and vulnerable. We cannot and should not be complacent in the face of increasing stresses affecting water quality and water quantity, the biological diversity and healthy functioning of aquatic ecosystems, sustainable water use and water allocation, governance and administration of water supplies, and impacts upon Wisconsin's waters that originate from beyond our borders.

As noted previously, Wisconsin has much existing and de facto water policy. Overall, however, our policies tend to be fragmented and reactive and will not suffice to meet emerging needs. The many water challenges we face cannot be regarded as separate issues. Wisconsin water policy must better reflect the interconnected nature of water and the interdependence of varied uses and demands. In the face of uncertainty and increasing pressures on water, both within the state and beyond, Wisconsin needs a forward-looking, broad-based, coherent, consistent, and integrated state policy to protect, manage, and sustain our waters.

As a starting point, the Waters of Wisconsin committee has adopted for its use the following statement (see chapter 5): *The goal of Wisconsin's water policy should be to assure for this generation and future generations a safe and plentiful supply of water to meet essential human needs; to strive toward efficient use and environmentally responsible management of our waters; and to ensure the resilience, viability, and beauty of Wisconsin's watersheds and aquatic ecosystems.* Development of a state policy along these lines should include, and be based upon, a review and assessment of our myriad existing de facto water policies and laws.

To encourage action toward a more comprehensive state water policy, the WOW committee recommends the following:

- **The governor of Wisconsin, working together with the state legislature and with Wisconsin's Native American tribes and bands, should establish in 2003 a Wisconsin Water Policy Task Force to outline steps toward a comprehensive state water policy.** The goal of the task force should be to assess existing policy and develop recommendations that reflect and represent the public interest in healthy water resources and aquatic ecosystems in the state. Achieving this goal will require the active participation and involvement of all agencies of the state government and of decision makers at all levels of government. In working toward this goal, the task force should seek extensive and meaningful public participation. The task force should be broadly constituted — comprising citizens from varied sectors, with experience and expertise in water science, use, policy, public health, conservation, and environmental protection. The task force should base its discussions on the best available scientific information and should explicitly seek to address the connections between water and public health, transportation, tourism, agriculture, energy, commerce, research, education, land use, and other areas of public policy.

- **The proposed Wisconsin Water Policy Task Force should seek to examine all major topic areas related to water use, management, and protection and address the long-term and cumulative impacts of current policy on Wisconsin's waters.** In carrying out its mission, the task force should include consideration of the following topic areas: the status and future of the public trust doctrine and water law; trends and needs related to water quality; drinking water supplies and public health; water quantity, use, and management; water allocation, priorities, and property rights; climate change issues; drought preparedness; groundwater protection and groundwater quantity management; protection and restoration of Wisconsin's lakes, rivers, and wetlands; protection of the aesthetic value and quality of Wisconsin's waters; the importance of water to Wisconsin's economy; the impact of existing incentives on water use, conservation, and management; fisheries management; exotic and invasive aquatic species; dams and dam removal; floodplain management; shoreline protection; Great Lakes withdrawals and interbasin transfers; Great Lakes ports and navigation needs and impacts; the water policies and programs of Wisconsin's Native American tribes and bands; irrigation, drinking water, and watershed health; the security of our water bodies and water supplies; and the state of water-related educational efforts.

- **The proposed Wisconsin Water Policy Task Force should undertake the following specific activities:**
    - The task force should compile an annotated inventory of the main elements of current statutory, administrative, and other policies pertaining to water.
    - The task force should identify and assess gaps, conflicts, duplications, and weaknesses in the existing policy framework.
    - The task force should identify scientific data, sources, and additional information and monitoring needs upon which Wisconsin can base effective water policy.
    - The task force should provide a clear statement of future directions and a general policy framework to ensure a sustainable water future for the state.
    - The task force should develop specific recommendations for the modification of statutes and incentives, and other needed reforms.
    - The task force should assess needs associated with water education, as described next.

2003: A SPRINGBOARD TO BROADER PUBLIC EDUCATION AND CIVIC PARTICIPATION

The state of Wisconsin's water reflects the actions and commitment of its citizens. Over the long run, improved stewardship of water in Wisconsin depends on broad citizen awareness and on actions taken at the individual, community, and watershed levels. This in turn depends on the widespread acceptance of a shared water ethic that combines a critical understanding of water with an attitude of care and concern. Although adoption of such an ethic cannot be ensured, it can be encouraged through actions that offer opportunities for expanded public education and participation.

- **Wisconsin's Year of Water should serve as a catalyst for public education about the future of the state's waters and for expanded public and private participation in water stewardship activities.** October 2002 marked the 30th anniversary of the federal Clean Water Act. To recognize this anniversary, many state governments designated 2002 as a Year of Clean Water. In addition, the United Nation's General Assembly has designated 2003 as the International Year of Freshwater. In keeping with these events, Governor Scott McCallum in October 2002 declared 2003 to be the Year of Water in Wisconsin. In December 2002, governor-elect James Doyle affirmed the commitment of the governor's office to this designation. Wisconsin's Year of Water will yield multiple benefits:
    - The Year of Water provides opportunities for Wisconsin citizens to celebrate and acknowledge water quality improvements since the passage of the Clean Water Act.
    - The Year of Water allows students to participate in a common statewide effort to understand and appreciate our waters, to become aware of water uses and water issues, and to work together on local projects that conserve and sustain our waters for future generations.
    - The Year of Water focuses attention on key educational goals: to increase public awareness of the essential value of Wisconsin's water resources and aquatic ecosystems, to involve citizens in discussions about the future of our waters, and to encourage public participation in stewardship actions.
    - The Year of Water provides an occasion for a broad spectrum of nonprofit organizations; federal, tribal, and state agencies; elected officials; communities; schools; universities; businesses; and others in the private sector to highlight their water-related work and to stimulate creative activities around the theme of water and water stewardship.
    - The Year of Water can stimulate a wide range of specific activities, such as "Water Conservation Days," community water festivals, stream and lake cleanups, demonstrations of water-conserving industrial technologies and business practices, participation in volunteer monitoring, and water education conferences.

- **A broad partnership of Wisconsin's educators and institutions should conduct a full review and assessment of statewide water education efforts at all levels.** Despite longstanding efforts to enhance public appreciation of water, water use, and water issues in Wisconsin, we are still confronted by widespread lack of public understanding about even the basics of water and its role in our lives and landscapes. In the long run, better stewardship of our water requires a higher level of water literacy across the state. Water education in this sense involves not only K–12 students, but all Wisconsin's citizens.

  A full assessment of current water education goals, programs, and requirements in Wisconsin is needed. Because this is necessarily a broad undertaking, a variety of institutions, organizations, and agencies should be involved. Within the state government, the Wisconsin Department of Public Instruction and Department of Natural Resources should assume a lead role in this effort. Other partners in this effort should include the Wisconsin Environmental Education Board; the University of Wisconsin System (including the UW Center for Biology Education, the UW Center for Limnology, UW–Extension, the Water Resources Institute, and the Wisconsin Center for Environmental Education at UW–Stevens Point); and the Wisconsin Academy of Sciences, Arts and Letters. Other state agencies, municipalities and local governments, conservation and environmental organizations, utilities, businesses, and other private sector partners should also be involved. Specific tasks that should be carried out include

  - a review of existing information regarding the state of public understanding and water and awareness of water issues;
  - an inventory of water education efforts in the Wisconsin DNR, across the University of Wisconsin System (including the UW–Extension system), in Wisconsin's private colleges and universities, and in nature centers and nonprofit organizations;
  - identification of innovative opportunities for water education;
  - identification of important nontraditional audiences;
  - consideration of the role of the media in improving water literacy in Wisconsin;
  - establishment of broad water education goals; and
  - a statement of recommendations for improving water education.

- **As part of the general review of water education in Wisconsin, special attention should be given to assessing K–12 water education programs and needs.** Water education at the K–12 level deserves special attention. Although water education programs at this level have increased in recent years, they are often general in nature (i.e., not tailored specifically to Wisconsin's waters). We have limited information about their effectiveness in improving water literacy in the state. To meet future K–12 water education needs in Wisconsin, educators must come together to:

  - assess the degree to which water is included in current K–12 curricula;
  - inventory and review existing K–12 water education programs and curricula materials;
  - define essential water concepts that students in Wisconsin should acquire;
  - identify opportunities to integrate water education into existing science, math,

history, health, social studies, language arts, visual arts, and other programs;
- identify opportunities for students to become involved in monitoring programs and to make meaningful contributions to their communities' decision-making processes; and
- develop and implement a comprehensive plan to integrate water resources education into both teacher education programs and the K–12 curriculum.

• **The Wisconsin Department of Natural Resources, working with partner organizations, businesses, schools, and communities, should lead efforts to support, expand, and improve volunteer monitoring programs and to coordinate an effective statewide volunteer monitoring network.** Volunteer monitoring is a powerful way to involve local citizens and organizations in gathering useful information about their local waters, and to supplement technical monitoring programs (see following section). At the same time, state- and county-level budget constraints limit the capacity of the DNR and counties to gather essential baseline data, monitor remediation and restoration efforts, and implement Wisconsin's new nonpoint pollution control program. The recent reorganization of DNR administration, following the state's river basins, is premised on the need to bring watershed management decisions "closer to home," and to involve local citizens and organizations in natural resource planning and decision making. For these reasons, the Wisconsin DNR should lead a concerted and coordinated effort to expand involvement in existing volunteer monitoring programs, and to create new opportunities for citizen participation.

Local monitoring efforts not only are important in and of themselves, but also can contribute to better understanding of entire watersheds and Wisconsin's water in general. But to be used effectively, the information gathered through volunteer monitor programs must meet certain quality standards and must be consistent and carefully coordinated. A statewide volunteer monitoring network, working through the water basins, would achieve multiple education and stewardship goals while giving citizens a greater stake in, and understanding of, their waters. Future actions to provide for more effective volunteer monitoring of Wisconsin's waters should include

- development of consistent sampling protocols;
- identification of funding sources for required equipment;
- identification of a primary coordinating institution (such as the DNR or the University of Wisconsin);
- development of standard, user-friendly data reporting methods;
- preparation of accessible and timely summary reports of monitoring results;
- support and training opportunities for local organizations and their leaders; and
- coordination of local monitoring programs with K–12 science and water education programs.

MEASURING AND MONITORING THE HEALTH OF WISCONSIN'S WATERS

Effective public policy decisions involving water require accurate, reliable, and timely scientific information, compiled and analyzed consistently over time. Wisconsin has a globally renowned tradition in the water-related sciences. Because of the durability of that tradition, we have within the state a high level of expertise, research capacity, and available data. And yet, like water, this special asset should not be taken for granted. It requires stewardship and support if it is to remain viable, timely, and relevant and if it is to effectively serve the citizens and decision makers of Wisconsin.

Today our system for assessing the state of our waters and watersheds is incomplete. Our capacity to acquire, manage, and provide information about our waters faces a number of challenges. We lack sufficient understanding in key areas of water science. The feedback loops in our water assessment system — the links between databases, available information, and use of that information in water management activities — are inadequate. Funding for essential water monitoring programs is at risk as state and federal budgets tighten.

These challenges draw attention to the weaknesses in our current water assessment system. But we can restate the same points in a more positive manner. How, in fact, can we make more effective use of our existing financial, scientific, and information resources? How can we take best advantage of the opportunities afforded by new and emerging research, monitoring, and data management technologies? How can we most effectively coordinate the findings from technical monitoring programs and volunteer monitoring programs (as recommended earlier)? How can we make water information more accessible and available to Wisconsin's citizens and decision makers? Can we develop more consistent and compatible protocols for collecting, managing, and documenting data?

With these realizations and questions in mind, the Waters of Wisconsin committee recommends the following actions.

