3 percent of all water on Earth is fresh water • 20 percent of all unfrozen surface fresh water is in the Great Lakes • 40 billion gallons of Great Lakes water is used by the U.S. daily • 0.02 percent of all fresh water is in lakes and rivers • 2 billion people affected by water shortages • 1.1 billion people don't have clean drinking water • 5 million people die from waterborne diseases each year • 18 percent of Wisconsin is water • 6.4 million acres of Lakes Michigan and Superior • 982,155 acres of inland lakes • 95,000 acres of Upper Mississippi River • 15,057 lakes • 32,000 miles of perennial streams and rivers • 13,500 miles of navigable waterways • 1,449 square miles of inland waters • 3 percent of land area under water • 1.2 quadrillion gallons of groundwater • 1/3 of Wisconsin was once wetlands • 50 percent of state's primeval wetlands lost • 86 percent of Wisconsin's border is water • 1,000 miles of Great Lakes coastline • 200 miles of Mississippi River shoreline • 2,700 trout streams totaling over 10,000 miles • 575,000 registered motorboats • 33,000 personal water craft • 1 boat for every 10 residents • 50 million sport fish hooked annually • 500,000 Great Lakes trout and salmon netted yearly • 162 exotic species in the Great Lakes • $5 million a year to protect water intakes from zebra mussels • 36 percent of residents in 11 counties along Lake Michigan • 250 miles of coastal property in Door County worth $2 billion • 13 commercial ports, cargo value $7 billion a year • 40 million tons of commodities at ports annually • 1,400 miles per gallon per ton of freight moved by Great Lakes ships • 1.3 million fishing licenses sold annually • $1.5 million a year from fishing license fees • $1.7 million a year from Great Lakes trout and salmon stamps • $2.3 billion economic impact from sport fishing • 56 gallons of water used per day per person • 1,500 gallons of water to make one barrel of beer • 45 gallons of water per dairy cow for 12 gallons of milk • 200 hydroelectric generator stations • 1.6 million kilowatt-hours from hydroelectric generators • 7.25 billion gallons of water used daily • 600 million gallons of water daily for public water utilities • 600 million gallons of treated wastewater released daily • 760 million gallons of groundwater pumped daily

University of Wisconsin Aquatic Sciences Center

Liquid Assets: Wisconsin's Water Wealth

Water is the best of all things. — Pindar (c. 522-438 B.C.), *Olympian Odes*

Liquid Assets: Wisconsin's Water Wealth

university of wisconsin aquatic sciences center

ASC

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ASC

welcome to the UW Aquatic Sciences Center

Wisconsin is a water state. Bordered by two of the Great Lakes—the largest system of freshwater on the planet—we are privileged to have an abundant supply of high-quality water. Our state is also fortunate to have a strong tradition of stewardship of natural resources. The work of native son Aldo Leopold gave rise to a new ecological consciousness that changed the way people relate to the Earth. Wisconsin also has a long history of water-related scientific endeavor. Edward A. Birge founded the science of limnology—the study of lakes—at the University of Wisconsin-Madison more than 100 years ago.

The UW Aquatic Sciences Center continues that tradition of stewardship and study. Established in 1999 on the UW-Madison campus, the center encompasses two highly respected statewide research and education programs with complementary missions—the UW Water Resources Institute and the UW Sea Grant Institute.

These two institutes build on the same fundamental concept on which the university itself was built: the Wisconsin Idea, a philosophy of service that extends to the boundaries of the state and beyond.

Both programs administer funds that support research, education and outreach in areas of importance to the entire state. Both represent federal-state partnerships that leverage every federal dollar with matching monies. Both competitively award research money that's directed at only the most meritorious, strategically important projects.

The results of research supported by both institutes are extended to wide audiences through education and outreach. Our outreach specialists ensure that research results are transferred to the people who need it most. They work daily with legislators, tribal and community leaders, policy-makers and managers, teachers, commercial fishing operators, harbormasters and charter boat captains, among others.

The joining of Wisconsin's Sea Grant and Water Resources institutes under the Aquatic Sciences Center creates an elegant mechanism for coordinating university research, education and outreach on all of Wisconsin's aquatic resources—our lakes, rivers and groundwater, as well as the nearly 6 million acres of Lakes Michigan and Superior that lie within the state's borders. Every year, the Wisconsin Sea Grant and Water Resources programs sponsor a variety of projects that involve approximately 230 faculty, staff and students from across the state.

With the establishment of the Aquatic Sciences Center, the University of Wisconsin is poised to examine, in an interdisciplinary fashion, the most pressing water-related issues of the day, as well as anticipate the problems that future generations may face—issues such as ensuring the sustainability of plentiful, pure, clean water, and preventing natural and anthropogenic increases in contaminants.

The UW Aquatic Sciences Center serves as a vehicle for bringing the very best scientific minds to bear on the state's most pressing water issues. At the same time, it helps train the next generation of leaders to address emerging and continuing water quality and quantity issues of the state, region, nation and world.

The Aquatic Sciences Center is more than the sum of its two parts. Because both Sea Grant and Water Resources are part of national networks, our scientists and staff are linked with counterparts at more than 300 of our country's most prestigious research institutions. Together, these experts identify the nation's most pressing water-related issues and help focus available funds on the most critical research priorities. These networks thus support interdisciplinary, applied research to address issues of national importance.

The university has taken a significant step forward by creating the first direct link between these two national networks within the Aquatic Sciences Center. This partnership is unique in the nation—no other state's Sea Grant and Water Resources programs are similarly joined. As such, we believe the center offers an excellent model for bringing together two highly efficient and cost-effective state-federal partnerships, and providing both with an expanded ability to foster collaborations among the best aquatic scientists in Wisconsin and around the nation.

Anders W. Andren

Anders W. Andren, Director

UW Sea Grant Institute

ESTABLISHED: 1968; designated a Sea Grant College in 1972

ANNUAL BUDGET: $4.5 million

MAJOR SOURCES OF FUNDING: National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and the State of Wisconsin

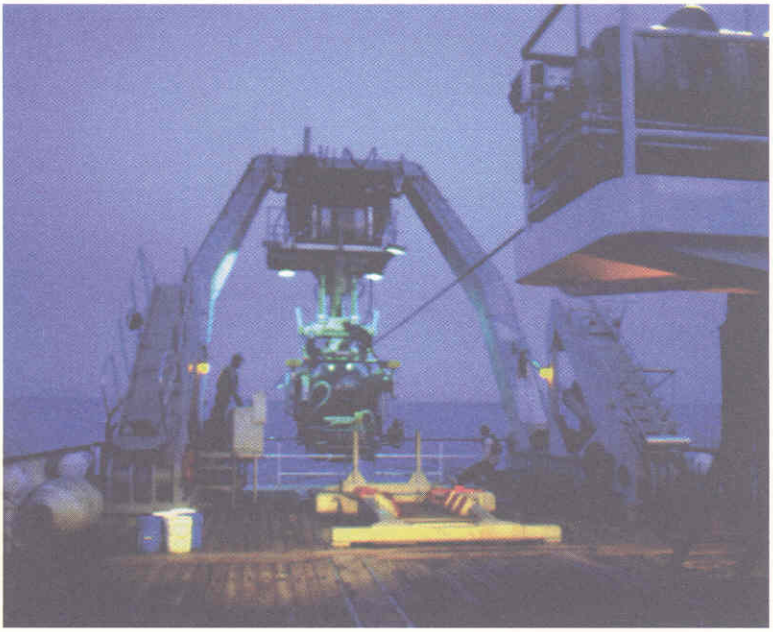
MISSION: To enhance the practical use and conservation of coastal, marine and Great Lakes resources to create a sustainable economy and environment

