EQB

920445

March 4, 1992

The Honorable Henry Kalis, Chair
Legislative Water Commission
543 State Office Building
St. Paul, MN 55155-1201

Dear Representative Kalis:

The final report of the Environmental Quality Board Water Research Advisory Committee is enclosed, for your information and use. The Board believes that it represents a significant step forward in a constructive process of communication and coordination between the University community and State Government. We hope that it will strongly influence the development and funding of water research in Minnesota.

In particular, the Board recommends that the Legislature fund research on the following project-level priorities from the Advisory Committee's report. The Board believes that adequate funding of these priorities is **immediately required to support state water management activities.**

The Board strongly urges funding in the upcoming biennium to:

a. Delineate and quantify the factors that determine wetland functions and develop standardized methods for their measurement.

b. Determine the fate of toxic compounds in lakes.

c. Develop a system for monitoring water availability and water quality trends in the state.

d. Continue the accelerated development of county ground water atlases and regional sensitivity assessments.

e. Evaluate the effectiveness of nitrogen management practices in minimizing contamination of water resources.

ENVIRONMENTAL QUALITY BOARD 658 CEDAR STREET, ST. PAUL, MN 55155 612 296-2603 FAX 612 296-3698 STAFF PROVIDED BY MN PLANNING

f. Improve the understanding of contaminant movement through the unsaturated zone.

g. Develop and implement a Twin Cities metropolitan ground water model.

h. Determine the effectiveness of urban stormwater management practices.

i. Develop and apply models to predict contaminant transport in Minnesota's large rivers.

There is no order of priority in the Board's recommendation. An expanded explanation of the priorities is attached, for your information.

We hope that this report aids in focusing state funds on research of these key project-level priorities. If it does so, the management of water resources in Minnesota will be greatly enhanced.

Sincerely,

Robert Dunn

ROBERT DUNN
Chair
Environmental Quality Board

cc: Pat Jensen, Director
Legislative Water Commission

EQB

February 6, 1992

The Honorable Gene Merriam
Chairman
Legislative Commission on Minnesota Resources
Room 65 State Office Building
100 Constitution Avenue
St. Paul, MN 55155-1201

Dear Senator Merriam:

The final report of the Environmental Quality Board Water Research Advisory Committee is enclosed, for your information and use. The Board believes that it represents a significant step forward in a constructive process of communication and coordination between the University community and State Government. We hope that it will strongly influence the development and funding of water research in Minnesota.

In particular, the Board recommends that the Commission fund research on the following project-level priorities from the Advisory Committee's report. The Board believes that adequate funding of these priorities is immediately required to support state water management activities.

The Board strongly urges funding in the upcoming biennium to:

a. Delineate and quantify the factors that determine wetland functions and develop standardized methods for their measurement.

b. Determine the fate of toxic compounds in lakes.

c. Develop a system for monitoring water availability and water quality trends in the state.

d. Continue the accelerated development of county ground water atlases and regional sensitivity assessments.

e. Evaluate the effectiveness of nitrogen management practices in minimizing contamination of water resources.

f. Improve the understanding of contaminant movement through the unsaturated zone.

g. Develop and implement a Twin Cities metropolitan ground water model.

h. Determine the effectiveness of urban stormwater management practices.

i. Develop and apply models to predict contaminant transport in Minnesota's large rivers.

There is no order of priority in the Board's recommendation. An expanded explanation of the priorities is attached, for your information.

We hope that this report aids in focusing state funds on research of these key project-level priorities. If it does so, the management of water resources in Minnesota will be greatly enhanced.

Sincerely,

Robert Dunn

ROBERT DUNN
Chair
Environmental Quality Board

RESEARCH PRIORITIES RECOMMENDED BY THE BOARD

January 16, 1992

The Environmental Quality Board particularly recommends funding of the following research priorities during the next biennium. These are selected from the broader list of project-level priorities presented in the report of the EQB Water Research Advisory Committee.

The Board strongly urges funding in the upcoming biennium to:

a. **Delineate and quantify the factors that determine wetland functions and develop standardized methods for their measurement.** To reasonably support state wetland conservation policy, the state needs to develop a better understanding of the factors that drive wetland ecosystem and hydrologic system functions, and of the technology of wetland restoration. These must be tied to the different types of wetlands, and the different locational characteristics of the individual wetland in question.

During the last decade, a great deal of effort was devoted to development of a Minnesota methodology for assessing wetland functions. The method provides a good starting point for this priority research.

b. **Determine the fate of toxic compounds in lakes.** The transformation and fate of mercury, PCBs, and pesticides in Minnesota lakes needs to be better understood. The factors affecting accumulation of these toxics in food chain organisms must be evaluated.