- **The state of Wisconsin — working in partnership with federal, tribal, and local governments; the private sector; and nonprofit organizations — should maintain the state's long-term commitment to, and capacity for, effective water monitoring.** The goal of the state of Wisconsin should be *to develop and maintain the most cost-effective, efficient, well organized, and responsive water monitoring, data collection, and information management system possible.* That system should provide reliable and timely information on atmospheric water, surface water, and groundwater; on watershed functioning; and on water quality and quantity. The health of Wisconsin's waters, and the effectiveness of water management strategies, requires a reliable commitment to monitoring and information gathering by the responsible agencies as well as citizens, communities, and the private sector.

  Adequate funding for water monitoring, data collection, and data analysis programs, and for making this information available to the general public, must be assured. One of Wisconsin's traditional strengths — support for water monitoring programs — is now threatened. Monitoring programs are always highly vulnerable when budgets are constrained. This is a classic case of being penny-wise and pound-foolish, for threats to the sustainability of our waters will not go away, whether we are able to detect them or not. We must be efficient, but we must maintain the sensors that are essential to effective water management.

- **The state of Wisconsin, in partnership with relevant state, tribal, federal, and private entities, should explore options for improving coordination of water information within the state and identifying key research and monitoring needs.** Wisconsin currently lacks a mechanism to determine overall water research priorities, develop indicators of water health, identify and anticipate emerging water information needs, organize reporting of water information, and establish a consistent protocol for the documentation of water data sources. A wide range of information exists, but it is not always available, and its value is not being fully leveraged. Water researchers need to be supported in their efforts to strengthen ties between existing programs; to fill gaps in monitoring programs; and to make the information under their stewardship available to one another, to the public, and to decision makers.

  A key goal is to work toward a more consistent process for determining monitoring needs and research priorities at the state level. In some areas, especially the coordination of groundwater information needs through the Wisconsin Groundwater Coordinating Council, we have been able to make important progress in this direction. But we do not, for example, adequately understand the effects of changes in groundwater hydrology on surface water ecology. We do not have an effective system for accounting for water use in Wisconsin (i.e., who's using how much). We have limited understanding of the cumulative impacts of contaminants; of potential threats associated with microcontaminants (such as synthetic pharmaceuticals and hormones); of means of controlling invasive aquatic species; and of historic changes in watersheds and effective restoration techniques.

- **To help make information on Wisconsin's waters more available and useful to educators, state legislators, local officials, and other decision makers, the state of Wisconsin should coordinate and prepare a regular "State of Wisconsin's Waters" report.** The Wisconsin DNR is required under the federal Clean Water Act to prepare and present an annual 305b report to the U.S. Environmental Protection Agency. The 305b report summarizes a broad range of information on state water quality and water issues. No such equivalent requirement exists at the state level. Adapting the 305b report for state purposes, or otherwise providing a regular assessment (e.g., every five years) of the overall health of Wisconsin's waters, should be a high priority for state government.

- **To make information on Wisconsin's waters more accessible to the public, institutions engaged in gathering and analyzing such information should collaborate in developing a web-based, interactive repository of documented water status and trend data.** Information about the condition of, and changes in, Wisconsin's water is important to water users, educators, legislators and decision makers, resource managers, and interested citizens. Yet much of the existing information on water in the state is difficult to access. A web-based repository of such information should be developed that builds upon and links existing information sources and makes this information more generally available. This should include a user-friendly querying function that allows professionals and others interested in Wisconsin waters to search for relevant data and information. Educators should also be involved in this effort to ensure that it may also serve broad educational goals.

MANAGING WISCONSIN'S WATER FOR SUSTAINABILITY

The ways in which the people of Wisconsin have used and protected the state's waters have evolved throughout the state's history in response to changing economic forces, demographic trends, environmental threats, scientific information, legal mandates, policy tools, and stewardship opportunities. We are now poised for further significant changes in the way we manage our waters.

As in the past, we are constrained by uncertainties and gaps in our knowledge. However, we have the benefit of past experience and of greatly expanded understanding of the status, trends, and functioning of our waters, both within the state and as a part of the global hydrologic system. In the past we have regarded water as a discrete resource and have sought to manage particular water uses, activities, or impacts. Increasingly we understand water as an integral part of the landscapes and watersheds where it occurs. To sustain water for human health, environmental quality, and economic prosperity, we must sustain as well the hydrologic systems and ecosystems through which our waters flow.

Managing for sustainability means taking the long view and seeking ways to integrate human needs and ecosystem values without compromising either. It implies constant assessment of the impacts of our decisions and actions. It depends upon citizens becoming more aware of Wisconsin's waters and more involved in the decisions that affect them.

The principles in chapter 4 underlie the following recommendations for management of our water resources and aquatic ecosystems.

- **Sustainability should be recognized as the foundation and guiding principle of Wisconsin's water policy.** As efforts to frame a comprehensive state water policy continue, sustainability should be the core consideration. The proposed Wisconsin Water Policy Task Force should consider sustainability principles in its work and should further define how they may be embraced and implemented in decision-making processes. For example:
    - The task force should examine options for developing groundwater quantity management policies that allow for a sustainable level of withdrawal while ensuring the protection of surface waters.
    - The task force should recognize the connections between land use and water and propose ways to better integrate water policy with the planning provisions of Wisconsin's Smart Growth legislation.
    - The task force should consider the efficacy of both regulatory and nonregulatory approaches, including the existing incentive structures in state policy, on water conservation, use, and management.

- **Our approach to the protection and management of Wisconsin's water resources and aquatic ecosystems should be flexible, adaptive, and responsive to the complex nature of hydrologic systems.** Because ecosystems are constantly changing, management must itself remain flexible and dynamic. Such adaptive approaches are a fundamental attribute of sustainable resource management. Adaptive management suggests that all water management actions can be thought of as experiments-in-progress, that the results of these actions should be monitored, and that the knowledge and lessons gained should be applied in planning future actions. Adaptive management feeds information back into the decision-making process, so that actions that tend to deplete or degrade water resources are more likely to be self-correcting. Adopted widely, the concept of adaptive management can help to reduce the inherent uncertainty in water resource management. At present, the feedback loops connecting our water assessment system and water management efforts are weak or lacking. These links need to be strengthened if adaptive management is to be realistically achieved. The Water Policy Task Force should review how well basic adaptive management principles are, and can be, embedded in water management programs.

- **Collaborative water basin and watershed-based approaches are fundamental to sustainable water management and should be supported and strengthened through both private- and public-sector actions.** The Wisconsin DNR has recently reorganized its programs according to the state's water basins. This change is intended to encourage more comprehensive and better integrated approaches to water and other resource management responsibilities, and to more actively engage partners in shared management responsibilities.

The DNR's water basin teams deserve public support and will require broader citizen participation to become more effective. Supporting such citizen engagement and partnerships should be regarded as a common, cross-sector goal. Collaborative watershed groups should be established in all of Wisconsin's major watersheds to build a stronger foundation for long-term water stewardship, involve citizens more actively at the local level, and provide input into state- and federal-level decisions.

- **Local governments, organizations, institutions, and businesses in Wisconsin should be encouraged to discuss, embrace, and apply sustainability principles, in both public and private decision making.** The Waters of Wisconsin committee urges others to consider, test, and apply the basic water management principles outlined in this report. Sustainability is a broad societal goal. Laws and policies are essential to promote improved water stewardship and to protect the state's waters against abuse. However, most of the activities and decisions that contribute to greater sustainability are not mandated by law but are made every day by individual citizens, local governments, businesses, and organizations. Observance of sustainability principles is an expression of commitment to future generations and to the well-being of Wisconsin's waters.

Bob Martini

FACING TOMORROW'S WATER CHALLENGES

As we look ahead, Wisconsin will confront many of the same water challenges that other parts of the nation and the world face. Wisconsin will likely have a larger population, greater competition for water uses, more pressured and threatened resources, and more conflicts associated with water allocation and management. These conflicts will likely bring into sharper focus the problems associated with meeting society's need for water while considering ecosystem values and the needs of future generations.

The recommendations outlined here can help us to meet these challenges. We need to adopt a comprehensive and long-range approach to state policy, with the sustainability of the environment and of human communities in mind. We as citizens need to be actively engaged in understanding and stewarding the waters of Wisconsin. We need to anticipate problems by maintaining effective monitoring, research, and planning programs. And we need to address water resource management and protection in a way that is sensitive to the interconnectivity of our waters and the interdependence of their varied uses and values.

Over the last century, Wisconsin has distinguished itself through its efforts to define and live according to a conservation ethic that crosses cultural, generational, and jurisdictional boundaries. By implementing these recommendations, we can once again lead the way.

WDNR

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APPENDIX A

WATERS OF WISCONSIN: GOALS, PRODUCTS, PROCESS

In the spring of 2000, the Wisconsin Academy of Sciences, Arts and Letters embarked on a wide-ranging effort to review the current state and future needs of Wisconsin's water resources and aquatic ecosystems. The Waters of Wisconsin initiative has sought, in the process, to engage a broad spectrum of participants: water scientists, policy makers, members of Wisconsin's 11 Native American tribes and bands, legislators, labor and business leaders, environmental advocates and conservationists, farmers and other landowners, educators and students, writers and artists, the media, and interested citizens throughout the state. This approach is based on the premise that if we are to successfully address many of the water issues we face and enhance the long-term sustainability of our waters, Wisconsin must continually build a broad base of informed citizens and engaged institutions.

The Waters of Wisconsin (WOW) initiative has deliberately sought to look at the big picture of water in Wisconsin, to see our waters as an interconnected hydrologic and ecological system. This system is subject to many, varied, and changing human needs and impacts. Some of these are national or global in scope and long-term in nature, from global climate change to intensified demand for freshwater. Some are more local and immediate, emerging as the water issues that Wisconsin citizens are well familiar with: reducing polluted runoff from our cities and farms; protecting our state's remaining wetlands; addressing risks to water associated with mining; the rapid loss of undeveloped lakeshore along our northern waters (to name several notable examples). Because our waters are connected, so are these issues, and so must be our means of addressing them.

In seeking to comprehend this big picture, WOW has examined human uses of water as well as the goods and services provided by aquatic ecosystems; the challenges associated with water *quantity* as well as water quality; the Great Lakes basin as well as the Mississippi River basin; the state's groundwater and atmospheric water as well as its surface waters. In so doing, WOW has sought not to downplay more particular concerns or opportunities, but rather to reframe them by temporarily stepping back from them, to see them in their broader context. By bringing the best scientific information and policy expertise to the task, and involving Wisconsin citizens in the effort, WOW has tried to provide the foundation for a sustainable water future.

The Wisconsin Academy defined the mission of WOW in this way:

The initiative will, through a process of informed discussion, examine and analyze the current state and long-term sustainability of Wisconsin's waters. The project will provide a forum for citizens, policy makers, the private sector, and academic and governmental leaders to undertake a comprehensive and integrated review of the state of Wisconsin's waters; identify and assess present, emerging, and future demands for the goods and services these waters provide; and examine various strategies for addressing water management and conservation issues and ensuring a high-quality economic and environmental future for the state. The project will be pursued in a manner sensitive to concerns for sustainability, equity, and interdependencies; issues of scale; and the need for adaptive management of Wisconsin's water and related resources.

In carrying out this mission, WOW set several goals for itself. WOW participants have sought to (1) describe the present state of water quality and quantity in Wisconsin, including consideration of water both as a commodity and as an intrinsically important part of our environment; (2) identify the major stressors or factors affecting Wisconsin's water quality and quantity; (3) examine the interactions among these factors; (4) describe selected alternative futures for Wisconsin's water quality and quantity over the next two human generations; and (5) outline a vision of a sustainable future for Wisconsin's waters, with recommendations and strategies needed to achieve this vision by 2075.

The WOW initiative defined several products that would emerge from its efforts, including a review of the status of Wisconsin's waters, based primarily on synthesis of existing data and information; an assessment of our current base of knowledge of our waters; an initial review of current water policies; an array of scenarios illustrating plausible future water conditions; and strategies for promoting the sustainable management of Wisconsin's water resources. In addition to these conceptual outcomes, WOW aimed to produce: a series of public forums, including a statewide forum in October 2002; published articles and other outreach materials; a special water-themed issue of the Academy's peer-reviewed journal, *Transactions of the Wisconsin Academy of Sciences, Arts and Letters*; and this report, with a statement of recommendations.