NATIONAL NETWORK: One of 30 university-based programs authorized under the National Sea Grant College Program Act of 1966

PROGRAM DEVELOPMENT: Strategic plan developed with input from constituent groups, faculty, staff and students, and the Sea Grant Advisory Council, appointed by the chancellor of UW-Madison

AREAS OF STRENGTH: Aquaculture, aquatic nuisance species, diving physiology, fisheries biology and management, geographic information systems, toxic contaminants

WEB SITE: *www.seagrant.wisc.edu*



UW Water Resources Institute

ESTABLISHED: 1964

ANNUAL BUDGET: $1 million

MAJOR SOURCES OF FUNDING: Water Resources Research Institute Program, U.S. Geological Survey, U.S. Department of the Interior, and the State of Wisconsin

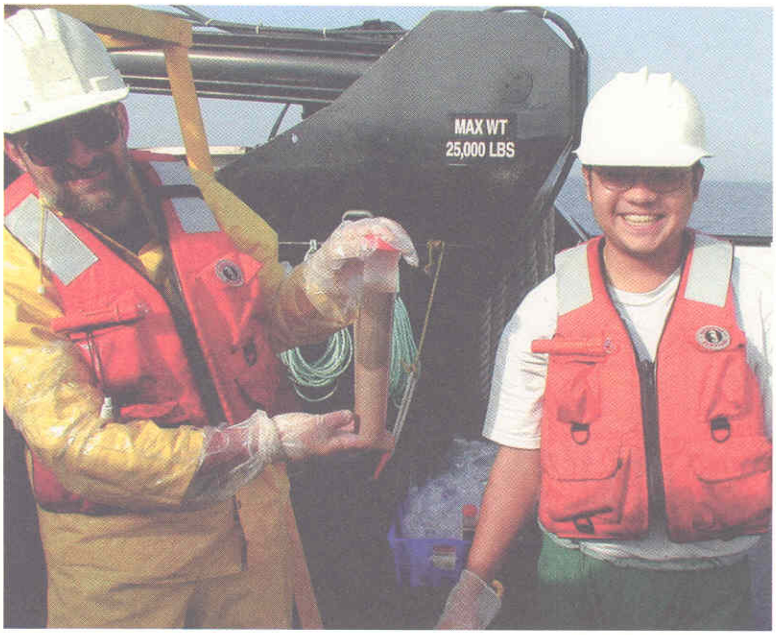
MISSION: To establish the University of Wisconsin as a leading provider of objective, science-based information regarding water supply and water quality issues of importance to Wisconsin and the United States

NATIONAL NETWORK: One of 54 university-based programs authorized under the Water Resources Research Act of 1964

PROGRAM DEVELOPMENT: Strategic plan developed with input from constituents, the UW System, the Wisconsin Groundwater Coordinating Council and the Groundwater Research Advisory Committee, appointed by the chancellor of UW-Madison

AREAS OF STRENGTH: Contaminant cycling, drinking water treatment, groundwater, rivers and inland lakes, water supply

WEB SITE: *www.wri.wisc.edu*



When the well's dry, we know the worth of water. — Benjamin Franklin

The Worth of Water

by Jill Ladwig

It's hard to know the worth of something that seems so plentiful, and water in Wisconsin is nothing if not plentiful. From the coasts of the Great Lakes to the sandy banks of the Mississippi River, it is a land forged by water—its rolling hills sculpted by glaciers, its bounteous fields and majestic forests nurtured by vast reserves of groundwater.

Early French explorers called this area "Ouisconsin," derived from a Native American word meaning "gathering of the waters." The state's liquid assets include more than 32,000 miles of perennial rivers and streams, more than 15,000 lakes, and more than 5 million acres of wetlands. Bordered by more than 800 miles of Great Lakes shoreline on the north and east, and more than 190 miles of Mississippi River shoreline on the west, our state is framed by water. It also has an enormous supply of groundwater—an estimated two quadrillion gallons flows in its subterranean depths.

This wealth has played an elemental role in defining the economy and character of the state. Abundant, high-quality water is the foundation on which much of Wisconsin's agriculture and industry was built, including dairying, cranberries, lumber, paper and breweries. The state's foreign trade depends on transoceanic shipping afforded by the modern ports of Milwaukee, Green Bay and Superior.

The U.S. Geological Survey estimates Wisconsin uses 7.25 billion gallons of water each day and consumes 443 million gallons daily. When you consider the dwindling supply and quality of water in the rest of the world, you begin to appreciate just how valuable a gallon of water is—and that potable water will become even more precious in the decades ahead. It is perhaps because of its apparent abundance that many of us do not recognize its true value.

A Legacy of Stewardship and Study

Wisconsin is fortunate in that it has a long tradition of scientific inquiry into water and water resources. In fact, the science of limnology was born in the 1880s at the University of Wisconsin-Madison, where Lake Mendota today has the reputation of being "the most studied lake in the world."

That legacy continues with the establishment of the UW Aquatic Sciences Center. Composed of the Sea Grant Institute (SGI) and the Water Resources Institute (WRI), the center brings the state's best minds to bear on current and emerging water-related challenges. The center helps support a cadre of experts—including water chemists, fisheries biologists, hydrologists, geologists and ecologists—who continually generate new knowledge and information. Through education and outreach efforts, the information is disseminated to the public through news media, teachers, policy-makers and managers of the state's water resources.

The work funded through the Aquatic Sciences Center helps ensure that Wisconsin's worldwide reputation as a leader in aquatic research is maintained. By leveraging the support of their respective national networks, Sea Grant and Water Resources are able to prioritize problems and engage the best intellectual capital to work on those issues at a local level.

The Aquatic Sciences Center embodies "the Wisconsin Idea"—the concept that university expertise should extend outside the confines of a campus, to the borders of the state and beyond. The center supports the development of new generations of scientists, teachers and policy-makers, who share their knowledge with government agencies, businesses and individuals around the globe.

In an era of conflicting priorities over the management of water resources, the UW Aquatic Sciences Center is a nonadvocate source of science-based information. It offers a uniquely holistic approach to science: both programs administer funds to conduct research; transfer new knowledge to managers and scientists, and educate the public through teacher training, support of graduate students and communication with the media. This approach ensures that scientific discoveries are applied to real-world problems.

Protecting Water Quality

Despite the apparent abundance, scientists and managers are increasingly concerned about the continued availability of high-quality water. The ever-expanding population is placing increasing demands on the water contained in the state's aquifers, resulting in unprecedented changes to subterranean sediments.

Urbanization and industrialization also affect water quality, even in the most remote areas of the state. In spite of legal restrictions, industrial and municipal discharges still release a variety of pollutants; others arrive via the atmosphere, thousands of miles from where they emanated.

Because it's so difficult to control, nonpoint-source pollution is an even graver problem. Sediment and agricultural runoff pour loads of nutrients into streams and lakes, causing eutrophic conditions that can suffocate resident fish populations. Urban runoff adds pollutants such as bacteria, lawn chemicals, construction debris and other toxins to lakes and rivers.