The LCMR has supported investigations of mercury in northeastern Minnesota through the Pollution Control Agency. These studies have resulted in a good understanding of the presence, magnitude, and possible sources of mercury. However, what drives the transformations of mercury in lakes, and the significance of this for the lake and its management are not well understood. In addition, the magnitude of the mercury problem outside of northeastern Minnesota is poorly understood. Little is known about the transformation and ultimate fate of PCBs and pesticides in lakes.

c. **Develop a system for monitoring water availability and water quality trends in the state.** Because ambient monitoring has not been adequately supported, the determination of trends in either water quality or quantity is difficult, at best. Research is needed to resolve the issues of spatial resolution (i.e., Can we afford to design a system that allows detection of trends significant at the county level?), sampling frequency, and usefulness of existing monitoring programs.

The EQB recently completed assessments of quality and quantity trends. It is required to make these assessments every two years. The Board concluded in both assessments that the data do not support sound analysis of trends. The PCA and MDA reached a similar conclusion in their assessment of trends in nitrate contamination of ground water.

d. **Continue the accelerated development of county ground water atlases and regional sensitivity assessments.** County atlases provide new hydrogeologic interpretations and mapping, detailed analysis and interpretation of existing water well records and other subsurface data, and synthesis of other available information that characterizes a county's geologic and ground water resources. Regional assessments involve new hydrogeologic interpretations and mapping that characterize the envelope of glacial deposits overlying bedrock, and new geologic interpretations and mapping of bedrock in those areas where bedrock crops out at the land surface. They provide less detailed, multicounty assessment of the sensitivity of aquifers in glacial deposits, and locally of the hydrogeologic interactions between glacial deposits and bedrock.

The Ground Water Protection Act of 1989 increased the funding of county atlases significantly, and initiated the Regional Assessment program. To date, six atlases have been completed; three more are underway and another is to be started in 1992. Three regional assessments are in progress. The LCMR recognized the need to augment the rate of progress with its commitment in 1991 to accelerate the production of atlases and regional assessments.

e. **Evaluate the effectiveness of nitrogen management practices in minimizing contamination of water resources.** The effectiveness of various nitrogen management practices needs to be evaluated in order to develop a set of reliable and accepted "best" management practices. This should involve a systems approach with analysis of combinations of practices to minimize the effects on surface and ground water. The approach must include evaluation of new technologies that allow more precise fertilizer nitrogen applications on a soil-by-soil basis. Large plot evaluation of irrigation practices on coarse-textured soils would be addressed, as would the effectiveness of manure management plans based on soil, manure, and crop types.

The call for this evaluation is a priority of the recently completed interagency state report "Nitrogen in Ground Water."

f. **Improve our understanding of contaminant movement through the unsaturated zone.** Important transport and transformation functions occur in the subsurface zone above ground water. These are poorly understood. We need a greater understanding of the factors that control the movement of contaminants through the zone so that their transport and fate can be understood and managed. Stable isotope tracer methods and subsurface hydrologic models should be applied to develop this understanding. These will greatly aid efforts to meet the degradation prevention goal of the Ground Water Protection Act of 1989.

g. **Develop and implement a Twin Cities metropolitan ground water model.** The model will simulate water levels and flow pathways for the entire metropolitan Twin Cities region. It will aid in management of pollutant sources, the siting of potential sources of pollution, and the delineation and management of wellhead protection areas. Once established, the model will focus these management efforts and guide managers toward appropriate solutions.

The LCMR has funded development of a model under consideration for application in the metropolitan area, but further work is needed to gather and apply the physical information needed to implement the model on a region-wide basis.

h. **Determine the effectiveness of urban stormwater management practices.** Little research has been done in Minnesota on urban best management practices despite the mix and suspected levels of toxics that appear in urban runoff. Efforts have been undertaken to use wetlands for retention and treatment of nutrients in runoff, for example, but we have not adequately studied the effectiveness of these systems on removing toxics, nor the response of the wetland over time.

The Metropolitan Council studied stormwater runoff characteristics in the early 1980s, and initiated studies in 1989 of the efficiency and response of wetlands used to mitigate the effects of polluted stormwater runoff. These studies paint an incomplete picture of the conditions under which wetlands effectively remove contaminants. We must learn about the maintenance requirements needed to keep such systems from actually contributing to pollutant loads. We must also investigate the effectiveness of other urban "best" management practices.

i. **Develop and apply models to predict contaminant transport in Minnesota's large rivers.** Models are needed to predict flow and transport of contaminants in large rivers. One use of these models will be to aid state and local officials in management of spills. The models should aid in early warning communications and in targeting spill monitoring and cleanup efforts. Spills response preparedness on the upper Mississippi River is a priority application. A second use should be to describe the effect of sporadic nonpoint source river inputs. Implementation of the Minnesota River Assessment Project is a priority application.

The Corps of Engineers is developing a model that estimates the time of travel from the Mississippi headwaters reservoirs at specified flows. The predictions that the model makes need to be verified before it can be considered to provide a reasonable basis for major water supply decisions, like shutting off water intakes. Furthermore, the model does not currently attempt to address the dispersal and transport of various types of contaminants. During the recent Grand Rapids oil spill, officials had little idea of how contaminants reaching the river were dispersing, or how fast they were moving down river.

The Minnesota River Assessment Project has called the modeling of nonpoint pollution effects in the mainstem river a priority research need.