Development of the WOW initiative took place in four phases (see project timeline). In an initial scoping phase, the Wisconsin Academy sought out leading water scientists, policy makers, advocates, and users in an effort to define the focus of the entire effort. In the second phase, WOW's co-chairs — Dr. Stephen M. Born, Professor of Urban and Regional Planning at the University of Wisconsin–Madison; State Conservationist Patricia Leavenworth of the U.S. Department of Agriculture's Natural Resources Conservation Service; and Dr. John J. Magnuson, Emeritus Professor of Zoology and Emeritus Director of the Center for Limnology at the University of Wisconsin–Madison — worked with the Wisconsin Academy to develop WOW's goals, products, and committee. In the third phase, the WOW committee held a series of meetings and public forums around Wisconsin to gather information and interact with colleagues and citizens from across the state. Finally, participants gathered for a statewide forum in October 2002 to review the WOW committee's draft report and recommendations, to exchange information and ideas, and to consider future steps (see the forum declaration in appendix E).

In carrying out these activities, WOW has been devoted to a broadly participatory process. To ensure that WOW encompassed a wide spectrum of views and fields of knowledge, and that its work would reach a broad range of interested citizens, WOW organizers undertook a number of specific steps:

WOW committee. In forming the 20-member WOW committee, the Wisconsin Academy sought participants from across the state of Wisconsin and from a wide range of sectors, interest areas, and disciplines.

WOW advisory network. Interested experts and citizens were invited to participate in WOW through an extended statewide advisory network. Through the advisory network, some three hundred people across Wisconsin were able to communicate with the WOW organizers on a regular basis, to receive regular updates on WOW activities, to submit background papers and provide reviews, and to share information and ideas with the WOW committee. In turn, members of the network served as a resource to the WOW committee and Wisconsin Academy organizers.

WOW partners. WOW has been an open and collaborative effort. Many organizations, from both the public and private sectors, contributed valuable resources to the Waters of

Wisconsin initiative and worked with the Wisconsin Academy to bring to the table necessary information and expertise.

WOW forums. WOW's public forums have been open to the interested public and have been organized in such a way as to inform experts and citizens alike. Five regional forums focused on local water bodies and water issues. The statewide forum in October 2002 brought together more than 700 participants from across the state and beyond.

WOW outreach. Organizers of WOW sought to expand the audience for their efforts through varied means. Articles in the Wisconsin Academy's publications reach the Academy's 1,200 individual and institutional members. Other articles in local and statewide newspapers and periodicals reached a still broader audience. WOW representatives offered many presentations to professional and nonprofit organizations around the state. WOW participants also met regularly with elected leaders to inform them of WOW's work and to invite their participation.

The Wisconsin Academy and its many WOW partners took these steps to ensure that their discussions would be as accessible as possible. Historically, the Wisconsin Idea represented the conviction that the public interest would be best served through open exchange among informed citizens, elected officials, and other state leaders. The Wisconsin Academy has sought to reinvigorate that tradition in every step of its Waters of Wisconsin initiative.

WATERS OF WISCONSIN TIMELINE

Spring 2000 Identification and selection of water science, policy, and conservation as focus of initial "Wisconsin Idea at the Academy" project.

June – October 2000 Wisconsin Academy consultation with water experts on scope and content of water initiative and development of advisory network.

October – December 2000 Identification of WOW committee chairs and development of project mission, objectives, and products.

January – April 2001 Identification of WOW committee.

May – June 2001 First WOW committee meeting; identification of WOW working groups, criteria for assessing the status of Wisconsin's waters, and specific work plans.

July 2001 – September 2002 WOW committee meetings and public forums:

Madison (May 2001)
La Crosse (September 2001)
Green Bay (November 2001)
Stevens Point (January 2002)
Milwaukee (March 2002)
Trout Lake Station/Ashland (May 2002)
Madison (September 2002)

July – October 2002 Initial drafting and review of WOW committee report and recommendations

October 21 – 22, 2002 Statewide WOW forum in Madison

November 2002 Follow-up WOW meeting at the Wingspread Center, Racine

December 2002 – March 2003 Revision, review, and production of final WOW report

January 2003 Year of Water in Wisconsin begins

April 2003 Release of WOW report

2003 Publication of special volume of *Transactions of the Wisconsin Academy of Sciences, Arts and Letters*

APPENDIX B

WISCONSIN WATER DATA: SOURCES AND DOCUMENTATION

The following table lists useful sources of water-related data in Wisconsin. The table includes information on the type of data; the custodian, format, geographic area, and frequency of collection; and a brief description of the data set. This should not be considered an exhaustive list of all available water data on water in Wisconsin; it does provide links to major data sources and demonstrates the breadth of institutions involved in collecting water-related data. The following acronyms are used in the table:

CAFO	Concentrated Animal Feeding Operation
DRG	Digital Raster Graphic
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
GEMS	Ground and Environmental Monitoring System (WDNR)
GEO	Geographic Services (WDNR)
GIS	Geographical Information System
GLIFWC	Great Lakes Indian Fish and Wildlife Commission
NAPP	National Aerial Photography Program
NRCS	Natural Resources Conservation Service (within USDA)
NRI	Natural Resources Inventory
NSDI	National Spatial Data Infastructure
NTL-LTER	Northern Temperate Lakes — Long-Term Ecological Research
NWISWeb	National Water Information System Website (program of USGS)
OLIS	Office of Land Information Services (within WDOA)
SCO	State Cartographer's Office
SHWIMS	Solid and Hazardous Waste Information Management System (WDNR)
STORET	Storage and Retrieval Database (USEPA and WDNR)
SWAMP	System for Wastewater, Applications, Monitoring, and Permits (WDNR)
TIGER	Topologically Integrated Geographic Encoding and Referencing
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UW ERSC	University of Wisconsin Environmental Remote Sensing Center
UWSP	University of Wisconsin–Stevens Point
WCMP	Wisconsin Coastal Management Program (within WDOA)
WDATCP	Wisconsin Department of Agriculture, Trade and Consumer Protection
WDNR	Wisconsin Department of Natural Resources
WDOA	Wisconsin Department of Administration
WGNHS	Wisconsin Geological and Natural History Survey
WISCLAND	Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data
WISCLINC	Wisconsin Land Information Clearinghouse
WWI	Wisconsin Wetland Inventory (WDNR)

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Aerial Photography	SCO	Publications	Statewide		Reports on photography acquired by public and private agencies and other groups. Generally medium-scale, vertical, stereoscopic photography used for mapping, resource inventories, and land-use studies. Lists aerial photography projects from 1936 to present. Contains summary info on more than 1,000 Wisconsin projects. See http://www.geography.wisc.edu/sco/
Aquatic and Terrestrial Resource Inventory (ATRI)	DNR, Wisconsin State Herbarium	Website	Variable	Ongoing	ATRI provides integrated environmental information including interactive maps, statewide inventories, and metadata. The website is http://maps.botany.wisc.edu/atri/
Aquifers	USGS	Publications	Statewide		Wisconsin aquifers are defined in two USGS publications: Kammerer 1995 and Kammerer et al. 1998
Beach Closings	WDNR			Completion in a few years	For Great Lake beaches only initially; then entire state
Bureau of Remediation and Redevelopment Tracking System (BRRTS)	WDNR	Website	Statewide	Daily updates	BRRTS is a tracking system maintained on the internet to better provide information to internal and external partners interested in contaminated-site information. It brings together several streams of data about different types of environmental pollution, each of which has a long history. http://www.dnr.state.us/org/aw/rr/brrts/
Climate — Lake Ice Cover Studies	UW–Madison Center for Limnology		Variable		The Center for Limnology has gathered and analyzed ice cover data from sites in Wisconsin and around the world. Contact Barbara Benson at bjbenson@wisc.edu
Coastal	WDOA, WCMP	Publication	Coastal Area		Coastal wetlands assessment; coastal wetlands reports, http://www.doa.state.wi.us/dhir/boir/coastal

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Concentrated Animal Feeding Operations (CAFOs)	WDNR	1:24,000 data layer	Statewide		This data was collected for the Source Water Assessment Program and is maintained by the Watershed Management program. It includes locations of CAFOs with at least 1,000 animal units.
Dam Locations	WDNR	1:24,000 data layer	Statewide	Irregular	This data set is a point shape file representing 4,600 large and small dams in Wisconsin, including approximately 1,000 abandoned or removed dams. The DNR Bureau of Watershed Management is the custodian for the state's dam inventory, which is maintained in a relational database. The original location reference is latitude/longitude for large dams, and Public Land Survey System notation for other dams. Users should note that, due to imprecisions in the source information, overlaying dam locations with hydrography or other data layers may result in positional offsets (i.e., dams not coinciding with rivers). Selected attribute information is included with the dams' point data layer. See http://maps.dnr.state.wi.us/dams/viewer.htm
Drainage Basins — Major	WDNR	1:24,000 data layer	Statewide	Periodic (updated when error has been identified and accepted)	Identifies the 3 major river basins in Wisconsin (identified by the primary water body into which the basin drains: Lake Superior, Lake Michigan, and the Mississippi River).
Fish Advisory Sites	WDNR	1:24,000 data layer	State waters	Ongoing	Information on state waters with health advisories for human fish consumption. Generated from fish/sediment contaminant database.
Fish — Contaminated	WDNR	1:24,000 data layer	Statewide	Ongoing	Fish/sediment contaminant data derive from routine monitoring of lakes and streams, as well as special investigative sites. This database contains information on type/size of fish and levels of bioaccumulative toxins (amount and type) in their tissue and/or organs. The sediment portion of the database includes the amount of organic and inorganic levels of contaminants in the soil. This is based on the depth of the samples, so the methodologies of sampling techniques are described as well.

APPENDIX B — WISCONSIN WATER DATA: SOURCES AND DOCUMENTATION

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Fisheries Diversity	WDNR/USGS	Lat/long	Statewide	In progress, ongoing	DNR Biological Database currently under development at USGS. Includes info on fish, habitat, insects, and fish propagation, as well as treaties.
Floods/Flood-Prone Areas	FEMA	1:2,000 is most common, some are 1:400, 800, or 1,000 data layers	Nationwide		The Mitigation Directorate's Flood Hazard Mapping Technical Services Division maintains and updates the National Flood Insurance Program maps. Flood maps tell us where the flood risks are based on local hydrology, topology, precipitation, flood protection measures such as levees, and other scientific data. The WDNR is geo-referencing the scanned Flood Insurance Rate Maps into WTM 83/91 coordinates to be used with other ancillary GIS datasets in Wisconsin. WDNR is also gathering vector information where available.
Geographic Data Layer Overview	WDNR	Website	Statewide		Geographic data holdings of Wisconsin DNR that have statewide coverage and are available from the DNR Geographic Services Station (DNR/GEO) without restriction, unless otherwise noted. Related data themes include County Boundaries, Landnet Sections and Townships, minor civil division, and Wisconsin state outline. See http://www.dnr.state.wi.us/maps/gis/
Geology	WGNHS	Website — Adobe pdf	Statewide		The WGNHS has numerous publications describing Wisconsin geology and a new map showing landscapes. The WGNHS publications are on line in Adobe pdf at http://www.uwex.edu/wgnhs/maps.htm

APPENDIX B — WISCONSIN WATER DATA: SOURCES AND DOCUMENTATION

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
GIS Services at the Wisconsin Department of Administration (DOA) Office of Land Info Services (OLIS)	WDOA/OLIS	Website	Statewide		Includes access to Wisconsin TIGER data for each of the 72 counties, 13 themes (which include 1998 municipal boundaries), the 1990 census boundaries, roads, water, and the county outline. Also includes statewide files for the municipal boundaries, water, and federal and state highways. The WDOA website is http://www.doa.state.wi.us
Geology — Surficial	WGNHS	1:1 million; state and county publications; web page — Adobe pdf	Statewide		Derived from the USGS 1:1,000,000 scale map (Wisconsin portion). The map was originally digitized by DNR for use as a layer used to produce the Groundwater Contamination Susceptibility Map. Originally, the sole attribute was a numerical scoring label. WGNHS was able to obtain a copy of the linework and provide a label that would reflect the units on the published map. Since some of the units were differentiated on the map only by a gray screen, WGNHS added a suffix to the label to distinguish the units. WGNHS has the linework for Wisconsin, but the metadata is not yet complete. The WGNHS publications are on line in Adobe pdf at http://www.uwex.edu/wgnhs/maps.htm
Great Lakes — Water Level Changes	Great Lakes Commission, USGS, U.S. Army Corps of Engineers	Hydrographs	Great Lakes	Monthly	Data on lake level trends and fluctuations. Hydrographs showing monthly average water levels on each of the Great Lakes since 1865.