The continuing invasion of Wisconsin waters by nonindigenous species jeopardizes water resources on another level by disrupting the intricate balance of the food web. These new residents are most successful in waters where local fish populations have already been weakened by pollution and fishing pressure.

The impact of all these threats can be seen everywhere, from disappearing fisheries in Lake Michigan to large-scale die-offs in the world-class trout streams of southwestern Wisconsin.

Research supported by the Aquatic Sciences Center is aimed at addressing these problems through a combination of rigorous scientific inquiry, innovative education and targeted outreach. These activities ensure that the results of cutting-edge science will not reside forever in the lab or merely be published in a scholarly journal; new information is regularly communicated, making it useful to everyone.

Safeguarding Wisconsin's Water Supply

One of the great challenges for water resource managers across the country is in safeguarding the availability and suitability of groundwater for a variety of uses—municipal, industrial, agricultural and domestic. The issue is of particular importance in Wisconsin, where 70 percent of the population relies on groundwater for drinking.

Research supported by WRI is directed at ensuring the supply of water for future generations. Much of this effort is concentrated on determining what quantity exists, how much that amount varies throughout the state, and how over-pumping water may adversely affect its quality.

Determining the quantity of groundwater and how it varies in different locations helps scientists more precisely map aquifers and determine where these underground reservoirs interconnect. Most important, this effort is pinpointing areas of recharge, areas where water enters the ground, trickles down through the substrate and enters the aquifer. Identification of recharge areas helps managers determine how aquifers are replenished and how they can be protected from contamination.

Another WRI study is investigating the impact of over-pumping, which causes a lowering of the water table. Because of the increasing pressure on water supplies, researchers have determined that over-pumping is becoming a major management and scientific issue in Wisconsin. Here, the concern about quantity overlaps with increasing concern over quality.

Scientists supported by WRI are investigating how the process of withdrawing water from aquifers changes its chemical composition. They have discovered that aquifers in certain areas of the state are being drawn down to the extent that subterranean chemical reactions are occurring, posing a detrimental change to the quality of groundwater supplies. One result is elevated levels of arsenic in drinking water.

Between earth and earth's atmosphere, the amount of water remains constant: there is never a drop more, never a drop less. This is a story of circular infinity, of a planet birthing itself. — Linda Hogan, *Northern Lights*, 1990

All the water that will ever be is, right now. — *National Geographic*, 1993

Although a natural component of sedimentary material, drawdown exposes arsenic-bearing deposits to oxygen, making arsenic mobile in the water and thus a threat to human health. As usage increases and certain aquifers are drawn down, arsenic is mobilized. Some areas of Wisconsin are experiencing alarming increases in the concentrations of this contaminant.

Another effect of drawdown comes from high-capacity wells, which draw older, deeper groundwater than private wells. Water from these wells tends to have increased levels of dissolved solids. There also is some indication that increases in background radioactivity, which occur naturally in decaying radioisotopes in deep bedrock, are showing up in drinking water.

Combating the Cancer of Contaminants

Perhaps the number one public concern regarding water quality is contamination—specifically, toxic chemical contamination. Understanding and ameliorating this threat is one of the main areas of emphasis at the Aquatic Sciences Center.

Scientists supported through the center have a long history of research into the sources, transport and fate of contaminants. While SGI-supported research is aimed at understanding the impact of toxins and pathogens on Great Lakes ecosystems, contaminant research at WRI focuses on the origin, transport and fate of contaminants in the groundwater and inland lake systems.

Besides studying well-known contaminants, scientists supported by the center also are involved in the study of toxins that are just beginning to emerge as global concerns. One such chemical is a flame-retardant used in foam furniture padding, television casings and other household products. Polybrominated diphenyl ethers (PBDEs) are a persistent organic pollutant, meaning they remain in the environment for decades without breaking down, and they accumulate in fat cells. Sea Grant-supported scientists recently discovered PBDEs in Lake Michigan salmon at some of the highest levels found to date anywhere in the world. Although researchers have not yet determined the human health risk posed by the contaminant, studies indicate the effect of exposure is similar to polychlorinated biphenyls (PCBs)—a well-known and much-studied carcinogen.

Scientists supported by the center are involved in the study of toxins just beginning to emerge as global concerns—like PBDEs.

Groundwater and inland-lake research supported through Water Resources historically has focused on volatile organic compounds, pesticides and nitrates. Volatile organic compounds include industrial solvents and household products, which leach into the ground primarily from landfills, and gasoline spills and leakage from underground storage tanks. Another concern is the widespread use of chemical nutrients and pesticides in agriculture, which enter groundwater through field applications. Nitrates—used in fertilizer—are the most common groundwater contaminant in Wisconsin.

Mapping Mercury to Protect Public Health

One of the major goals of research supported by WRI is to identify the sources, transport and fate of mercury in the aquatic environment. Primarily a product of coal burning, mercury is dispersed into the air and then falls back again to earth—either nearby or thousands of miles from where it was generated. Recent WRI and SGI studies have focused on mercury in groundwater and surface waters.

The greatest human health threat posed by mercury is methylmercury, an organic form of the contaminant that accumulates in the natural food chain. Despite years of research, we do not yet fully understand how the less toxic forms of inorganic mercury transform into methylmercury.

A related high-profile project is tracking mercury as it moves from the atmosphere through an ecosystem in Canada. This work involves the use of state-of-the-art analytical tools, which enable researchers to introduce individual, nonradioactive, stable isotopes of inorganic mercury to a lake and the upland and wetland areas that make up its watershed. The goal of this unique, four-year experiment is to identify the link between atmospheric mercury deposition and accumulation of methylmercury in the lake's fish. Ultimately, the findings will help us to understand what happens to mercury that's added to the environment by human activity.

SGI also supports research aimed at understanding the behavior of toxins and pathogens in the aquatic environment. Current efforts focus on determining specific forms of mercury and other heavy metals as they enter Great Lakes ecosystems, either through the water or from the atmosphere, and assessing the effects these metals have on aquatic organisms. Sea Grant-supported scientists are also trying to understand how methylmercury interferes with fish reproduction and developing ways to identify such contamination in the field.

Getting to the Bottom of PCBs

Wisconsin may have the image of being a pristine, pastoral state, but it also has the distinction of being home to one of the most heavily industrialized rivers in the world: the Lower Fox River, between Lake Winnebago and Green Bay in northeastern Wisconsin. This region was designated as one of 43 Great Lakes Areas of Concern by the International Joint Commission of the United States and Canada.

Now home to more than a half-million people, the area was at one time the site of 13 paper mills, which used the river for cooling and waste discharge. From the 1950s to the mid-1970s, the mills routinely released PCBs into the river in the process of recycling carbonless copy paper. More were being released through five municipal wastewater treatment plants sited along the river, along with other

FOLLOWING THE PATH OF HEAVY METAL IN A CANADIAN LAKE

Although it sounds like the name of a heavy metal band, METAALICUS is actually a multimillion-dollar, international research effort. The goal of the "Mercury Experiment to Assess Atmospheric Loading in Canada and the United States"—METAALICUS—is a better understanding of the link between atmospheric mercury deposition and the accumulation of methylmercury in fish.

The project—supported by private, state, provincial and federal agencies in Canada and the United States, including the UW Water Resources Institute—brings together more than 50 widely regarded experts on mercury in the environment.

Multimillion-dollar question: How do mercury particles in the atmosphere become the toxic methylmercury in fish?