1991 *Minnesota* Water Research Needs Assessment

EQB WATER RESEARCH ADVISORY COMMITTEE
MINNESOTA ENVIRONMENTAL QUALITY BOARD

February 1992

MN PLANNING

The Minnesota Environmental Quality Board is an environmental policy forum. This report was prepared by the ***Water Resources Program of the Environmental Quality Board***, which coordinates and integrates water policy, planning and programs through the Minnesota Water Plan and related projects.

Minnesota Planning, charged with developing a long-range plan for Minnesota, provides staff to the Environmental Quality Board.

1991 *Minnesota* Water Research Needs Assessment

Prepared by
EQB Water Research Advisory Committee
Minnesota Environmental Quality Board
and
Minnesota Planning
February 1992

This report is one of five implementing the Minnesota Water Plan. The other reports are:

Water Quality Assessment: An Evaluation of Trends
Assessment of Water Availability in Minnesota
Water Quality Program Evaluation
Minnesota Water Monitoring Plan

For copies of the 1991 Minnesota Water Research Needs Assessment or other water plan reports contact:

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1991 *Minnesota* Water Research Needs Assessment

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CO-CHAIR: JOHN WELLS, Minnesota Environmental Quality Board

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SARAH TUFFORD, Brian Rongitsch, Department of Natural Resources

Executive Summary

WATER RESEARCH IS ESSENTIAL to management and policy decisions made in Minnesota. For research to adequately support management and policy, it must be properly focused on the key questions facing Minnesotans. It must also be adequately and consistently financed.

The purpose of this assessment is to help focus research in its support of management and policy. Ultimately, it is also to help the state meet its goals for managing and protecting Minnesota's water resources.

The Minnesota Water Plan (MWP) articulates these goals. They are:

> *"To improve and maintain the high quality and availability of Minnesota's water for future generations and long-term health of the environment.*
>
> *"To ensure that our uses of water are sustainable, and that in meeting our needs for water, we recognize its limits and interconnections, accept its changing and variable nature, and adjust our demands upon it when necessary to safeguard it for future needs."*

Research must allow us to adequately understand and describe the "quality and availability of Minnesota's waters," and the "long-term health of the environment." It must help us understand water's interconnections and define what "sustainable" might mean in the context of land and water uses. It must help us understand why and how there are limits to these uses.

THE EQB CHARGE AND THE BOARD'S RESPONSE

The Environmental Quality Board is required by law to:

"... evaluate and report to the Legislative Water Commission and Legislative Commission on Minnesota Resources on statewide water research needs and recommended priorities for addressing these needs. Local water research needs may also be included." (Minnesota Statutes, Section 103A.43)

To aid it in addressing this charge, the Environmental Quality Board appointed an advisory committee of experts. The Board made a special effort to make this committee a blend of academic and management interests. The intent was to bring together the often divergent perspectives of these communities. The thought was that this approach would give the Board the best opportunity to identify Minnesota's research priorities.

The EQB Water Research Advisory Committee identified a series of research needs throughout the course of its deliberations from May through November 1991. Four "subcommittees" focused on the categories of ground water, surface water, fate and reduction of environmental pollutants, and integrated water management. These subcommittees consisted of Advisory Committee members, plus other individuals known for their expertise. The results of their efforts and subsequent refinements by the full Advisory Committee make up the text.

The Advisory Committee also identified 21 research areas of importance from this broad list of identified needs. From these areas, and to focus attention on the most pressing needs, the committee identified a short list of the top priority project-level research priorities. This list was kept intentionally restricted, both to better highlight the most pressing needs, and to make it clear that other important needs do exist.

Finally, the committee identified systemic issues relating to Minnesota's approach to research. These are described as "overall conclusions and recommendations."

Overall Conclusions and Recommendations

Policy makers, policy developers, water managers, and citizens need to recognize the importance of good research to water management. The research and management communities can help achieve this recognition by accompanying research with educational efforts that explain why research is important to water resources.

New requirements to share research results are needed. The communication of research results, transfer of new technology, and the ability to tranfer data should be required as part of publicly funded research.

Research should be adequately supported in Minnesota. Support must be predictable and sustained over the term of study, not just the biennium. It is not well-served by the two-year timeframe frequently imposed by the legislative process.

Impartial research experts should review detailed research proposals in a two-step process. Peer review and selection procedures for funding research need to be revamped. The first step should involve review of substantive preliminary proposals. It should occur before the final selections are recommended. The second step should involve review of detailed, full-length work plans before state funds are released.

Funding requests should be adequately coordinated and integrated with water policy and management needs. The Minnesota Water Plan provides the framework for state water policy development and management. It therefore provides the framework for identifying water research priorities.

The attached package of project-level water research priorities should guide water research funding requests and allocations.

1991 Project-Level Priorities

Fourteen project-level research topics are highlighted above the 100-plus identified. Funding of these fourteen priorities is considered by the Advisory Committee to be particularly important in the upcoming biennium. Their support will immediately aid the state in making decisions mandated by the Legislature. The priorities are presented in groupings defined by the extent of support they received among Advisory Committee members. However, each, regardless of its grouping, is considered urgent and important.