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Groundwater	USGS and WGNHS	Database	Statewide		The USGS investigates the occurrence, quantity, quality, distribution, and movement of surface and underground waters and disseminates the data to the public, state and local governments, public and private utilities, and other federal agencies involved with managing our water resources. The WGNHS works in cooperation with the USGS to compile statewide groundwater data. The database of current water table hydrographs, historical hydrographs and Little Sand Lake lake levels and precipitation is available at http://wi.water.usgs.gov/gw/
Groundwater — Atlas	USGS	Website	Nationwide		Intended for use as an introduction to the nation's groundwater resources and as a teaching tool. Http://capp.water.usgs.gov/gwa/ch_j/index.html
Groundwater — Private Well Water Quality	Central Wisconsin Groundwater Center — UWSP, Dave Madovich	Digital	Statewide — more intensive in some counties than in others	Continuous	Private well water–quality database including location, well characteristics, nitrate, bacteria, some metals, some trianzine. Generally accessible by request. Drinking water well samples submitted by citizens, often through extension programs.
Groundwater — Public and Private Wells — Groundwater Retrieval Network (GRN)	WDNR	Website	Statewide	Weekly	This website provides information from the Department's public water supply (public drinking water supply wells) and, private water supply (private drinking water supply wells, non–point source priority watershed projects, and special groundwater studies) databases, and from the Bureau of Waste's Groundwater and Environmental Monitoring System (GEMS) (landfills wells).

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Herpetology Atlas	Milwaukee Public Museum	Website	Statewide		The Wisconsin Herpetology Atlas Project was initiated in 1986 by the Milwaukee Public Museum, and tracks the distribution of Wisconsin's 56 amphibian and reptile species. http://www.mpm.edu/collect/vertzo/herp/atlas/atlas.html
Hydrography	WDNR	1:24,000 data layer	Statewide	When USGS Quad maps are updated	This layer makes up all the "blue lines" seen on the USGS 7.5" topographic quadrangle maps. There are names and Water Body Identification Codes (WBICs) coded on the streams and lakes. The flow direction and other items for connectivity for modeling have been added into this layer.
Invasive Species	WDNR	Website	Statewide		Provides species lists, resources, and additional information on invasive plants and animals in Wisconsin. http://www.dnr.state.wi.us/org/land/er/invasive/index.htm
Invasive Species	Great Lakes Indian Fish and Wildlife Commission (GLIFWC)	Website	Upper Great Lakes		Website of the GLIFWC Exotic Plant Information Center. http://www.glifwc.org/epicenter/welcome.html
Invasive Species — Zebra Mussel Monitoring Locations	WDNR	1:24,000 data layer		Annual	The sampling sites were originally located on maps of various scales in 1993. During the summer of 2000 the information was updated, and the sites were located on USGS 7.5" Digital Raster Graphics (DRGs) in WTM83/91. Even though some sampling sites are no longer monitored, we retained the information in the layer for a historic record of where sites were sampled. The GIS layer can be linked to an Excel spreadsheet (Zebra Mussel Monitoring Locations_all), which contains additional information on the sampling location, along with the name and address of the person collecting the samples. WDNR also has a GIS layer of zebra mussel infestation locations.

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Lake Classification System	WDNR	Database	Statewide		29 counties completed.
Lakes — Aquatic Plants	WGNHS	Database	Statewide		Information available for about 50 lakes in Wisconsin. Includes long-term trend lakes, inland lake studies, and special studies of aquatic plants. Maintained by the Wisconsin Geological and Natural History Survey. For further information Stan Nichols at sanicho1@facstaff.wisc.edu
Lakes — Lake Maps	WDNR	Website	Statewide		The DNR Conservation Department makes the maps. There are maps for approximately 1,350 lakes. They are scanned at a resolution of 300 dpi. http://dnr.state.wi.us/org/water/fhp/lakes/lakemap
Lakes — North Temperate Lakes — Long Term Ecological Research (NTL-LTER) Spatial Data Catalog	UW–Madison Center for Limnology	Website	Madison Lakes and Trout Lake regions		This page contains the catalog of spatial data available for NTL-LTER researchers or produced by LTER researchers. The National Science Foundation established the LTER program to support research on long-term ecological phenomena in the U.S. http://limnosun.limnology.wisc.edu/catalog.html
Lakes — Trophic Status	WDNR	Website	Statewide	Biweekly 900+ lakes	Self-help lake data collected: secchi depth, clarity, chlorophyll a, total phosphorus, aquatic plants, ice dates, dissolved oxygen and temperature profiles. http://dnr.state.wi.us/org/water/fhp/lakes
Lakes — Trophic Status	UW ERSC	1:40,000 data layer	Statewide	In progress	UW ERSC is currently working on a statewide lake water clarity project using secchi estimates based on Landsat satellite imagery. Data processing and analysis was done by the UW ERSC. Field measurements were from the Self-Help Lake Monitoring Program used for model development and validation. Meetings are currently under way to discuss the DNR (Lakes and/or ISS) maintaining this project.

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Land — Boundaries	USGS	ESRI shapefile	Nationwide		National Atlas of the United States of America. On-line interactive atlas with on-line data to download in ESRI shape file format. Includes county boundaries, federal lands, metropolitan areas and Public Land Survey System boundaries. http://www.nationalatlas.gov/
Land Information	WDOA, OLIS	Website, text	Statewide	Ongoing	The Wisconsin Land Information Clearinghouse (WISCLINC) is a gateway to geospatial data and metadata, related land and reference information, and the Wisconsin agencies that produce or maintain these items. WISCLINC is also a registered node in the web of NSDI clearinghouses. http://wisclinc.state.wi.us
Land Use Trends	NRCS	Website database	Statewide and Nationwide	Annual	The National Resources Inventory (NRI) provides updated information on the status, condition, and trends of land, soil, water, and related resources on the nation's non-federal land. The 1997 NRI is unique in that it provides a nationally consistent database that was constructed specifically to estimate 5-, 10-, and 15-year trends for natural resources from 1982 to 1997. Data for the 1997 NRI was collected for more than 6,500 locations in Wisconsin by primarily remote sensing. "Area" reports on acreage within a specified area that does or does not meet the user-defined condition, practice, or use. "Non-area" reports about year-specific units of measure other than acreage that meet user-defined condition, practice, or use. "Trending" analyzes 5-year, 10-year, and 15-year time spans for some data elements in the 1997 NRI. "Changes" reports on the shift from one use, condition, or practice to another. http://www.nrcs.usda.gov/nri/sdata.asp

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Landcover — WISCLAND	WDNR	40K/Raster dataset	Statewide		The land cover data product was derived from LANDSAT Thematic Mapper (TM) satellite imagery acquired from flyovers in August 1991; May, July, September, and October 1992; and May 1993. TM data are organized by rectangular areas referred to as scenes, each 108 miles on a side. Twelve scenes are required to cover Wisconsin. A scene is comprised of roughly 50 million cells, or pixels, each representing a 30-meter square, or an on-the-ground area of 900 square meters.
Landscapes	WGNHS	Website — Adobe pdf	Statewide		WGNHS has numerous publications describing Wisconsin's water and geology, and a new map showing landscapes. The WGNHS publications are on line in Adobe pdf at http://www.uwex.edu/wgnhs/maps.htm
NWISWeb Data for Wisconsin • Real-time • Site Information • Surface Water • Groundwater • Water quality	USGS	Database	Statewide		Category descriptions: Real-time — current conditions data transmitted from selected surface-water, ground-water, and water-quality sites; Site Information — descriptive site information for all sites with links to all available water data for individual sites; Surface Water — water flow and levels in streams, lakes, and springs; Ground Water — water levels in wells; Water Quality — chemical and physical data for streams, lakes, springs, and wells.
Pesticide Use	WDATCP	Township, Range, Section (TRS)	Statewide		DATCP's water quality section provides information on wells with atrazine and nitrate contamination. Atrazine prohibition areas designated are also shown at the county level.

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Pollution — Point Source Discharges	WDNR	1:24,000 data layer	Statewide	Ongoing	The DNR regulates municipalities, industrial facilities, and significant animal waste operations discharging wastewater to surface waters or groundwater of the state of Wisconsin through the Wisconsin Pollutant Discharge Elimination System (WPDES) Permit Program. No person may legally discharge to waters of the state without a permit issued under this authority.
Population Density (history/trends)	Demographics Services Center/Applied Population Lab		Census data: Entire U.S. down to the level of census blocks	Every 10 years for census data; more frequently for other data	The two organizations provide census data technical support to a network of 39 affiliates, other governmental agencies, and the general public. Tables can be linked with county, or minor civil division GIS datasets. www. doa.state.wi.us/dhir/boir/demographic and www.ssc.wisc.edu/poplab.
Precipitation Data	State Climatologist	Website	Statewide	Ongoing	These climatological extremes are based on observers' records on file in the State Climatologist's Office. The records are from official climatological observing stations. The National Weather Service provides and maintains instruments for official observers in the Cooperative Climatological Observer Network. Other sources of precipitation data include WGNHS and the Weather Service. http://mcc.sws.uiuc.edu/summary/wisconsin.html.
Raster Graphs, Enhanced Digital	WDNR	Website	Statewide		Access to downloadable copies of Wisconsin Digital Raster Graphics (DRGs), and optically scanned map images originally produced by USGS. DNR Geographic Services (GEO) has acquired statewide DRG coverage and has made DRGs available for download via web browser. http://www.dnr.state.wi.us/maps/gis/datadrg.html

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
River Basin Reports	WDNR	Text	River basins	~Five years	"State of the Basin" reports are being prepared in each basin in Wisconsin. These plans provide a picture of the status of the basins resources and identify key areas for DNR work. http://www.dnr.state.wi.us/org/gmu/
Sediments — Contaminated	WDNR	1:24,000 data layer	Statewide	Ongoing	The fish/sediment contaminant routine monitoring of lakes and streams, as well as special investigative sites. The information tracked in this database contains type/size of fish and levels of bioaccumulative toxins (amount and type) in their tissue and/or organs. The sediment portion of the database reports1, the amount of organic and inorganic levels of contaminants in the soil. This is based on the depth of the samples, so the methodologies of sampling techniques are captured as well.
Shoreland — Development Trends	UWSP, DNR	Database	Wisconsin north of Rt. 29		Data generated by the Wisconsin DNR during an aerial survey of 235 lakes in northern Wisconsin.
Source Water Assessment Program (SWAP) potential contaminant source data	WDNR	1:24,000 data layer	Wisconsin Source water assessment areas only	Completion by 1/04	The SWAP data layer includes only potential contaminant sources identified through the source water assessment program that are not included in other databases such as BRRTS, SWAMP, or SHWIMS. It covers only areas of the state that are within groundwater-supplied public water system source water areas and is maintained by the Drinking Water and Groundwater program.
Stream flow	USGS	Website	More than 250 sites in Wisconsin	Real-time and historic data	Real-time and historic streamflow data is available for more than 250 sites in Wisconsin. http://wi.water.usgs.gov/data.html