For decades, researchers have sought to understand how mercury is converted into methylmercury, which poses a threat to human health because it accumulates in the food chain. METAALICUS seeks to explain the methylation process and to find out what happens to "new" mercury after it's been added to the environment by human activity. Armed with sophisticated low-level detection technology, scientists in the 1990s discovered mercury enters surface water through rainfall in remote areas. But they have not been able to explain why it accumulates in fish.

The answer lies in the methylation process. Research over the last decade has tried to pinpoint where methylation takes place and to identify the environmental parameters that sustain the process. Scientists also have tried to follow the path of atmospherically loaded mercury—from deposition to toxicity.

METAALICUS provides the ideal situation for following that path. The project is being conducted in the Experimental Lakes Area of Canada, a region encompassing 58 lakes and watersheds in western Ontario. Since 1968, the area has served as a unique laboratory in which scientists can conduct biological experiments on entire ecosystems. Lake 658 and its watershed provide the METAALICUS team with 129 acres in which to conduct the experiment. The research team is investigating every aspect of how mercury works in the environment—in the upland, lake and adjacent wetlands—simultaneously.

Wetlands appear to be a key to the methylation process. The same sulfur-reducing bacteria that produce methylmercury in lake sediments also are present in wetlands, making them ideal incubators for the contaminant.

An expanded understanding of heavy metal pollution, coupled with major advances in analytical techniques, has made this project possible. State-of-the-art, ultrasensitive tools for detecting minute amounts of contaminants allow scientists to isolate, analyze and follow individual stable isotopes of mercury through a system. The METAALICUS team will add separate, nonradioactive, stable isotopes of mercury to the wetlands, upland and the lake itself at levels slightly above those occurring naturally in the environment.

Over the entire course of the project, the researchers will add approximately one teaspoon of stable mercury isotopes to the lake and its watershed. In addition to tracking the upland, lake and wetland isotopes, researchers will be able to distinguish the "new" mercury from that which was present before the experiment, thus uncovering the path of mercury as it travels from the atmosphere to its toxic form on Earth, where it accumulates in fish.

industries, such as energy companies and outboard motor manufacturers. This combination of activities and intensity of use put pressure on the river beyond its natural capacity to flush or assimilate the pollution.

More than 20 years after PCBs were banned for use in open systems, we continue to live with their legacy. PCBs buried in the sediments of the river and the bay continue to haunt us today.

Sea Grant has a long history of discovery into the sources, transport and fate of chemical contaminants, particularly PCBs in the Fox River-Green Bay system. The studies began with its Green Bay research program more than three decades ago, resulting in millions of state and federal dollars being poured into the region for research and cleanup.

Today, the challenge is to clean up the contaminated sediments—not an easy task when they are buried beneath a river. Scientists and outreach specialists supported by SGI and WRI have been involved in devising scenarios for cleanup, working on technical advisory committees and in task forces, such as the Fox River Remediation Advisory Team. This is another realization of the Wisconsin Idea—bringing the most up-to-date scientific information to bear on a multibillion-dollar investment.

Understanding the Workings of Watersheds—and Global Change

Current Sea Grant research in the Green Bay/Fox River area is aimed at gaining a more comprehensive understanding of the complex dynamics of Great Lakes watersheds. One project is examining the transformation of nutrients, soils and contaminants as they flow from Lake Winnebago through the Fox River into Green Bay.

Researchers have found that dams on the river have a major impact on water quality. Water forms pools between these impoundments, and Sea Grant-supported scientists are finding that these pools, or settling basins, behave like biogeochemical reactors.

Material sequestered in these basins changes as it flows downstream. Inorganic nutrients that wash off a farmer's field, for example, into this biogeochemical system leave it transformed.

Another important discovery is that these impoundments appear to act as atmospheric sinks for carbon, nitrogen and phosphorous. Because the pools tend to be organic-rich and have long residence times, they may also produce climate-altering greenhouse gases.

BUILDING THE PLATINUM DATA SET ON P.C.B.'S

For more than 20 years, UW Sea Grant supported a research program focused on the Green Bay watershed and its physical characteristics, water quality and pollution problems, fisheries and food web dynamics.

> The Green Bay study stands as a model for researching the behavior of contaminants in a freshwater estuary.

Largely because of the quality and quantity of data collected during the Sea Grant effort, the U.S. Environmental Protection Agency (EPA) selected Green Bay for a PCB "mass balance" study in the mid-1980s. The goal of the project was to develop the first complete input-output accounting for the sources, movement and fate of a chemical contaminant in an ecosystem.

Green Bay's principal tributary is the heavily industrialized Fox River—host at one time to the largest concentration of paper mills in the world. By the early 1970s, effluent from paper mills and other industrial sources had resulted in massive PCB contamination of the bay and river.

Scientific investigation of the estuary began in 1969, when the one-year-old UW Sea Grant program initiated its Green Bay research effort. The goal of the long-range subprogram was to examine all aspects of a contaminated estuary—economic, physical and environmental.

Projects were initially aimed at understanding the fundamental processes of the bay. Early studies mapped sediment patterns, which later helped establish PCB loads found in bottom sediments. Over time, investigations revealed where the PCBs were, how they were transported, and how much was being buried in sediments or resuspended in water. Other projects addressed the bioaccumulation of PCBs in the food web and related socioeconomic issues.

The EPA study determined: (1) the amount of PCBs entering the bay from the Fox River, (2) the degree of PCB contamination and residence time of PCBs in the river and bay, (3) the exchange of PCBs between water and atmosphere, and (4) quantities of PCBs remaining in the river, settling in the bay or migrating into Lake Michigan.

The five-year, $12 million study involved the collaboration of researchers from six federal agencies, the Wisconsin and Michigan departments of natural resources, four UW System campuses, and nine other U.S. universities.

This research helped identify options for remediation of the Fox River-Green Bay system, and the UW Water Resources program assisted state agencies in determining the best alternatives for resolving the problem. Later Sea Grant-sponsored work helped determine if reduced inputs would result in lower concentrations of contaminants in fish from the bay.

The EPA Mass Balance study had enormous scientific impact as well as practical management applications. In the scientific world, it was dubbed "a platinum data set" that stands as a yet-unmatched model for researching the behavior of contaminants in a freshwater estuary.

Results from this landmark study still play a central role in the ongoing debate over how best to address PCB pollution of Green Bay and the Fox River. As a microcosm of the Great Lakes, Green Bay continues to provide a research and remediation model for the entire region.

Fending Off Alien Invaders

While chemical and natural contaminants, point- and nonpoint-source pollution, and increasing demand threaten the supply and quality of Wisconsin's water resources, another challenge is posed by nonindigenous species. Dozens of these exotic aquatic plants and animals have been introduced into the state's waters. Through a combination of research, statewide outreach and public education, the SGI has helped lead the effort to slow the spread of zebra mussels, purple loosestrife and other invasive aquatic nuisance species.

Much of past research has focused on the effect zebra mussels have on the ecosystems they invade. Researchers found that these tiny animals have a huge impact on their environment by negatively affecting the growth and survival of larval fish.

Because they're filter-feeders, they remove plankton from the water. The clearing of the water has a fundamental effect on the ecology of the entire system. Water clarity makes small fish more vulnerable to predators and food less available for fry. Bigger and more light-sensitive species, such as walleye, also are changing their depth and forage habits. These changes to the aquatic food web affect the fishery, as commercial operators are forced to deeper and deeper waters to catch fish in the Great Lakes.