Under priority level one, the priorities are that we:

Delineate and quantify the factors that determine wetland functions and develop standardized methods for their measurement. To reasonably support state wetland conservation policy, the state needs to develop a better understanding of the factors that drive wetland ecosystem and hydrologic system functions, and of the technology of wetland restoration. These must be tied to the different types of wetlands, and the different locational characteristics of the individual wetland in question.

Determine how our changing climate influences the availability of surface and ground water. The range of effects of climate change on the availabiltiy of surface and ground water must be defined to aid in the development of management strategies. Agriculture is particularly dependent upon climate. The need for stability in agriculture dictates that climate change, like that represented by drought cycles, be better understood in Minnesota. The growing demand of public water supplies in the Twin Cities metropolitan area also urgently necessitates this expanded understanding.

Improve our understanding of contaminant movement through the unsaturated zone. Important transport and transformation functions occur in the subsurface zone above ground water. These are poorly understood. We need a greater understanding of the factors that control the movement of contaminants through the zone so that their transport and fate can be understood and managed. Stable isotope tracer methods and subsurface hydrologic models should be applied to develop this understanding. These will greatly aid efforts to meet the degradation prevention goal of the Ground Water Protection Act of 1989.

Under priority level two, the priorities are that we:

Determine the fate of toxic compounds in lakes. The transformation and fate of mercury, PCBs, and pesticides in Minnesota lakes needs to be better understood. The factors affecting accumulation of these toxic substances in food chain organisms must be evaluated.

Develop a system for monitoring water availability and water quality trends in the state. Because ambient monitoring has not been adequately supported, the determination of trends in either water quality or quantity is difficult, at best. Research is needed to resolve the issues of spatial resolution (i.e., Can we afford to design a system that allows detection of trends significant at the county level?), sampling frequency, and usefulness of existing monitoring programs.

Develop practical economic tools to promote consideration of the value of water in decision-making. Allocation of water among competing users and, more broadly, management of land and water, is not governed by water's real value. Consequently, decisions affecting water and land resources are often inefficient or inappropriate.

Evaluate the importance of denitrification in Minnesota aquifers. Denitrification is a process where nitrate is converted to nitrogen gas and removed from water. It is thought to occur in ground water where organic matter is present but oxygen is not. It could be a significant factor in some locations in removing nitrate from ground water. Because no one is sure of this, it is difficult to use nitrate as an indicator of pollution, or to assess how vulnerable a well may be to pollution.

Continue the accelerated development of county ground water atlases and regional sensitivity assessments. County atlases provide new hydrogeologic interpretations and mapping, detailed analysis and interpretation of existing water well records and other subsurface data, and synthesis of other available information that characterizes a county's geologic and ground water resources. Regional assessments involve new hydrogeologic interpretations and mapping that characterize the envelope of glacial deposits overlying bedrock, and new geologic interpretations and mapping of bedrock in those areas where bedrock crops out at the land surface. They provide a less detailed, multicounty assessment of the sensitivity of aquifers in glacial deposits, and locally of the hydrogeologic interactions between glacial deposits and bedrock.

Analyze the organization of state water management programs. It is important to determine whether state programs and activities can be better organized to address state water needs in an effective and efficient manner.

Determine the effectiveness of urban stormwater management practices. Little research has been done in Minnesota on urban best management practices despite the mix and suspected levels of toxic substances that appear in urban runoff. Efforts have been undertaken to use wetlands for retention and treatment of nutrients in runoff, for example, but we have not adequately studied the effectiveness of these systems on removing toxic substances, nor the response of the wetland over time.

Develop and apply models to predict contaminant transport in Minnesota's large rivers. Models are needed to predict flow and transport of contaminants in large rivers. One use of these will be to aid state and local officials in management of spills. The models should aid in early warning communications and in targeting spill monitoring and cleanup efforts. Spills response on the upper Mississippi River is a priority application. A second use should be to describe the effect of sporadic nonpoint source river inputs. Implementation of the Minnesota River Assessment Project is a priority.

Under priority level three, the priorities are that we:

Quantify the transport and fate of contaminants in Lake Superior. The transport and fate of contaminant loadings within the world's largest lake are not well understood. Studies of these items must include contributions from atmospheric transport.

Evaluate the nitrogen contributions of manure and other organic sources. The contributions of manure and other organic sources to the total pool of available nitrogen in soils, runoff, and infiltration in agricultural areas are not well understood. A better understanding of these contributions would improve nitrogen management and ground water protection efforts.

Develop and implement a Twin Cities metropolitan ground water model. The model will simulate water levels and flow pathways for the entire metropolitan Twin Cities region. It will aid in management of pollutant sources, the siting of potential sources of pollution, and the delineation and management of wellhead protection areas. Once established, the model will focus these management efforts and guide managers toward appropriate solutions.

The Policy Connection in Research

THE *MINNESOTA WATER PLAN* (*MWP*) identifies the principles, policies, and actions needed for managing water in the 1990s and beyond. The *MWP* stresses the importance of understanding water's interconnections. It emphasizes the need to integrate efforts to address them. The *MWP* goals, presented in the *Executive Summary*, embrace these requirements.