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Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Upper Mississippi	USGS	Database	Upper Mississippi River		Environmental Information System for Upper Mississippi and Lower Missouri River Basins. Includes access to USGS quadrangles for the river basin area.
USDA — Natural Resource Conservation Service (NRCS): Wisconsin Data & Technology	NRCS	Website	Statewide		Available data include digitized soil maps, soil attribute data for GIS use, and state general soil maps. A variety of related reports including soil survey reports, hydric soils lists, prime soils lists, erosion factors, and soil groups reports are available. http://www.wi.nrcs.usda.gov/news/default.asp
USGS: Programs in Wisconsin	USGS	Website	Statewide		Topics include non–point source contamination by ag and urban runoff, contamination of Great lakes by toxic substances, inland lake contamination, ground-water contamination, ground-water availability, and mercury contamination of recreational lakes. Also includes inland lake and ground water contamination, mercury contamination of recreational lakes, and rapid submergence of Lake superior shorelines. http://wi.water.usgs.gov/index.html
USGS: Status Graphics for Wisconsin Mapping Products	USGS	Website	Statewide		Shows availability of different USGS mapping products for Wisconsin, such as DRGs, Digital Elevation Models (DEMs), and Digital Orthophotoquads (DOQs). Also includes national status of National Aerial Photograph Program (NAPP) products. http://www.usgs.gov/
USGS Midwest Environmental Sciences Center — Data library	UMESC	Website	Upper Mississippi River		Data sets for the Mississippi River. Wildlife data, sediments, contaminants and nutrients, fisheries, macroinvertebrates, land use, land cover data, bathymetry data, etc. http://www.umesc.usgs.gov/data_library/data_library.html

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
USGS — Upper Midwest Environmental Sciences Center (UMESC): Available Data Applications	USGS	Website	Upper Midwest		Includes DRGs, hydrology, transportation. Data sets for Mississippi River projects also available. http://www.umesc.usgs.gov/
Water — Outstanding and Exceptional Resource Waters (OERWs)	WDNR	1:100,000 data layer	Statewide	When code changes	Outstanding and Exceptional Resource Waters: The DNR's Water Division maintains a database of information on Outstanding and Exceptional Resource Waters (NR102).
Water Use	USGS	Publication	Statewide		Ellefson, B.R., G.D. Mueller, and C.A. Buchwald, 2002, Water use in Wisconsin, 2000; U.S. Geological Survey Open-File Report 02-356, 1 sheet.
Water, Surface (STORET Data)	WDNR/EPA	Website	Statewide		STORET is a repository for water quality, geological and physical data used by state environmental agencies and others. There are two parts to the surface water quality data base; Legacy STORET and Modernized STORET. The Legacy system contains data to the end of 1998. The Modernized system is on line at EPA but Wisconsin has not fully developed this. Access to both systems is through the website. See EPA website: http://www.epa.gov/storet/.

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Waters — Impaired (303d)	WDNR	1:24,000 data layer	Statewide	2 years	Section 303(d) of the 1972 Clean Water Act requires states, tribes, and territories to develop lists of impaired waters. Impaired waters are those not meeting water quality standards, including both water quality criteria for specific substances or designated uses (those uses that are codified in water quality standards regulations, i.e., NR 104, Wis. Adm. Code). The 303(d) ArcView shape files were originally developed based on the 1998 Wisconsin 303(d) list of impaired waters. The associated 303(d) ArcView shape files will be edited to reflect changes in the 303(d) list as updated lists are submitted and approved by EPA. Each state is required to submit an updated 303(d) list every two years.
Watersheds	USGS	Publication	Statewide		Watershed delineations will soon be available in digital format based on Henrich and Daniel 1983. Drainage areas include all named streams draining more than 5 square miles and all unnamed streams draining more than 10 square miles. Wisconsin's major river basins (watersheds) are described in a series of USGS Hydrologic Investigations (USGS 1968–1975)
Watersheds — Boundaries	WDNR	1:24,000 data layer	Statewide	Periodic (updated when error has been identified and accepted)	Identifies areas in Wisconsin that drain water into a common river system or lake. There are 334 watersheds identified in Wisconsin.
Wells – Groundwater – Municipal High Cap	WDNR	Township/Range/ Section location table	Wisconsin		A high-capacity groundwater extraction system is defined as any well or combination of wells on a single property that has a maximum pumping capacity of 70 or more gallons per minute (Ch. 281.17(1) Wisconsin Statute). There are different types of high-capacity wells depending on both the geology in which the well is constructed and the purpose for which the well is used. http://prodmtin00.dnr.state.wi.us/pls/prod1/hicap$.startup.

Data Set Title	Custodian	Format	Geo. Area Covered	Collection Frequency	Description and Source
Wetland Gains	WDNR, USDA, USFWS	Varied	Statewide		Wetland restoration programs include the USDA NRCS Wetlands Reserve Program, USFWS Partners for Fish and Wildlife, and WDNR wetland restoration activities. The agencies attempt to quantify the cumulative annual statewide restorations of wetlands, but because of the crossover of funding between programs, the data are not considered an accurate estimation of wetland restoration accomplishments.
Wetland Inventory — Wisconsin (WWI)	WDNR	1:24,000 data layer	Statewide		The WWI was completed for the state in 1985. Based on aerial photography from 1978 to 1979, it shows approximately 5.3 million acres of wetlands remaining in the state, representing a loss of about 47% of original wetland acreage. This figure does not include wetlands less than 2 or 5 acres in size (minimum mapping unit varies by county), which are depicted as point symbols on the maps. Because the original WWI utilized aerial photographs taken in the summer, some wetlands were missed, especially in the northern counties since interpretation was difficult because of leaf cover. Also, wetlands that were farmed on the date of photography and then abandoned due to wet conditions were not captured as part of the WWI inventory. County by county wetland acreage is available. County wetland acreage information is available for those updated counties that have been digitized. Currently there are 18 updated counties that need to be digitized to determine wetland acreage. Contact Lois Simon, simonl@dnr.state.wi.us
Wetland Losses — Permitted	WDNR	Database	Statewide		Accurate information on Wisconsin wetland losses is not available, but two evaluations of wetland losses based on Corps of Engineers wetland permits provide some data: 1982–1991, 1,200 acres/year; 1991–1998, 312 acres/year.

APPENDIX C

WISCONSIN ECOSYSTEM VOLUNTEER MONITORING: PROGRAMS AND RESOURCES

Volunteer monitoring programs in Wisconsin provide opportunities for individuals, organizations, and communities to learn firsthand about the health of the land, water, and biological diversity of their local landscapes. Volunteer monitoring can provide vital information and meaningful learning experiences while informing decision making and giving people in local communities personal, hands-on experience.

Although the Wisconsin DNR has primary responsibility for managing our state's natural resources, it does not have sufficient staff or funding to gather all the baseline information needed to target sites for protection or remediation in our river basins, or to monitor changes in our resources. Volunteer monitoring programs can supplement DNR monitoring efforts, and in many cases it provides the only data available for a given site. By helping to keep track of the health of the resources they are enjoying, Wisconsin's citizens can greatly enrich their outdoor experiences.

This list includes programs that focus on aquatic ecosystems and resources. A full list of volunteer monitoring programs is available on the website of the Wisconsin Academy of Sciences, Arts and Letters (www.wisconsinacademy.org). Corrections, additions, and suggestions for this list are welcome.

A. Volunteer Monitoring Programs

Amphibians

North American Reporting Center for Amphibian Malformations
http://www.npsc.nbs.gov/narcam/
Amphibian malformations — North America
USGS

Amphibians

Terrestrial Salamander Monitoring Program
http://www.mp1-pwrc.usgs.gov/sally/
Salamander survey — USA
USGS

Amphibians

Wisconsin Frog and Toad Survey
http://www.mbr-pwrc.usgs.gov/wifrog/frog.htm
Frog and toad count — Wisconsin
Part of North American Amphibian Monitoring Program (NAAMP)
www.pwrc.usgs.gov/naamp
USGS & WDNR
Robert.Hay@dnr.state.wi.us (608) 267-0849

Birds

Annual Midwest Sandhill Crane Count
http://www.savingcranes.org/getinvolved/cc_mainnew.asp
Crane count — Upper Midwest
International Crane Foundation
explorer@savingcranes.org (608) 356-9462 x 142

Birds	**Birds in Forested Landscapes** http://www.birds.cornell.edu.bfl/ Forest Bird Survey Cornell Lab of Ornithology	 North America
Birds	**Christmas Bird Count** http://www.audubon.org/bird/cbc/ Bird Count National Audubon Society	 North America
Birds	**Horicon Grassland Bird Point Count Survey** http://midwest.fws.gov/Horicon/ Grassland bird counts Horicon National Wildlife Refuge	 Horicon
Birds	**Loonwatch, a program of the Sigurd Olson Environmental Institute** http://www.northland.edu/soei/loonwatch Loon nesting success loonwatch@northland.edu (715) 682-1220	 Wisconsin & Minnesota
Birds	**North American Breeding Bird Survey** http://www.uwgb.edu/birds/wso/ Breeding bird survey Wisconsin Society of Ornithology	 North America
Butterflies	**North American Butterfly Association** http://www.naba.org/ Butterfly Count NABA naba@naba.org	 North America
Exotics	**"See Cella Chow!" Purple Loosestrife Survey** http://www.wiscwetlands.org/ WI Wetlands Association derek@wiscwetlands.org (608) 250-9971	 WI coastal counties and possibly statewide
Exotics	**Phragmites Survey** www.wiscwetlands.org Wisconsin Wetlands Association derek@wiscwetlands.org (608) 250-9971	 Wisconsin coastal counties
Exotics	**Zebra Mussel Watch** http://seagrant.wisc.edu/zebramussels/index.html Zebra mussels UW Sea Grant Institute	 Wisconsin

Fish	**Fish Kill Network** http://www.iwla.org/fishkill/ Fish kills and agricultural runoff Izaak Walton League of America fishkill@iwla.org (651) 649-1446	Upper Mississippi states
Fish	**Lake Watch** Fishing violations (262) 617-6343	Wisconsin
Forestry BMPs	**DNR Forest BMP for Water Quality — Monitoring** http://www.dnr.state.wi.us/org/land/forestry/usesof/bmp/bmp.html Forestry BMP Application and Effectiveness WDNR gassed@dnr.state.wi.us (608) 266-1667	Wisconsin
Groundwater	**Farm*A*Syst** http://www.uwex.edu/farmasyst/ Well water threats UW–Extension farmasys@uwex.edu (608) 262-0024	Wisconsin
Groundwater	**Groundwater Guardians** http://guardian@groundwater.org/ Groundwater monitoring/education The Groundwater Foundation guardian@groundwater.org (800) 858-4844	USA
Groundwater	**Home*A*Syst** http://www.uwex.edu/homeasyst/ Home health and safety UW–Extension homeasys@uwex.edu (608) 262-0024	Wisconsin
Groundwater	**UWSP Well Water** http://www.uwsp.edu/water/portage/action/wtrtest.htm Well water screening Central Wisconsin Groundwater Center cmecheni@uwsp.edu (715) 346-4276	Wisconsin
Health & Water	**Riverwatch Health Survey** http://www.riverwatch.org/health/index.cfm Human health and water River Network info@rivernetwork.org (503) 241-3506	USA

Lakes **Adopt-A-Lake**
http://www.uwsp.edu/cnr/uwexlakes/youthprograms/
Multiple Wisconsin
UW–Extension/DNR
lfelda@uwsp.edu (715) 346-3366

Lakes **Community Stewardship Program**
http://www.inlandsea.org/programs.html
Lake Superior Inland Sea Society Lake Superior
iss@inlandsea.org (715) 373-0674

Lakes **Great North American Secchi Dip-in**
http://dipin.kent.edu
Water quality USA
Kent State University
dipin@kent.edu (330) 672-3992