UW Sea Grant, in partnership with the Wisconsin Department of Natural Resources, launched an award-winning public education and outreach effort in the early 1990s to help slow the invasion of zebra mussels into inland lakes. This partnership continues today. Research into the effects, control and monitoring of these species is being transferred to the public, helping boaters, commercial fishing operators and other users of the lake to protect their resources.

SGI-supported researchers, in partnership with departments of natural resources in Wisconsin and other states, government agencies in the United States and Canada, and Sea Grant programs throughout the Great Lakes region, are now studying aquatic plants, such as purple loosestrife, Eurasian milfoil and other nonindigenous organisms, including spiny zooplankton, round gobies, ruffe and white perch. The ultimate impact of these exotic species on the ecosystems they invade is, in most cases, yet to be determined.

A Holistic Approach to Fisheries Management

The Great Lakes are essentially a living laboratory for fisheries management—a dynamic, giant laboratory closely regarded by the scientific world. In just the past 150 years, the lakes have seen fundamental changes to their coasts, contamination of their waters, forays of foreign invaders, and the decimation of entire populations of native fish. The ax and the plow have been just as devastating as the hook and the net. Activities on

SPREADING THE WORD ABOUT NONINDIGENOUS SPECIES

Invasions of nonindigenous species are a growing global concern. One symbol of this problem in North America is the zebra mussel—one of about 160 foreign species that have invaded the Great Lakes, mostly within the last 40 years.

First discovered in 1988 in Lake St. Clair—presumably introduced via the ballast water of a transoceanic ship—this prolific biofouling mussel quickly spread throughout the Great Lakes. By 1995, lakeshore power plants, municipalities and other Great Lakes water users were spending over $30 million annually on zebra mussel control, including nearly $5 million in Wisconsin. By 2002, zebra mussels had spread to 22 states and two Canadian provinces.

Sea Grant has printed 2.2 million "Zebra Mussel Watch" cards, distributed across 22 states and two Canadian provinces

Great Lakes Sea Grant programs were among the first to respond to the invasion, organizing the first national conference on zebra mussels in 1989 and establishing a zebra mussel information clearinghouse in 1990.

Wisconsinís Sea Grant initiated a water intake and harbor monitoring program to detect the mussel's arrival in state waters. It launched *Zebra Mussel Update*, a statewide quarterly newsletter for public officials, the power industry, news media and researchers. A wallet-sized "Zebra Mussel Watch" card was created to raise public awareness of the problem. Program personnel conducted dozens of public presentations, media interviews, and zebra mussel monitoring and control workshops. In 1991, these efforts won a gold medal for community relations from the national Council for Advancement and Support of Education.

In cooperation with the Wisconsin Broadcasters Association and the Wisconsin Department of Natural Resources, UW Sea Grant produced public service announcements for radio and television that were broadcast more than 3,000 times in 1992 by television and radio stations statewide. In 1995, it published and distributed over 12,000 copies of *Aquatic Exotic*, a catalog of all zebra mussel-related information available from the national Sea Grant network. By 1997, the *Zebra Mussel Update's* readership had topped 100,000 in the U.S. and Canada. To date, UW Sea Grant has printed more than 2 million "Zebra Mussel Watch" cards for other Sea Grant programs, state and federal agencies, and private companies encompassing 22 states and two Canadian provinces.

These outreach efforts continue and now cover several other aquatic nuisance species (ANS). These range from the award-winning Sea Grant Nonindigenous Species Web site that UW Sea Grant maintains in cooperation with Illinois-Indiana Sea Grant, to "ANS Attack Packs" for training high school students to teach elementary school students about the issue.

In 2002, UW Sea Grant led the development of a public service announcement in collaboration with the nationally syndicated "Babe Winkelman's Good Fishing" television program and launched a special new "Zebra Mussel Watch" Web site (*seagrant.wisc.edu/zebramussels*).

Thanks largely to such efforts and the strong environmental ethic of Wisconsinites, zebra mussels have invaded fewer than 40 Wisconsin lakes to date.

By linking Sea Grant's ANS research and outreach expertise with the inland waters mission of the Water Resources Institute, the UW Aquatic Sciences Center is poised to better focus university resources to help address ANS issues statewide.

land, such as deforestation, agricultural development and urbanization, have resulted in significant loss of nearshore habitat. The unbridled commercial harvests of the past had long-lasting impacts on the lakes' fisheries.

The need to respond to these challenges has resulted in the development of scientific expertise recognized throughout the world. Wisconsin and the Great Lakes region are decades ahead of other states, as well as other countries, in terms of their understanding of fisheries management. UW Sea Grant has played a key role in developing a whole-ecosystem approach to managing these dynamic resources through the use of bioenergetics.

Bioenergetics is the flow of food-energy in an ecosystem. Sea Grant-sponsored research has resulted in the development of modeling tools that enable scientists to understand how predator-prey interactions operate. These tools enable scientists to determine, for example, how much a fish eats and how that is affected by temperature. Why is that important? Because human beings today largely control the top of the aquatic food web, either through stocking or fishing regulations, which means they therefore control predator-prey interactions.

Bioenergetics models allow scientists to evaluate new regulations and suggest alternatives. They help to answer questions such as, if we were to increase stocking rates in this lake, how would that impact predator-prey interactions? Bioenergetics models offer a sort of lake-system-in-a-lab, an effective way of calculating "what-if?" scenarios and providing answers about tradeoffs. In this way, bioenergetics facilitates the adaptive management of ecosystems. Many of these tools are now also being applied in marine fisheries.

Undoing Damage Done

Just three decades ago, the Great Lakes were not so great; entire populations of fish had been wiped out by pollution, invasive species and over-fishing. Lake Superior, the furthest away from the industrial centers of Chicago, Milwaukee and other cities, was, not surprisingly, the least damaged of the lakes. Yet even there, native fish populations had dropped to alarmingly low numbers.

Over-fishing in some ways enabled the invasion of exotic species. Exotic populations explode in areas where there are few or no natural predators to limit their growth. Many exotic species are now firmly established in the lakes, limiting the numbers of fish available for predators to eat.

Today, Lake Superior is looked upon as a success story. Some of its aquatic communities have been restored. Lake trout, for example, appear to have once again attained self-sustaining populations.

But while these native fish populations have been restored, they are not being used by the fishing community. The fatty lake trout is not on any angler's list of most desirable species. While the goal of fishery restoration has been achieved, a significant question remains: is such a restoration truly successful if the fishery is not being used?

CULTIVATING 21ST CENTURY LEADERS

At the University of Wisconsin, research and graduate education are inseparable. The guiding philosophy of UW Sea Grant is that education, especially graduate education, is a risk-free investment that pays large dividends to the nation's security, economic well-being and overall quality of life. Likewise, WRI is committed to technology transfer—training graduate students, as well as resource managers and state agency personnel, in the latest water research methodology.