These goals, the principles described below, and a series of *MWP* recommendations provide the policy framework within which the assessment of research needs and priorities was made. This framework was developed with extensive participation by both citizens and officials interested in the management of Minnesota's water resources.

The *1991 Minnesota Water Research Needs Assessment* identifies the research required to support the management and policy decisions called for in the *MWP*. This chapter of the *Assessment* introduces these needs by highlighting:

A. Measures to correct problems in the way research is conducted and supported;
B. The ties between the *MWP* and 21 areas of research need; and,
C. The 14 project-level priorities considered most in need of funding during the 1991-1993 biennium.

Principles for Water Management and Research

The principles identified in the *Minnesota Water Plan* (*MWP*) must also serve as a guide when identifying and carrying out the associated research needed.

The *MWP* calls for a "focus on the resource" and "integrated water resources management." Both are prerequisites for sustaining the high quality of Minnesota's environment. This assessment identifies the research elements necessary to support this new approach.

The first principle related to research is that Minnesotans understand its importance. Research provides the scientific basis for sound water management decisions.

Minnesota's other water principles are that we:

Manage water's interconnections. These occur between water and ecosystem health, surface and ground water, water quality and quantity, and among air, land, and water resources.

Focus on the resource. A wide range of programs must be brought together to protect and manage the lake, wetland, stream, or aquifer in jeopardy.

Manage hydrologic units. Minnesotans need to manage the inter-connections of streams, lakes, wetlands, and ground water through their watershed, river basin, and "ground-watershed" systems.

Make partnerships work for water. Partnerships bring people together to address Minnesota's complex water needs. Local, regional, state, and federal governments, the academic community, the non-profit sector, and interest groups must all take part in Minnesota's water partnerships.

Make prevention the focus. Minnesotans must focus efforts on prevention of water degradation and overuse. It costs far less in the long run.

Put public health and safety first. Public health and safety must never be compromised in the management of water.

Let citizens make a difference. Citizens help to identify, understand, and reconcile the competing demands for water.

Educate people to change behavior. People pollute. People waste water. People need to understand the consequences of their behavior. Otherwise, they will be less likely to change habits. Formal and non-formal water education are keys to the success of all water management activities.

Minnesotans must recognize the importance of information. Sound information makes for sound decisions. Minnesotans need water information that accurately describes what is happening to water. They also need information that is accessible, understandable, and interconnected.

Think long-term. The long-term costs and benefits to society, not short-term demands and crises, must guide water decisions.

Accept limits to growth. The vulnerability and availability of water resources should limit economic development when environmental quality would otherwise not be sustained.

Make those who benefit pay. The public at large should share the cost of government actions where society benefits, but when individuals benefit, they should bear the costs.

Make government understandable, adaptable, and accountable. Minnesotans must understand how programs protect resources. Programs must adapt to changing conditions. They must respond to changing needs. Administrators must account for program results.

Overall Conclusions and Recommendations

The Water Research Advisory Committee identified several overall concerns with the conduct and support of research in Minnesota. These in its view clearly need to be addressed.

Policy makers, policy developers, water managers, and citizens need to recognize the importance of good research to water management. The research and management communities can help achieve this recognition by accompanying research with educational efforts that explain why research is important to water resources. Both communities have a responsibility to help convince the public of the need for good research.

New requirements to share research results are needed. The communication of research results, transfer of new technology, and the ability to transfer data should be required as part of publicly funded research.

A technology transfer plan should be a condition for funding. Data collected during the course of research should be formatted in a neutral file format, well documented, and archived in a central location at the Land Management Information Center (LMIC).

Geographically based database management systems should be used where location-specific data are collected. In these cases, investigators should consult with staff from LMIC to determine the coordinate system that will facilitate conversion into the right format.

Research should be adequately supported in Minnesota. Support must be predictable and sustained over the term of study, not just the biennium. It is not well-served by the two-year timeframe frequently imposed by the legislative process.

Many research studies require a period of several years to reach a legitimate conclusion. Some way must be found to ensure long-term support of such projects, despite the constitutional prohibition against one Legislature making future funding commitments for another.

Complications may also result with research that must start in the Spring. Since funds are not available until later in the year, a full year of the two-year cycle often may be missed.

Impartial research experts should review detailed research proposals in a two-step process. Peer review and selection procedures for funding research need to be revamped. The first step should involve review of substantive preliminary proposals. It should occur before the final selections are recommended.

The second step should involve review of detailed, full-length work plans before state funds are released. The one- or two-page form used by LCMR may be sufficient to identify priority topics, but it is entirely inadequate to allow one to judge the technical viability of the proposal *or* the proposer.

Funding requests should be adequately coordinated and integrated with water policy and management needs. The *Minnesota Water Plan* provides the framework for state water policy development and management. It therefore provides the framework for identifying water research priorities. The EQB Water Research Advisory Committee is in a good position to link academic expertise and perpectives with state policy and management needs.