Lakes **WI DNR — Self Help Citizen Lake Monitoring**
http://www.dnr.state.wi.us/org/water/fhp/lakes/shlmmain.htm
Water quality, exotics Wisconsin
WDNR
filbej@dnr.state.wi.us (608) 264-8533

Rivers **Dane County Water Watchers**
River monitoring Dane County
Dane County UW–Extension Office
habecker@co.Dane.WI.US (608) 224-3718

Rivers **Kickapoo Stream Monitoring**
www.kickapoovsn.org
River monitoring Kickapoo River
Valley Stewardship Network
vsn@frontiernet.net (608) 637-3615

Rivers **Rock River Coalition Citizen Monitoring**
http://clean-water.uwex.edu/rockriver/
River monitoring Rock River Basin
Rock River Coalition
suzanne.wade@ces.uwex.edu (920) 674-8972

Rivers **Save Our Streams**
http://www.iwla.org/sos/
River monitoring USA
Izaak Walton League of America (800) 284-4952

Rivers	**Testing the Waters** http://www.muhs.edu/pages/teacherpages/science/riverstudies/ttw.html River monitoring Riveredge Nature Center education@RiveredgeNC.com	Milwaukee River
Rivers	**Trout Unlimited Stream Monitoring — Nohr Network of Monitors** http://clean-water.uwex.edu/gpsp/index.htm River monitoring TU Harry and Laura Nohr Chapter and UW–Extension Basin Educator kayndave@mhtc.net (608) 943-8454 peggy.compton@ces.uwex.edu (608) 342-1633	Southwest Wisconsin
Rivers	**Water Action Volunteers** http://clean-water.uwex.edu/wav River monitoring UW–Extension and WDNR kris.stepenuck@ces.uwex.edu (608) 264-8948	Wisconsin
Watershed	**Adopt-A-Watershed** http://www.adopt-a-watershed.org/ K–12 watershed stewardship Adopt-A-Watershed donna@adopt-a-watershed.org (530) 628-5334	Global
Watershed	**Geography Action** http://www.nationalgeographic.com/geographyaction/ Multiple — educators National Geographic Society	North America
Watershed	**GREEN (Global Rivers Environmental Education Network)** http://www.green.org/ Database of local monitoring results green@earthforce.org (703) 299-9400	Global
Watershed	**The Globe Program** http://www.globe.gov/ Multiple Office of Space Science Education, UW–Madison margaret.mooney@ssec.wisc.edu (608) 265-2123	Wisconsin

Wetlands	**American Wetlands Campaign** http://www.iwla.org/sos/awm Wetlands Izaak Walton League of America (800) 284-4952	USA
Wetlands	**Wisconsin Wetlands Watch (W3)** http://www.wsn.org/wetlands/W3announce.html Wetland filling	Wisconsin

B. References and Links to Other Programs

Citizen Science
http://birds.cornell.edu/whatwedo_citizenscience.html
Bird Data — North America
Cornell Lab of Ornithology

Frogwatch USA
http://monitoring2.er.usgs.gov/frogwatch

Global Lake and River Ice Phenology Database
http://nsidc.org/data/g01377.html
Ice duration — Global
U.S. National Oceanic and Atmospheric Administration

Great Lakes Atlas — Great Lakes
http://www.on.ec.gc.ca/great-lakes-atlas/intro.html

Great Lakes Declining Amphibians Working Group — Great Lakes
http://www.mpm.edu/collect/vertzo/herp/Daptf/daptf.html

Great Lakes Water Quality Report
http://www.ijc.org/ijcweb-e.html
Great Lakes health — toxics — Great Lakes
International Joint Commission

Groundwater Levels
http://wi.water.usgs.gov/gw/
Groundwater level data — Wisconsin
USGS
brellefs@usgs.gov

IOWATER
http://www.iowater.net/
Lakes Iowa
Iowa DNR

Links to National Programs — KWW
http://water.nr.state.ky.us/ww/vm.htm
Links to other Programs USA
Kentucky Water Watch

National Health Protection Beach Survey
http://www.epa.gov/ost/beaches/
Beach pathogens USA
US EPA

National Water Quality Monitoring Council
http://water.usgs.gov/wicp/acwi/monitoring/
Methods, quality control, and organizational assistance USA

Pesticide Use Reporting and Reduction Project
http://www.wsn.org/pesticides/
Pesticide distribution Wisconsin
WED & CBE

Radium in Drinking Water
http://www.dnr.state.wi.us/org/water/dwg/radium.htm
Radium in well water Wisconsin
WDNR

Satellite Lake Observatory Initiative
http://tidris.ersc.wisc.edu/sloi/pub/
Remote water-quality sensing Minnesota, Wisconsin, Michigan
University of Wisconsin Environmental Remote Sensing Center
jlrey@facstaff.wisc.edu

Surf Your Watershed
http://www.epa.gov/surf/
Watersheds USA
US EPA

The Lake Book
http://www.dnr.state.wi.us/org/water/fhp/lakes/wilkbook.htm
All about Wisconsin lakes Wisconsin
WDNR

US EPA Volunteer Monitoring Website
http://www.epa.gov/owow/monitoring/vol.html
Program info and links USA
US EPA

US EPA Watershed Information Network
http://www.epa.gov/win/

US Toxics Release Inventory Program
http://www.epa.gov/tri/
Toxic release inventory USA
US EPA

UW Family Medicine Research Program
http://www.fammed.wisc.edu/research/wren/summerResearch.html
Health research Wisconsin
UW Dept. of Family Medicine

Volunteer Wetland Monitoring Manual
http://www.epa.gov/owow/wetlands/monitor/volmonitor.html
Wetland program guidance USA
US EPA

Water Education of Teachers (WET)
http://www.uwsp.edu/cnr/uwexlakes/wet/
Educational resources Wisconsin
stensa@dnr.state.wi.us
WDNR

Wetland Bioassessment Methods — WI
http://www.epa.gov/owow/wetlands/bawwg/case/wi1.html
Wetland Biotic index Wisconsin
DNR Research
LILLIR@dnr.state.wi.us (608) 221-6338

WI Bird Conservation Initiative
http://www.wisconsinbirds.org/
Bird/habitat monitoring, ID, protection Wisconsin
masoffice@mailbag.com (608) 255-2473

WI Breeding Bird Atlas
http://www.uwgb.edu/birds/wbba/
Bird survey results Wisconsin
Wisconsin Society for Ornithology

WI Exotic Plants and Animals
http://www.dnr.state.wi.us/org/water/wm/glwsp/eOtics/policy
Wisconsin Exotic Species — Wisconsin
WDNR

WI Flora and Fauna Checklists
http://www.dnr.state.wi.us/org/es/science/pubs/tr/checklist.htm
DNR Bureau of Integrated Science Services Publications — Wisconsin

WI Herpetological Atlas Project
http://www.mpm.edu/collect/vertzo/herp/atlas/welcome.html
Herp sightings — Wisconsin
Milwaukee Public Museum
gsc@mpm.edu.

WI List of Impaired Waters
http://www.dnr.state.wi.us/org/water/wm/wqs/303d/index.html
303(d) List — Wisconsin

WI Rare and Endangered Species
http://www.dnr.state.wi.us/org/land/er/factsheets/etindex.htm
List for Wisconsin — Wisconsin
WDNR

WI Rivers Basin information
http://www.dnr.state.wi.us/org/gmu/
Basin specific information — Wisconsin
WDNR

WI Toxics Release Inventory
http://www.dnr.state.wi.us/org/es/science/program/tri/
Toxic Release for WI — Wisconsin
WDNR

Wisconsin Stewardship Network
http://www.wsn.org
Links to Environmental and Conservation Groups — Wisconsin

APPENDIX D

CASE STUDIES IN THE SUSTAINABILITY OF WISCONSIN'S WATERS

In carrying out its work, the Waters of Wisconsin committee traveled across the state, met with many colleagues, and focused on a series of regional water-related projects and problems. At meetings in Madison, La Crosse, Green Bay, Stevens Point, Milwaukee, Woodruff–Minocqua, and Ashland, the WOW committee worked through a series of drafts of its sustainability principles (see chapter 4 of the WOW report), testing them against water management and conservation challenges in these areas. This appendix provides a brief summary of these case studies and the committee's discussions.

In framing these discussions of sustainability in practice, the WOW committee considered several questions through these cases:

- What is the problem? (i.e., what is the gap between what is and what is desired?)
- What is the historic background of the problem?
- What options were identified?
- Who are/were the stakeholders?
- Who has/had decision-making authority?
- What were the key decision points in the process?
- Would the sustainability principles have been helpful in the process?
- How can the particulars of this case study improve the principles?

These summaries attempt to convey the richness of the discussion and of the stimulating effect that the sustainability principles had in seeking to understand complex water problems. The WOW committee thanks Barry Johnson, Michael Kraft, Steve Born, Ken Potter, and Laura Hewitt for facilitating these case studies.

CASE STUDY 1
MANAGING WATER LEVELS ON THE UPPER MISSISSIPPI RIVER

Management of water levels on the Upper Mississippi River dates back to the 1930 Rivers and Harbors Act that created the present-day system of locks and dams on the Mississippi River and mandated that a nine-foot navigation channel be maintained. The dams are low head, bottom release dams that allow sediment and fish to pass and are primarily in place to facilitate navigation. Water levels behind dams are held artificially high during periods of low flow, which has a variety of ecological effects, including increased erosion of islands and loss of shoreline plants.

A reduction in water levels, or drawdown, of the Upper Mississippi River during low flow periods was proposed to mimic a more natural hydrologic regime and to enhance natural communities dependent on low flow periods. In the summers of 2001 and 2002, as a demonstration, the water levels in Pool 8 of the Upper Mississippi River were drawn down 1.5 feet at Dam 8, with no more than a 0.5-foot drawdown at the upper end of the pool around La Crosse. The goals of the drawdown were to allow for soil compaction, sediment oxidation, increased light penetration, and increased growth of both submerged and emergent plants in shallow areas and along shorelines.

Many entities are involved in decision making on the Upper Mississippi River. The primary actors in this decision include the Army Corps of Engineers, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, the Environmental Protection Agency, the five bordering states (Minnesota, Wisconsin, Iowa, Illinois, and Missouri), cities on the river, commercial navigation, and recreational users (boaters, hunters, anglers, wildlife watchers). Secondary actors, not directly involved in Pool 8, include the U.S. Coast Guard, the National Park Service, and Minnesota and Wisconsin Native American tribes.

The Army Corps of Engineers is legally mandated to maintain the water levels at the dams. The proposed drawdown at Dam 8 would reduce water levels below the required band of operation. Several alternative options were considered involving different water levels and different drawdown seasons (summer or winter). A winter drawdown would allow for the desired soil compaction, would fit with the natural flow regime and impact recreational users less, but would be detrimental to the fish populations; therefore the summer drawdown was selected. A 1.5-foot drawdown was selected over a proposed 3-foot drawdown after a study by the Corps determined that the dredging needed to conduct a 3-foot drawdown would be cost prohibitive. The decision process also considered potential impacts to the endangered Higgins' eye pearly mussel. As the impacts were deemed to be minimal, regulatory restrictions were not invoked. Finally, public acceptance of the drawdown was needed from a wide variety of recreational users. In general, most users were willing to forego some use to realize the ecological benefits of the drawdown.

There were several key points in the decision process on the Upper Mississippi: convincing the cooperating agencies that the drawdown was a good idea; developing agreements among agencies on the drawdown plan; and gaining acceptance from the public on the drawdown plan. The primary outcomes of the decision process were the actual drawdown in summer 2001 and 2002; avoidance of litigation to prevent drawdown or for damages incurred; plans for further drawdowns; and a more informed discussion of water level management options for Pool 8 and other locations on the river.