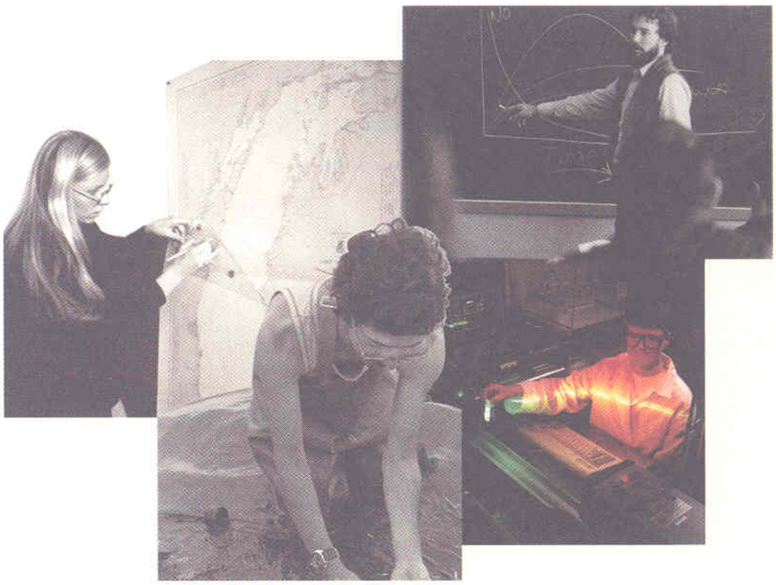
UW Sea Grant assistantships have helped 500 Wisconsin college students earn master's and doctoral degrees.

Graduate student support has always been considered one of the highest priorities and greatest accomplishments of both programs. Since UW Sea Grant and Water Resources began more than 35 years ago, the programs together have funded more than 35 graduate research assistantships and project assistantships each year.

In 2001, the SGI conducted a survey of former Sea Grant-supported graduate students—almost 450 of them at the time (196 Ph.D. and 278 master's degrees). The survey found Sea Grant alumni working in 39 of the 50 United States, one commonwealth and nine foreign countries. They have moved into the executive suites of major corporations, become senior scientists in government laboratories, started their own businesses, become professors and been elected to public office.

Besides recruiting and training the nation's future aquatic scientists and engineers, one of the goals of the UW Sea Grant and Water Resources programs is to establish a system for continuing to influence the future by educating tomorrow's leaders.

Simply stated: these two programs train students, a significant number of whom go on to become educators themselves and subsequently educate their own students. The percentage of Sea Grant-supported students who chose a career in academia (41 percent) is notable, and these alumni can be found at universities throughout the country. This "multiplier effect" in the aquatic sciences is essential to our nation's continued ability to compete in the global economy and one of the reasons Congress and state and federal governments support programs such as Sea Grant and Water Resources.



Lake Michigan presents another test case for managers. There, careful control strategies have restored the top of the food web. But it is an artificially managed system; its "top" is now dominated by salmon, which were brought in from the Pacific Northwest to stock the lake. Although the lake is now an artificial system, it is nonetheless widely regarded as one of the country's most remarkable models of resource management.

The big question for fisheries managers is: How do we restore native fish communities in the presence of exotic species? Restoration requires tough management choices. Sea Grant-supported research is providing tools, such as bioenergetics, to analyze the food web and assist in decision-making not only in Wisconsin, but around the globe.

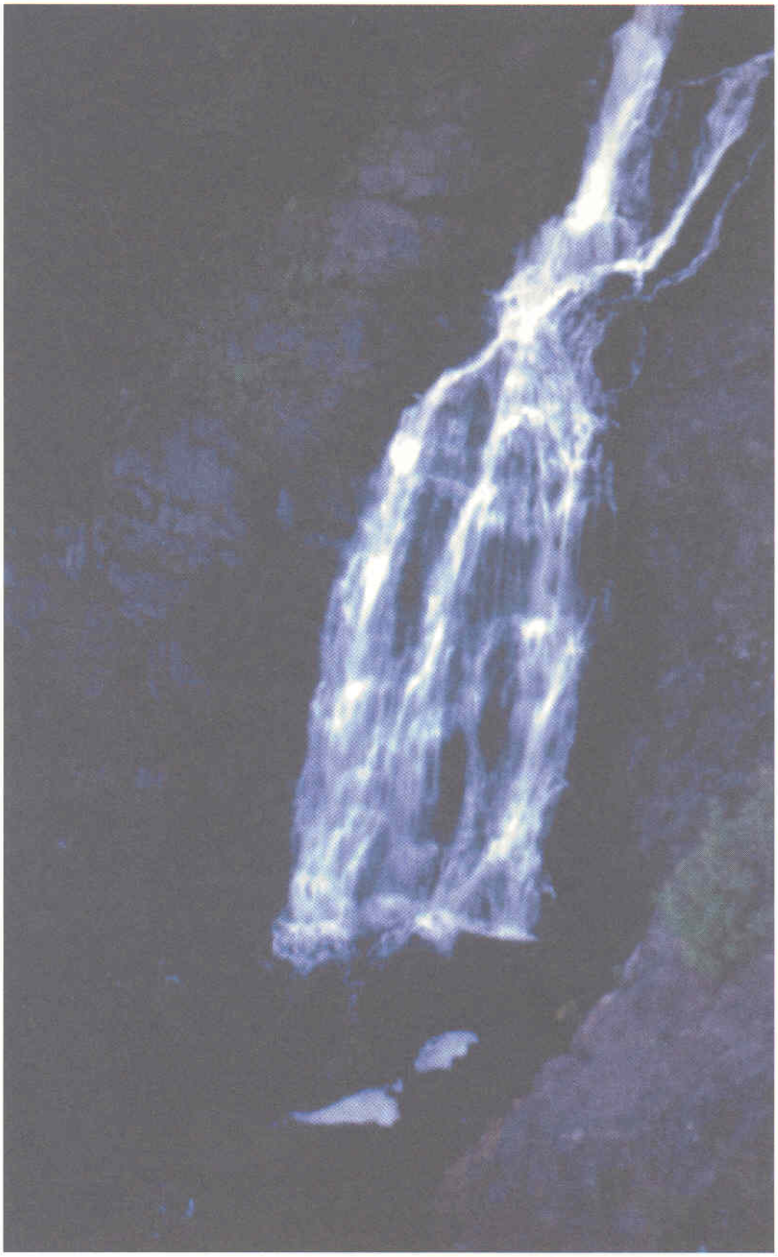
The Art of the Possible

Whole-ecosystem management is an approach to resource management that takes into account all of the resources and resident species of an entire system. The technique uses mathematical models that allow scientists to evaluate the likely outcomes of management decisions based on how they affect the entire system. Possibly the best decisions about managing water resources would come from such an approach. It has been called "the art of the possible," because it provides viable options for management, allowing managers and the public to weigh the alternatives and set priorities.