This package of water research priorities should guide water research funding requests and allocations. This assessment defines the essential relationship of research to management and policy and, from that, the project-level research priorities for the biennium.

1991 Areas of Research Need

The full set of identified water research needs, as well as additional discussion of the following research areas, are included in the body of this assessment. The research areas are identified to help focus researchers and funding agencies on the issues most in need of research.

The research areas are organized around the categories of Ground Water, Surface Water, Fate and Reduction of Environmental Pollutants, and Integrated Water Management. Each of the sections is prefaced by the related policy questions and recommendations of the *Minnesota Water Plan* (*MWP*).

The criteria used in developing the research areas list are:

Responsiveness to the goals, principles, and recommendations of the *MWP*.

Sequencing of research required in addressing the *MWP*'s goals, principles, and recommendations. For example, an added priority might be assigned to answering the basic question of where Minnesota's ground water is located before placing the full emphasis needed on what aquifer characteristics may be.

Ground Water

Questions from the policy side:

How can we better protect our ground water resources?

How can we better understand the vulnerability of ground water to contamination?

What is the best way to ensure that wells are protected and are not pollution hazards?

Recommendations from the MWP:

Protect and manage aquifers as units.

Gather sufficient hydrogeologic information for making adequate water management and protection decisions.

Strengthen enforcement of the well code at the state and local level.

Develop and implement wellhead protection for public and private wells.

The research response:

■ Continue accelerated production of county geologic atlases and regional sensitivity assessments.

■ Improve information on ground water and contaminant flow paths, and the age of ground water, for major drinking water aquifers.

■ Improve understanding of vadose zone properties and processes. The vadose zone is that area between the land surface and ground water.

■ Develop the tools needed to implement a wellhead protection strategy, including methods to delineate wellhead protection areas.

■ Develop the information and understanding needed to manage ground water as a sustainable resource.

■ Improve technologies for remediation of contaminated ground water.

SURFACE WATER

Questions from the policy side:

How can lakes be protected by comprehensive management of the environment?

What should be done to ensure that we do not lose the values provided by Minnesota's wetlands?

How can we tie together the various land and water-related programs so that rivers and streams are protected and enhanced?

How can we build on local water plans to address the problems and opportunities found in our major rivers?

Recommendations from the MWP:

Develop a strategy for integrated lake management.

Establish and operate a state-local "no net loss" program for wetlands. Note: the Legislature established the statutes governing this program in 1991.

Address water and related land resource issues from both a major river basin and a smaller watershed perspective.

The research response:

■ Quantify wetland functions and values in relation to their hydrologic characteristics, and define management strategies needed to maintain the functions.

■ Assess the potential for spread of exotic species (e.g., Eurasian water milfoil) in the state's surface waters, and develop management and control strategies for major pest species.

■ Investigate effective, integrated methods for protecting and improving the quality of inland lakes.

■ Develop a basic research and data collection program on large and poorly studied inland lakes and their watersheds, and on Lake Superior, to support integrated lake management.

■ Develop and evaluate methods to include information on ecosystem health in water monitoring programs and in regionally-based water quality criteria.

■ Develop better understanding of factors affecting water quality and availability in the state's large rivers, including models to predict contaminant dispersal, and travel times and flow rates under drought conditions.

Fate and Reduction of Environmental Pollutants

Questions from the policy side:

What new steps must be taken to meet state and federal clean water goals?

What can be done to reduce the amount and number of pollutants entering the environment?

How can we protect our water and soil resources while ensuring the vitality of the state's agriculture?

How can we ensure that water and wastewater treatment systems meet new health and environmental protection needs of the state?

How can we ensure that our water infrastructure (e.g., dams, water and wastewater treatment systems) is effectively operated and maintained?

Recommendations from the MWP:

Evaluate how state programs should be changed to move toward the Minnesota clean water goals; then begin making the changes.

Reduce the amounts of polluting materials used, wastes produced, and pollutants entering the environment.

Ensure that agricultural activities in the state are environmentally sound, and economically and socially viable in both the short and long term.

Upgrade Minnesota's water infrastructure with new technology to better safeguard public health and the environment.

Take steps to ensure that money is set aside for infrastructure maintenance and improvement.

The research response:

- Quantify the effects of contaminant loadings from urban stormwater on receiving waters, and design effective, cost-efficient treatment and management practices.

- Improve agricultural practices, including those for manure management and weed control, to decrease contaminant loadings of nutrients and pesticides.

- Determine the significance of atmospheric contributions of toxic substances, especially those of pesticides, PCBs, and mercury on lakes.

- Refine methods to evaluate the impact of toxic substances in wastewater discharges on surface waters, and develop cost-effective methods to remove such substances from waste streams and drinking water.

Integrated Water Management

Questions from the policy side:

What can we do to better manage water in the broader environmental context?

How can environmental protection needs influence the systematic management of growth?

How can Minnesota maintain a strong economy while sustaining the quality of its environment?

How can we ensure that Minnesotans have sufficient water to meet their future needs?