This case study starts, in effect, with a problem and involves a demonstration study to address that problem. That demonstration may, in turn, lead to a major policy change involving water level management of Pool 8. As the WOW committee applied its draft sustainability principles in this case, a key question quickly emerged, one that is at the very heart of the concept of sustainability: how can we enhance ecological values and environmental performance without constraining economic and recreational benefits? That question arose in different ways:

Tension between ecological and economic value. In the context of the Upper Mississippi River, management of the water levels has historically favored navigational uses over ecological functions, values, and services. The drawdown demonstration was intended to show how water levels could be managed in a more flexible and ecologically sensitive manner while still maintaining navigation. This clearly demonstrates the tension between ecological sustainability and other factors, such as recreation and transportation. The sustainability principles (still in an early draft at that stage of WOW's work) identified the broad uses and values of water but may need to make the human component of sustainability more explicit. Moreover, the economic values of resource use extend beyond just the goods and services they provide. This leaves open the question as to whether the principles attach adequate ethical significance to the protection of all uses and values, especially the most sensitive and easily sacrificed. Sustainability, in short, challenges us not only to sustain ecosystems or our economy, but to find ways to do both.

Pragmatism in choosing options. The draft principles stated that "Wisconsin's waters are best sustained when the connectivity of our waters, especially our flowing waters, are maintained, enhanced, and restored to the fullest extent possible." The committee discussed whether the Pool 8 drawdown plan met the "to the fullest extent possible" clause of this statement, or whether political and financial feasibility in fact limited the range of management options. In response, it was pointed out that the "fullest extent possible" language might in fact be accurate, since another plan entailing a further drawdown would not have occurred at all. This discussion suggested that opportunities to reconnect our fragmented water systems are plainly constrained by numerous factors.

Internalizing costs. The sustainability principles encourage development of polices that address the distortions imposed by economic forces, "including externalized costs that encourage wasteful or exploitive use" (draft language). Plainly, this principle would be politically problematic to implement. In the case of the Upper Mississippi, the externalized costs of alterations in the river's presettlement hydrology began to accumulate decades ago. This raises the point that, in formulating and applying principles of sustainability, we are addressing inherited constraints, but that sometimes those constraints can be identified and overcome.

All of these principles come back to the key question of how to balance diverse values and incorporate them into the principles. In looking for balance, we need to be mindful that both ecosystems and economies are subject to constant change. Related to this, we must resist simply taking a "midpoint" and calling that balance; if, on the ecosystems side, we always take such a compromise position, we end up with incremental but cumulative impacts.

CASE STUDY 2
CLEANUP IN THE FOX–WOLF RIVER BASIN

The Fox–Wolf River Basin is the largest tributary to the Lake Michigan Basin and third largest to the Great Lakes. It empties into the world's largest freshwater estuary in the bay of Green Bay. The basin as a whole encompasses forested and agricultural lands in the upper reaches of its watershed and includes urban concentrations at Green Bay and along the highly developed Fox River between Lake Winnebago and Green Bay. Beginning in the late 1800s, the lower Fox River grew to become home to the largest concentration of paper production plants in the world. Over the next century, paper production contributed enormously to the economy of the basin and the entire state. It also left, however, a troubling legacy of pollution. Sediments in the lower Fox River and downstream Green Bay are known to contain over 100 known or potentially toxic substances, including PCBs, dioxins, mercury, lead, and other heavy metals. PCBs present the greatest risk to public health.

Passage of the federal Clean Water Act and the implementation of a state-administered permitting system to enforce water quality standards have led to a dramatic improvement in water quality in the Fox River. Total suspended solids from point source discharges decreased by 91% between 1971 and 1990. Similarly, biological oxygen demand levels declined by 94% between 1962 and 1990. Environmental concerns in the Fox–Wolf River Basin have historically focused strongly on the point source pollution problems; relatively greater attention is now being given to non–point source pollution and accumulated toxics in sediments. In addition to toxic chemicals, nutrient and sediment loading from nonpoint sources are now recognized as major ecosystem stressors.

Modern environmental policy in the Fox River Basin can be divided into three eras, paralleling the evolution of national policy. The first era began in the 1970s with passage in 1972 of the federal Clean Water Act. This first era emphasized a command-and-control approach, characterized by a federally driven regulatory process. The second era began in the 1980s and developed in response to attempts to reduce the costs of implementing regulations under the Clean Water Act and other pertinent legislation. During the second era, actions focused on improving efficiency and flexibility in environmental regulation, with greater attention given to pollution prevention. The third era began in the 1990s and moves away from the federally dominated regulatory approach to developing partnerships and incorporating sustainability concepts into environmental decision making. In this era, emphasis has been placed on cooperative and collaborative decision making — in contrast to the more typical adversarial relations between government agencies and polluters.

Since the early 1990s, efforts to clean up the Fox River have revolved around collaborative processes to deal with the problems of non–point source pollution. The Fox River Coalition was formed in 1991 and included paper mills, the Wisconsin DNR, local governments, and public water treatment plants, but no environmental/conservation organizations. Paper mills were interested primarily in voluntary cooperation out of a concern over possible Superfund listing and a desire to steer remediation toward cost-effective (from their perspective) strategies. The work of the coalition focused on a review of available data and education regarding the scientific issues related to remediation. The coalition was able to increase the level of trust and build working relationships among various participants while focused on science and planning, but its efforts broke down during the discussion of who should pay. A key weakness in the efforts of the Fox River Coalition was the lack of environmental and conservation organization involvement in the dialogue.

In 1997 the EPA intervened due to the failure to develop a comprehensive cleanup plan and proposed placing the river on the Superfund National Priorities list. State and local government officials were opposed to the listing because of the stigma attached to Superfund, but local environmental groups praised the listing because of expectations that the listing would hasten cleanup. EPA formally proposed listing without the state of Wisconsin's support in July 1998 but was reluctant to follow through with federally dominated Superfund designation. Instead, a DNR-led Remedial Action Plan was developed with the paper mills and proposed in October 2001. Public comment on the plan has been mixed. Some businesses and paper companies believe the $309 million cost of remediation is an underestimate, and that they will be asked or required to provide additional cleanup funds. Meanwhile, environmental groups have expressed concern that the plan does not go far enough.

In the context of the Fox–Wolf River Basin, the WOW sustainability principles stimulated discussion around four main themes: the scale and scope of the decision-making arena, the role of economic considerations in decision making, the definition of endpoints for regulations, and the capacity of people and institutions to change their behavior.

Scale and scope. The WOW committee found that the sustainability principles encourage consideration of a broader set of issues. In the case of the Lower Fox River and Green Bay, the key environmental driver is currently the cleanup of PCBs, but there are many other basinwide issues of comparable importance. Dredging will remove not only PCBs but also other toxic chemicals and may improve fish habitat. The arena of discussion may be too narrowly focused to allow room for use or adoption of the sustainability principles. Thus, the first step in decision making should be to consider the scale and scope of the problem (this is explicitly recognized within the principles). Development of the Remedial Action Plan for the Fox–Wolf River Basin did in fact include debate about boundaries and management units, due to awareness of the role of upstream agricultural areas in sediment loading to the rivers. This is an example of defining the scope of the problem to include consideration of aquatic and terrestrial connections. Similarly, the DNR is moving statewide toward whole water basin and regional management.

Economic considerations. The WOW committee noted that the Fox River case clearly shows the critical role of economics in the decision-making process, and the need to link economic issues more closely to the principles. Science can inform a decision, and the best science must be brought to the process; science, however, cannot make the decision. Decisions regarding cleanup in the Fox River entail, in part, the acceptability of risk, the inevitability of uncertainty, and the evaluation of trade-offs. Issues involving who pays, the true costs of remediation, and short- and long-terms costs and benefits are critical and can easily cause polarization. In approaching such issues, decision makers and stakeholders must be encouraged to think openly. In this case, the decision-making process should define not only the true cost of dredging, but also the cost of not dredging. This may be difficult, but expressing the types of costs associated with not dredging would, at minimum, help to explain the trade-offs of alternate decisions.

Endpoints. Another dimension of the economic side of sustainability involves decisions about the desired endpoint for the cleanup process. Theoretically, the endpoint in any cleanup effort should be based on the most reliable scientific findings. However, establishing ultimate endpoints may be so prohibitively costly that effective action is delayed or even derailed entirely. An alternative approach may be to measure progress by establishing interim outputs. These interim mileposts can be pursued over a longer time, emphasizing development of more efficient, less expensive, and more immediately effective treatments.

Changing behavior and recognizing success. Sustainability requires new ways of approaching problems and new ways to encourage and reward success. It has been observed that, when people lack an understanding of how to overcome problems, they may be prevented from treating it as a serious issue. Alternatively, people may learn and change if presented with manageable chunks of a problem to tackle. Therefore, appreciation of the rate of change and of the need for active feedback loops is important. It is also critical to recognize and reward positive changes as they occur. In the 1970s, the very low level of dissolved oxygen was the main issue of concern for the Fox River. The subsequent improvements stand as a success story and provide an example of society identifying, learning about, and solving a problem. In the future, success in achieving sustainability will require leadership in all sectors. Champions and leaders — those who are willing to identify and study problems, take a stand, and assume risks — must be recognized and rewarded for their work.

CASE STUDY 3
REFORM OF WISCONSIN'S HIGH-CAPACITY WELL LAW

There is growing recognition that current laws governing high-capacity wells are inadequate to manage and protect Wisconsin's groundwater and related resources (Born et al. 2000). A 1945 Wisconsin law requires permits for high-capacity wells, which are defined as wells that pump at least 70 gallons per minute (gpm) or 100,000 gallons per day (gpd). Permits for such wells can be denied only if the well adversely affects municipal water supplies. There have been numerous attempts to modernize this law to take into account the environmental impacts of high-capacity wells. The primary users of high-capacity wells in Wisconsin are agriculture, municipalities, and industries.

The need to modernize the existing law has arisen due to the change in demand for groundwater and changes in our scientific understanding of the hydraulic continuity between groundwater and surface waters. Statewide, groundwater withdrawal increased 33% between 1985 and 1999, from an estimated 570 million gpd in 1985 to roughly 759 million gpd. Ninety-seven percent of Wisconsin communities (about 70% of the population) depend on groundwater for their water supply. The Wisconsin DNR has explicit authority to restrict high-capacity well permits only in cases where there may be an impact on the supply of water to a public utility well. Further, the DNR has not routinely required high capacity well users to report water use, except in the case of impact to a public utility well. As a result, water use is based largely on estimates. Groundwater pumping has been associated with substantial declines in groundwater levels, with environmental consequences that are emerging but still little understood.

In 2000, the issue of groundwater management in Wisconsin achieved statewide and even national prominence when the Perrier company sought to develop a bottling plant in south-central Wisconsin. Perrier's proposal placed the issue of high-capacity well law reform before a much broader public. Regrettably, extensive misinformation was presented in the media during the debates. This demonstrates the importance of building on the common ground of basic hydrologic concepts and existing scientific information.

Wisconsin's Central Sands Plain has been another focal point in the discussion of groundwater quantity, demand, environmental impacts, and potential policy reforms. The WOW committee was able to review a unique effort in this region to anticipate coming changes in the law. The Groundwater Quantity Working Group is an unusual partnership involving the Wisconsin Potato and Vegetable Growers Association (WPVGA), the River Alliance of Wisconsin (RAW), and scientists from the University of Wisconsin System and the U.S. Geological Survey.

The Groundwater Quantity Working Group arose around a unique set of problems and opportunities and reflects a series of evolving relationships. The WPVGA has been working with conservation organizations in recent years to restore native species and ecosystems and to reduce pesticide use due to significant problems with groundwater contamination in the Central Sands Plains. WPVGA invited the River Alliance and scientists from UW–Extension, the U.S. Geological Survey, and UW–Madison to work with them on developing policy recommendation for the legislature on high-capacity well law reform. RAW became involved as a result of the critical importance of groundwater as a source of water for Wisconsin's rivers. The scientists in the working group also had a strong interest in participating. One of the first activities of the working group was to take a field trip in the Plover River watershed to explain how irrigation works from a hydrologic standpoint.