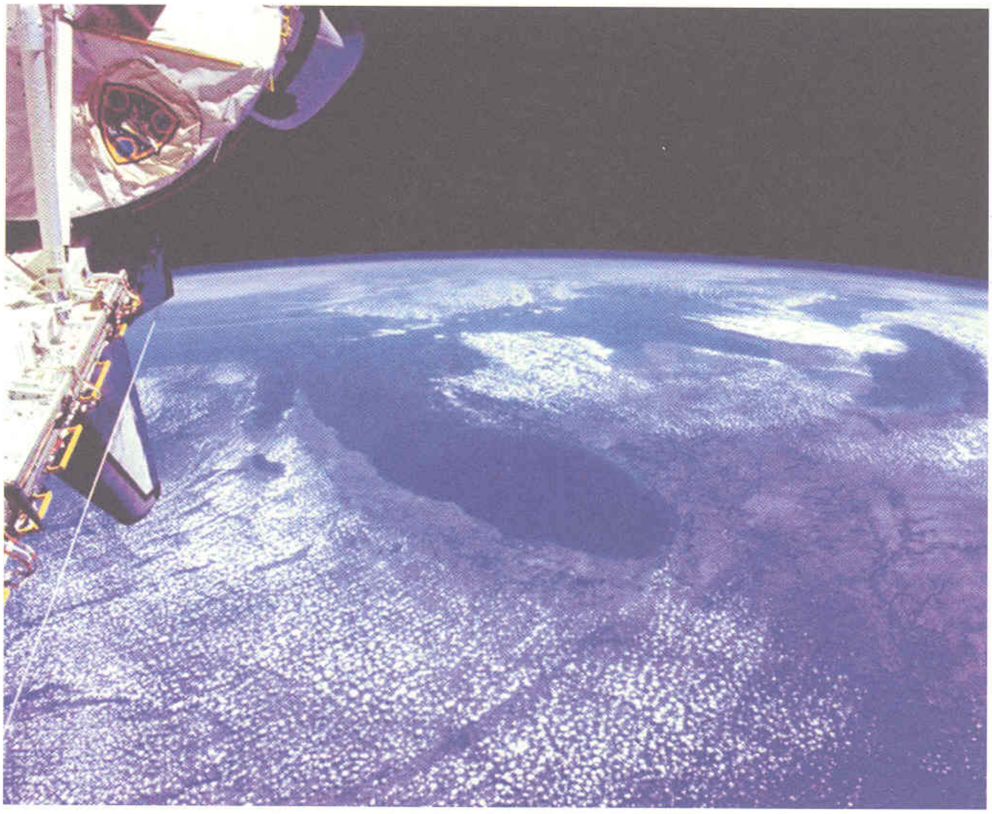
The real challenge for Wisconsin is to accept the constraints of history and make a choice for the future. The constraints include chemical and natural contamination of our waters, a decreasing supply of groundwater, deterioration of water quality, the depletion of our fisheries and the invasion of exotic species. We must decide how to move forward, and the demands of the public are often conflicting:

- How can we continue to thrive economically, without introducing more and new contaminants to the atmosphere and to our water?
- How can we incorporate smart growth planning to ensure sustainable development in our communities?
- How do we protect the quality and supply of our groundwater and still meet the needs of an expanding population?
- How many trout and salmon can we stock in the Great Lakes without overtaxing the forage base?
- Will new invading species, such as white perch and round goby, reduce or increase native fish populations?
- How will global climate change affect the Great Lakes?

The answers to these questions may be mutually exclusive, leaving managers and the public with some very tough choices. The University of Wisconsin Aquatic Sciences Center provides science-based information for intelligent decision-making. Research supported by the Sea Grant and Water Resources institutes is providing the best science possible to help managers, policy-makers and individuals make the best choices for the wise management and sustainable use of Wisconsin's greatest wealth—its water resources.



Water has become a highly precious resource.
There are some places where a barrel of water costs more than a barrel of oil.
— Lloyd Axworthy, Foreign Minister of Canada, 1999



50 Water Facts

Few Fresh Waters

Just 3 percent of the world's water is fresh water—2 percent frozen in the polar ice caps and glaciers, and 1 percent groundwater. Only 0.02 percent is freshwater lakes and rivers.

Globally, more than 2 billion people face water supply shortages. By 2025, that figure is expected to rise to 5.5 billion, or two-thirds of the world's population.

Over a billion people don't have access to clean drinking water, and more than 5 million die from waterborne diseases each year.

Worldwide water use has increased sixfold over the last 70 years as the human population tripled. Two-thirds of that water use is for agriculture.

The Great Lakes contain an estimated 5,500 cubic miles (22,700 cubic kilometers) of water—a fifth of all the unfrozen fresh water on the surface of Earth.

The United States draws more than 40 billion gallons (151 million liters) of water from the Great Lakes every day—half of which is used for electrical power production.

Wisconsin Waters

About 6.4 million acres (2.6 million hectares) of Lakes Michigan and Superior and 95,000 acres (38,445 ha) of the Upper Mississippi River lie within Wisconsin's borders.

Nearly 86 percent of Wisconsin's 1,730-mile (1,073 km) border is water.

Wisconsin has more than 15,000 lakes, 32,000 miles (51,500 km) of perennial streams, and 13,500 miles (21,700 km) of navigable waterways.

Almost 3 percent of Wisconsin's area—nearly a million acres (405,000 ha)—is lakes.

Nearly one-third of prehistoric, post-glacial Wisconsin was wetlands. Nearly half of the estimated 10 million acres of pre-settlement wetlands have been lost.

Wisconsin's 15 coastal counties contain more than 1.2 million acres of wetlands (486,000 ha)—nearly a fourth of all of the state's remaining wetlands. The wettest is Marinette County with nearly 228,000 acres (92,000 ha).

Water Ways and Byways

Wisconsin has about 1,000 miles (1,600 kilometers) of Great Lakes coastline and more than 200 miles (325 km) of Mississippi River shoreline.

There are 2,700 trout streams in Wisconsin—put end to end, they would stretch more than 10,370 miles (16,600 km).

With 28 lakes, the Eagle River chain of lakes is the largest in the world.

The Fox River is one of the few rivers in the nation that flow northward.

Practically all the natural lakes in Wisconsin were created by glaciers.

More than a third of Wisconsin's population lives in the 11 counties forming its Lake Michigan coast; 24 percent lives in the three southeast coastal counties of Milwaukee, Racine and Kenosha.

Wisconsin has more than 575,000 registered motorboats—about one for every 10 residents.

Anglers net about 50 million fish a year from Wisconsin waters, including more than 500,000 Great Lakes trout and salmon.

Over 160 nonindigenous aquatic species have colonized Great Lakes waters—over half of them since the opening of the St. Lawrence Seaway in 1959.

Wisconsin's power and water utilities spend about $5 million annually trying to protect water intakes from zebra mussels.

Highly Valued Assets

The assessed value of Lake Michigan lakeshore property in just one Wisconsin county—Door County—is almost $2 billion.

Each year, Wisconsin ports on the Mississippi River and Lakes Michigan and Superior handle more than 40 million tons (44.3 million metric tons) of commodities valued at over $7 billion.

A 1,000-foot Great Lakes carrier can move a ton of freight more than 1,400 miles on one gallon of fuel.

Wetlands and abundant high-quality water make Wisconsin the nation's top producer of cranberries and 10th-largest producer of trout.

The Wisconsin Department of Natural Resources sells more than 900,000 resident and 400,000 nonresident recreational fishing licenses annually, collecting over $1.5 million in fees. Great Lakes trout and salmon fishing stamp fees bring in nearly $1.7 million a year.

Anglers spend more than $1 billion annually on fishing-related items and trips in Wisconsin; this provides a $2.3 billion economic impact and generates $90 million in state and local taxes.

Thirsty People—and Cows

The state has 12,000 public drinking water systems—the second largest number in the nation.

Wisconsin uses an average of 56 gallons (212 liters) of water per day per person from public water supplies and private wells. The national per capita average is 90 gallons (341 liters) a day.

It takes 1,500 gallons (5,700 liters) of water to produce one barrel of beer (31.5 gallons/119.2 liters).

Wisconsin has about 1.3 million dairy cows, each of which needs to drink 45 gallons (170 liters) of water a day to produce 100 pounds (45 kilograms), or 12 gallons (45 liters), of milk.

Wisconsin public water utilities draw about 600 million gallons (2.3 million kiloliters) of water per day. The state's 642 wastewater facilities release about the same amount of treated water daily.