How can the state be better prepared for water emergencies and drought?

How can people be better educated about water issues?

What is needed so that people act in a manner that ensures the environment is safeguarded?

How can we make data readily accessible, and more useful for those who need it?

How can we get a better long-term understanding of changes in Minnesota's water quality and availability?

What steps should be taken to ensure a consistent approach to holding people liable for misuse of water?

How can the state do a better job of enforcing its water laws?

Recommendations from the MWP:

- Identify and remove barriers to managing water's inter-connections for a sustainable environment.

- Build consideration of water protection needs into land use decisions.

- Develop a water conservation strategy for long-term and seasonal water use throughout Minnesota.

- Launch a major environmental education initiative to show people how their actions affect the environment.

- Open up lines of communication among local, state, and federal levels of government, as well as citizens and the private sector.

- Improve the state's Geographic Information System so that all users can easily access and integrate data on surface water, ground water, and related land resources.

- Make the commitment of money and authority necessary to carry out the state Water Resources Monitoring Plan.

- Develop a consistent state approach to fairly and equitably assigning consequences and liability for water misuse.

- Enhance the state's strategy for compliance with environmental regulations.

The research response:

- Establish a demonstration project to evaluate the informational and institutional barriers to integrated water management.

- Investigate the technical issues that must be resolved to design an effective monitoring program to evaluate trends in the quality and availability of the state's water resources.

- Define and quantify the interactions between ground water and streams, wetlands, and lakes.

- Determine the impact of global climate change on the availability of Minnesota's surface and ground water resources.

- Develop economic information on the benefits and costs of policies affecting wetland preservation and ground water protection.

1991 Project-Level Priorities

The Advisory Committee determined that certain project-level priorities needed to be brought to the attention of policy makers. These priorities were selected from within the areas of research need in response to a combination of factors, including the urgency for use in management decisions, and the perceived viability and scientific necessity of the research.

The Advisory Committee concluded that it is especially important to fund projects on the following priorities during the next biennium. The priorities are grouped by the breadth of support reached in the Advisory Committee's selection process. They are not listed individually in any other priority order.

Under priority level one, the priorities are that we:

Delineate and quantify the factors that determine wetland functions and develop standardized methods for their measurement. To reasonably support state wetland conservation policy, the state needs to develop a better understanding of the factors that drive wetland ecosystem and hydrologic system functions (e.g., waterfowl production or flood attenuation), and of the technology of wetland restoration. These must be tied to the different types of wetlands, and the different locational characteristics of the individual wetland in question.

During the last decade, a great deal of effort was devoted to development of a Minnesota methodology for assessing wetland functions. The method provides a good starting point for this priority research.

Determine how our changing climate influences the availability of surface and ground water. The range of effects of climate change on the availability of surface and ground water must be defined to aid in the development of management strategies. Agriculture is particularly dependent upon climate. The need for stability in agriculture dictates that climate change, like that represented by drought cycles, be better understood in Minnesota. The growing demand of public water supplies in the Twin Cities metropolitan area also urgently necessitates this expanded understanding.

The Legislative Commission on Minnesota Resources (LCMR) laid the groundwork for this project-level research priority through its support of the 1987-89 DNR assessment of water availability. The 1991 EQB assessment of water availability found that the supply of water is not considered well-enough defined to allow a meaningful comparison with existing or projected demand.

Improve our understanding of contaminant movement through the unsaturated zone. Important transport and transformation functions occur in the subsurface zone above ground water. These are poorly understood. We need a greater understanding of the factors that control the movement of contaminants through the zone so that their transport and fate can be understood and managed. Stable isotope tracer methods and subsurface hydrologic models should be applied to develop this understanding. These will greatly aid efforts to meet the degradation prevention goal of the Ground Water Protection Act of 1989.

Under priority level two, the priorities are that we:

Determine the fate of toxic compounds in lakes. The transformation and fate of mercury, PCBs, and pesticides in Minnesota lakes needs to be better understood. The factors affecting accumulation of these toxic substances in food chain organisms must be evaluated.

The LCMR has supported investigations of mercury in northeastern Minnesota through the Pollution Control Agency. These studies have resulted in a good understanding of the presence, magnitude, and possible sources of mercury. What drives the transformations of mercury in lakes, and the significance of this for the lake and its management are not well understood. In addition, the magnitude of the mercury problem outside of northeastern Minnesota is poorly understood. Little is known about the transformation and ultimate fate of PCBs and pesticides in lakes.

Develop a system for monitoring water availability and water quality trends in the state. Because ambient monitoring has not been adequately supported, the determination of trends in either water quality or quantity is difficult, at best. Research is needed to resolve the issues of spatial resolution (i.e., Can we afford to design a system that allows detection of trends significant at the county level?), sampling frequency, and usefulness of existing monitoring programs.

The EQB recently completed assessments of quality and quantity trends. It is required to make these assessments every two years. The Board concluded in both assessments that the data do not support sound analysis of trends. The PCA and MDA reached a similar conclusion in their assessment of trends in nitrate contamination of ground water.