The diverse interests represented in the working group have undertaken a joint effort to develop recommendations for groundwater quantity legislation. These recommendations seek to advance a coordinated strategy that would protect environmental resources, allow for more flexible and responsive management, provide for a statutory standard of no significant environmental impact, and consider the time horizons required by planners in the public and private sectors. Among the steps recommended by the group: active use of groundwater extraction permits as management tools; a stronger state role, involving participatory processes, in apportioning the permissible amount of extracted groundwater among users; streamlining of the permitting process; adoption of adaptive management tools; and creation of special groundwater management zones in areas where substantial problems are known.

The limits, as well as the strengths, of the WOW sustainability principles were evident in applying them to this issue. The utility of the principles in assisting with decision making will vary from issue to issue. In the case of groundwater quantity management and the reform of our high-capacity well laws, the issue had recently become more clearly defined. A second tier of concrete actions and guidelines associated with the sustainability principles would be more directly useful. The principles in effect describe a philosophy that defines "where you want to be"; the next step is to define how you want to get there.

The Groundwater Quantity Working Group's methods and products address or consider, to some degree, almost all of the WOW sustainability principles. Application of the principles also reveals, however, a lack of attention to longer-term trends; to demographic forecasts and changing water demand for the region; and to global-scale impacts, such as a change in precipitation patterns or the impact of globalization on water demands. From the perspective of the working group, the greatest value of the WOW sustainability principles may be the support they offer to the varied partners who are working jointly to confront this critical issue.

CASE STUDY 4
SOURCE CONTROL AND MANAGEMENT OF STORMWATERS

The management of stormwater is an issue of growing concern as the patterns and pressures of human development alter hydrologic processes. This is especially true in urban and suburban growth areas where land use planning has paid relatively little attention to long-term impacts on groundwater and surface water connections. Such concerns, for example, have become front-page news in Madison, in the Milwaukee metropolitan area, and in the Chicago region.

Historically and currently, stormwater management relies on three strategies: (1) conveyance (i.e., move stormwater away from its source as quickly as possible); (2) detention (i.e., store and slowly release stormwater); and (3) wet detention (i.e., store stormwater in ponds with permanent pools to maximize settling of sediment and associated pollutants). Strong evidence indicates that these strategies do not fully mitigate the hydrologic impacts of urbanization and do not prevent the degradation of streams in urbanizing watersheds. Their main deficiency is that they do not mitigate the increase in stormwater resulting from the introduction of impervious surfaces. One significant result is that streams in more developed areas are becoming “flashier,” as the moderating influence of permeable surfaces in the watersheds and watercourses is lost.

Other factors impinge on the way we need to begin thinking about management of stormwater. Areas where urban and suburban development has increased the amount of impervious surfaces are also, almost by definition, areas where growing numbers of commercial and residential users are increasing the demands on water resources. The cumulative impact of altered hydrologic connections and increasing water demands in these areas are likely to make water management decisions even more complex and difficult than they already are. In addition, possible changes in storm frequency and intensity associated with climate change will require adaptive approaches to managing stormwater. Many climate change scenarios predict that extreme storm events will become more common, and there is some evidence that this pattern is emerging.

In response to the failure of the traditional approaches to stormwater management, new practices are being introduced to control stormwater at its source, primarily through infiltration. Development of rain gardens (sunken gardens that receive runoff from impervious surfaces) is an example of such a trend. The WOW committee examined these new approaches to storm runoff control to see if the thinking behind them, and the design of specific practices, reflect the WOW sustainability principles — and, conversely, to see if the principles capture the innovative ideas now being applied to this problem.

That exercise reveals that these practices meet each of the sustainability criteria. They reflect the values and goals toward which sustainability strives and the increasing scientific understanding of hydrologic systems. They incorporate recent research findings and emerging changes in water policy and support adaptive approaches to water management. They are, by design, appropriately scaled, and intended to maintain and restore connections between groundwater and surface water, and between aquatic and terrestrial ecosystems. This, however, is still an emerging field of research and application. The further refinement of practices is the subject of growing research interest, while widespread adoption and retrofitting lies in the future.

CASE STUDY 5
RECOVERY OF THE COASTER BROOK TROUT IN LAKE SUPERIOR

Coaster brook trout are a migratory form of native brook trout that spend part of their life cycle in one of the Great Lakes. They are primarily associated with Lake Superior but also occurred historically in the northern stretches of Lakes Michigan and Huron. The decline of coaster populations over the last century has been attributed to a combination of factors: historic overharvesting; habitat destruction and degradation from logging, mining, and road construction; and competition from introduced salmonids.

There are currently very few remnant populations and a limited amount of suitable healthy stream habitat. Attempts to reintroduce coasters have been undertaken in the past but proved unsuccessful. Renewed rehabilitation efforts are now under way. In 1999 the Great Lakes Fisheries Commission published *A Brook Trout Rehabilitation Plan for Lake Superior*, to be implemented through collaboration among federal, state, provincial, and tribal governments as well as nonprofit organizations. The goals of the Wisconsin Brook Trout Plan are to protect and improve the self-sustaining brook trout populations and their habitat in Wisconsin's Lake Superior Basin, and to attempt to establish several populations that exhibit life-history diversity.

The historical impacts of overfishing and habitat degradation are still evident. The primary issues now affecting coaster brook trout populations, and hindering their recovery, are the instability of stream habitat and the flashy flow of suitable streams. Trout Unlimited, the nation's largest coldwater conservation organization, working in partnership with the Wisconsin DNR, has coordinated assessments of five streams on the Bayfield peninsula to identify problem areas and to recommend watershed rehabilitation strategies. The assessments will include a study of stream planform, stream profile, channel dimensions, and hydrology. The desired outcomes for this study are thorough assessments of the five watersheds, plans for stream restoration alternatives that may be transferable to other streams, and increased understanding by watershed residents of healthy stream functioning.

Trout Unlimited's plans for stream assessments in summer 2002 for coaster brook trout rehabilitation served as a case study for the draft WOW sustainability principles. In general, the plan was found to be in compliance with the approaches and criteria laid out in the sustainability principles. However, there were several points where the plan came up short:

- The coaster brook trout project does not include a specific citizen participation component, beyond outreach efforts. The WOW principle states, "The well-being of Wisconsin's waters requires the active involvement and participation of citizens." This principle could be clarified to suggest the need for people to be aware of and support local projects if they are to be viable over the long run.

- The WOW principles place strong emphasis on the connections between Wisconsin's waters and other systems and cycles. Along these lines, the coaster brook trout case highlighted the need to consider the importance of the timing of flood pulses, along with water quality and quantity.

- The coaster brook trout rehabilitation project does not address economic forces in any concerted way. This suggests the need for an instruction sheet to accompany the sustainability principles, to serve project managers and decision makers who may apply them. This sheet would provide suggestions of what to do if your project or decision does not meet certain criteria.

The coaster brook trout project is unique among the case studies that the WOW participants examined, in that it is inherently reactive rather than proactive. As a restoration project, it seeks to correct a situation that began to develop more than a century ago, and that might in fact have been avoided if decision makers of the time had been thinking and acting with sustainability in mind. In that sense, it serves as an especially compelling case: It places the responsibility of us to be proactive, and to anticipate the problems and opportunities our decisions will produce in the future.

APPENDIX E

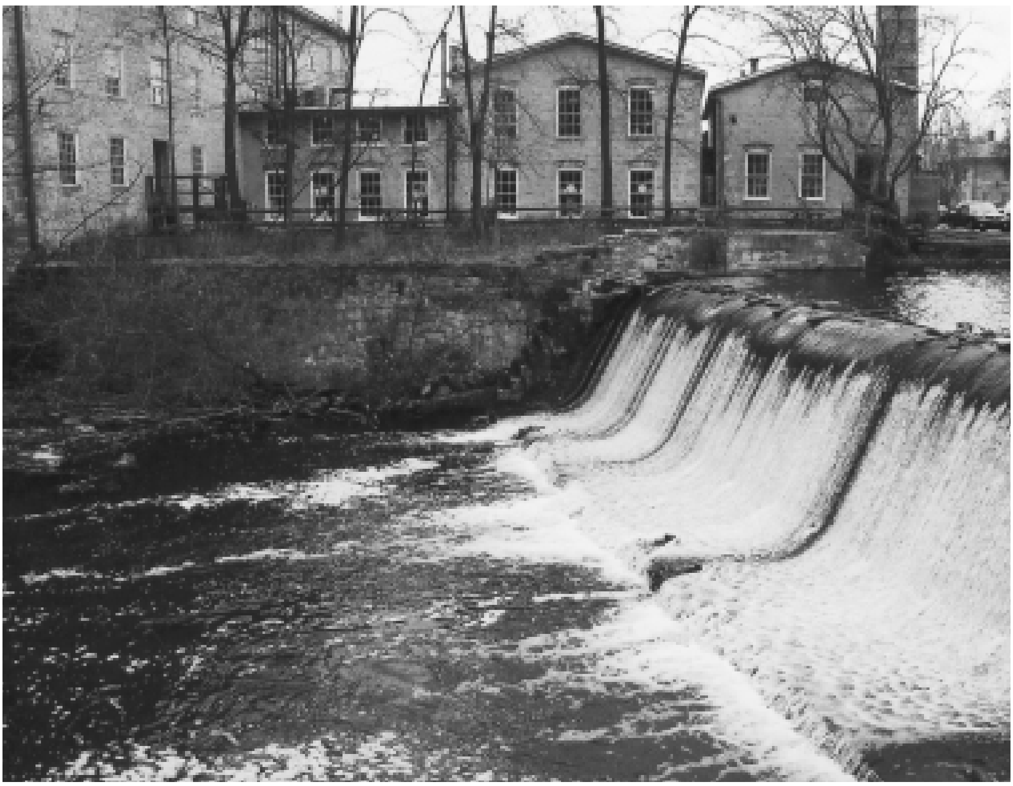
DECLARATION OF THE WATERS OF WISCONSIN FORUM

The Waters of Wisconsin Committee of the Wisconsin Academy of Sciences, Arts and Letters prepared this declaration after 18 months of deliberation, six public forums throughout the state, and regular consultation with an extensive advisory network. On October 21–22, 2002, more than seven hundred citizens from the State of Wisconsin, and representatives from several other states and Canadian provinces, gathered in Madison, Wisconsin, at the Waters of Wisconsin Forum to consider the state of our waters and to take steps to ensure their long-term health and vitality. The declaration was presented to and approved by the attendees of the Waters of Wisconsin Forum and reflects comments received from many forum participants.

Water is an essential part of our community of life in Wisconsin. Wisconsin's geology and geography, ecosystems and history, culture and economy, all reflect the wealth of water that is our natural heritage. Recognizing the vital role of water in our lives, landscape, and economy, we affirm the following:

> The well-being of our people, and of the diverse species and natural communities that share this land, depends on the health of the water in our lakes, rivers, streams, wetlands, and aquifers. However, Wisconsin's waters face a variety of short and long-term challenges to their healthy functioning, their quality and quantity, their biological integrity, and their beauty.
>
> In striving to sustain our waters, we assert a positive responsibility to protect, use, and restore them in a manner that benefits all our citizens and generations yet to come. We call upon our fellow citizens, our elected officials at all levels, and the institutions, organizations, and businesses in our state to recognize this responsibility as well, and to commit ourselves to actions that protect the public interest in clean, abundant, and healthy waters.
>
> We wish to communicate to our neighbors in the United States, Canada, and beyond our commitment to the well-being of our shared waters, and our desire to work together on their behalf. Because our waters connect us, we need to be connected as well in our efforts to sustain them for future generations.
>
> We wish also to communicate our commitment to our descendents. We hope you will look back on our efforts and recognize that, when faced with difficult choices and important opportunities, we strove to find sound and enduring approaches to sustaining our waters that reflect our state's strong conservation legacy. We trust that your generation will accept and extend this responsibility into the indefinite future.

We approve this declaration as an expression of our shared commitment.



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Center for Biology Education, UW–Madison

Center for Limnology, UW–Madison

Central Wisconsin Groundwater Center, UW–Stevens Point

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