Water Power

Wisconsin uses a total of more than 7 billion gallons (26.5 million kiloliters) of water per day—about 80 percent of it for thermoelectric power production.

Wisconsin's 50 fossil fuel power plants use nearly 4 billion gallons (15 million kl) of water per day. The state's two nuclear power plants use about 2 billion gallons (7.5 million kl) daily.

Almost all of the water used for thermoelectric power production in Wisconsin comes from surface sources.

Wisconsin has more than 200 hydroelectric generator units, which produce a total of 1.6 million kilowatt-hours of electricity.

Water Underground

Wisconsin has an estimated 1.2 quadrillion gallons (4.5 million billion liters) of groundwater—above ground, it would cover the entire state to a depth of 30 feet (9 m).

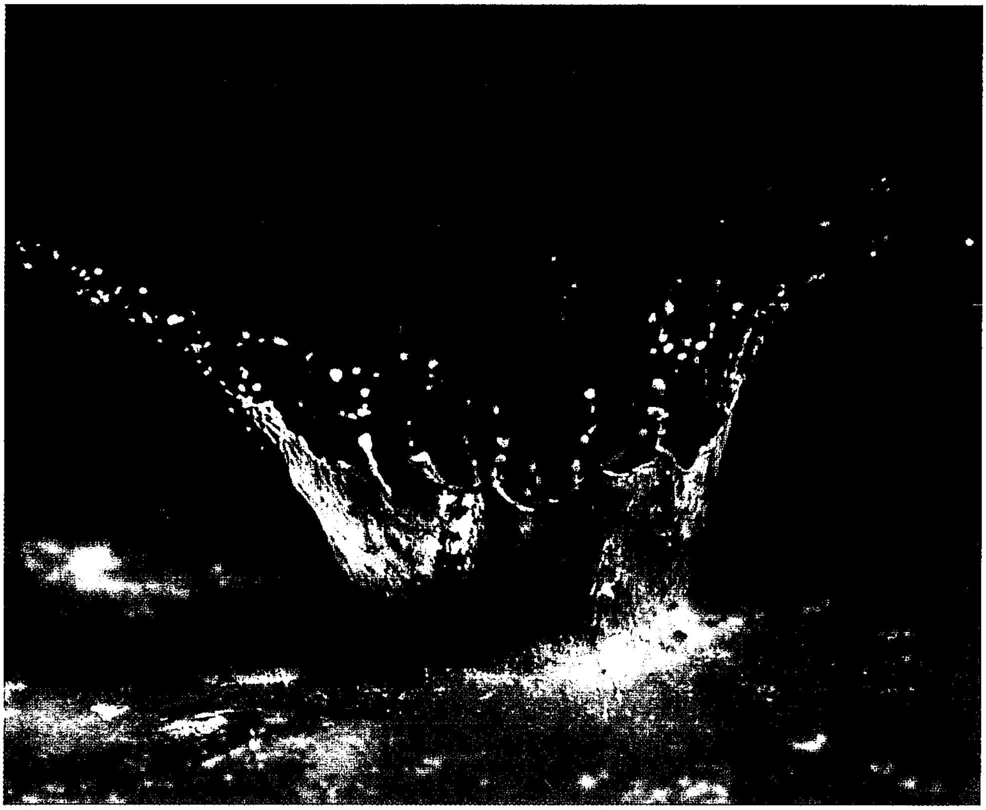
Groundwater use in Wisconsin totals about 760 million gallons (2.9 million kiloliters) per day.

Wisconsin has about 800,000 private wells, most of which tap groundwater less than 50 feet (15 meters) below the surface.

Seven in 10 Wisconsinites and 97 percent of the state's inland communities depend on groundwater for their water supply.

The Badger State has about 12,000 high-capacity wells serving farms, factories, breweries and other businesses.

Rainfall over Wisconsin averages 32 inches annually (82 centimeters); only 6-10 inches (15-25 cm) of it soaks in to become groundwater.



Common Contaminants

More than 800 toxic contaminants have been detected in Great Lakes water and sediment.

Nitrate—most of it from fertilizers—is by far the most common chemical contaminant found in Wisconsin groundwater.

More than 2 billion pounds (900 million kilograms) of nitrogen is added to Wisconsin soil annually, 80 percent of it from commercial fertilizers, manure and legumes.

Statewide, nitrate levels exceed state and federal standards in 10 percent of the private wells sampled.

Fifteen Wisconsin municipalities must treat their water to reduce nitrate levels.

Arsenic occurs naturally in Wisconsin groundwater, but unnaturally high concentrations have been found in 23 of the state's 72 counties.

In 2002, Wisconsin's fish consumption advisory included, for the first time, a mercury warning for all inland waters statewide.

OUTREACH SPECIALISTS

Aquaculture
Fred Binkowski
UW-Milwaukee
Great Lakes WATER Institute
600 E. Greenfield Avenue
Milwaukee, WI 53204-2944
Phone: (414) 382-1723
Fax: (414) 382-1705
sturgeon@uwm.edu

Superior area specialist
UW-Superior
143 Sundquist Hall
Superior, WI 54880-9985
Phone: (715) 394-8472
Fax: (715) 394-8454

Fisheries & Aquatic Nuisance Species
Philip Moy
UW-Manitowoc
705 Viebahn Street, Room E105
Manitowoc, WI 54220-6699
Phone: (920) 683-4697
Fax: (920) 683-4776
pmoy@aqua.wisc.edu

Geographic Information Systems
David Hart
UW-Madison
201 Goodnight Hall
Madison, WI 53706-1177
Phone: (608) 262-6515
Fax: (608) 262-0591
dhart@aqua.wisc.edu

Marine Education & Water Safety
James Lubner
UW-Milwaukee
Great Lakes WATER Institute
600 E. Greenfield Avenue
Milwaukee, WI 53204-2944
Phone: (414) 227-3291
Fax: (414) 382-1705
jflubner@aqua.wisc.edu

Water Quality & Habitat Restoration
Victoria Harris
UW-Green Bay
MAC 212
Green Bay, WI 54311-7001
Phone: (920) 465-2795
Fax: (920) 465-2143
harrisv@aqua.wisc.edu

KEY CONTACTS

UNIVERSITY OF WISCONSIN AQUATIC SCIENCES CENTER
Sea Grant Institute | Water Resources Institute
Goodnight Hall, 2nd Floor
1975 Willow Drive
Madison, WI 53706-1177
Phone (608) 262-0905
Fax (608) 262-0591
www.aqua.wisc.edu

ADMINISTRATION
Director
Anders Andren
Phone: (608) 262-0905
awandren@aqua.wisc.edu

Assistant Director for Administration & Information
Mary Lou Reeb
Phone: (608) 263-3296
mlreeb@aqua.wisc.edu

Assistant Director for Research and Outreach
James Hurley
Phone: (608) 262-1136
hurley@aqua.wisc.edu

MEDIA RELATIONS
Program Information Specialist
Stephen Wittman
Phone: (608) 263-5371
swittman@aqua.wisc.edu

WATER RESOURCES LIBRARY
Librarian
JoAnn Savoy
Phone: (608) 262-3069
josavoy@aqua.wisc.edu

If there is magic on this planet, it is contained in water. — Loran Eisely, *The Immense Journey*, 1957

The UW Aquatic Sciences Center is the administrative home of the Sea Grant and Water Resources institutes
www.aqua.wisc.edu