Develop practical economic tools to promote consideration of the value of water in decision-making. Allocation of water among competing users and, more broadly, management of land and water, is not governed by water's real value. Consequently, decisions affecting water and land resources are often inefficient or inappropriate.

A significant effort was made to understand the "value" of water in a 1987-89 project supported by the LCMR. Because of its broad focus, this effort did not result in practical, useable tools for decision-making. By examining the question in the context of specific management choices in specific areas of the state, it should be possible to develop practical applications from the work begun with this study.

Evaluate the importance of denitrification in Minnesota aquifers. Denitrification is a process where nitrate is converted to nitrogen gas and removed from water. It is thought to occur in ground water where organic matter is present but oxygen is not. It could be a significant factor in some locations in removing nitrate from ground water. Because no one is sure of this, it is difficult to use nitrate as an indicator of pollution, or to assess how vulnerable a well may be to pollution.

No research has been done on the occurrence and significance of denitrification as a process regulating nitrate levels in each of Minnesota's aquifers.

Continue the accelerated development of county ground water atlases and regional sensitivity assessments. County atlases provide a detailed analysis of existing well records, monitoring data, and other available information to characterize a county's ground water resources and geology. They are an extremely useful tool for making land use decisions that safeguard ground water resources. Regional assessments assess existing information to describe the characteristics of the first 100 feet below the earth's surface. They provide a multicounty assessment of the geologic sensitivity of surficial aquifers.

The Ground Water Protection Act of 1989 increased the funding of county atlases significantly, and initiated the regional sensitivity assessment program. The pace is still far too slow. To date, six atlases have been completed (three were completed before the acceleration); three more are underway and another is to be started in 1992. Three regional assessments are in progress. The LCMR recognized the need to augment this slow pace with its commitment in 1991 to accelerate the production of atlases and regional assessments.

Analyze the organization of state water management programs. It is important to determine whether state programs and activities can be better organized to address state water needs in an effective and efficient manner.

The Commission on Reform and Efficiency (CORE) is currently examining the organization and efficiency of state government, in general. A question exists as to whether this process will be able to give sufficient focus to water organization.

Determine the effectiveness of urban stormwater management practices. Little research has been done in Minnesota on urban best management practices despite the mix and suspected levels of toxics that appear in urban runoff. Efforts have been undertaken to use wetlands for retention and treatment of nutrients in runoff, for example, but we have not adequately studied the effectiveness of these systems on removing toxic substances, nor the response of the wetland over time.

The Metropolitan Council studied stormwater runoff characteristics in the early 1980s, and initiated studies in 1989 of the efficiency and response of wetlands used to mitigate the effects of polluted stormwater runoff. These studies paint an incomplete picture of the conditions under which wetlands effectively remove contaminants. We must learn about the maintenance requirements needed to keep such systems from actually contributing to pollutant loads. We must also investigate the effectiveness of other urban "best" management practices.

Develop and apply models to predict contaminant transport in Minnesota's large rivers. Models are needed to predict flow and transport of contaminants in large rivers. One use of these will be to aid state and local officials in management of spills. The models should aid in early warning communications and in targeting spill monitoring and cleanup efforts. Spills response on the upper Mississippi River is a priority application. A second use should be to describe the effect of sporadic nonpoint source river inputs. Implementation of the Minnesota River Assessment Project is a priority.

The Corps of Engineers is developing a model that estimates the time of travel from the Mississippi headwaters reservoirs at specified flows. The predictions that the model makes need to be verified before it can be considered to provide a reasonable basis for major water supply decisions, like shutting off water intakes. Furthermore, the model does not attempt to address the dispersal and transport of various types of contaminants. During the recent Grand Rapids oil spill, officials had little idea of how contaminants reaching the river were dispersing, or how fast they were moving down river.

The Minnesota River Assessment Project has called the modeling of nonpoint pollution effects in the mainstem river a priority research need.

Under priority level three, the priorities are that we:

Quantify the transport and fate of contaminants in Lake Superior. The transport and fate of contaminant loadings within the world's largest lake are not well understood. Studies of these items must include contributions from atmospheric transport.

The PCA is participating in an international study of contaminant loading to Lake Superior. A better understanding of what happens to the contaminants once they enter the lake will greatly aid in the management choices to be considered.

Evaluate the nitrogen contributions of manure and other organic sources. The contributions of manure and other organic sources to the total pool of available nitrogen in soils, runoff, and infiltration in agricultural areas are not well understood. A better understanding of these contributions would improve nitrogen management and ground water protection efforts.

The call for this evaluation is a priority of the recently completed inter-agency state report "Nitrogen in Ground Water."

Develop and implement a Twin Cities metropolitan ground water model. The model will simulate water levels and flow pathways for the entire metropolitan area. It will aid in management of pollutant sources, the siting of potential sources of pollution, and the delineation and management of wellhead protection areas. Once established, the model will focus these management efforts and guide managers toward appropriate solutions.

The LCMR has funded development of a model under consideration for application in the metropolitan area, but further work is needed to gather and apply the physical information needed to set the model up on a region-wide basis.

The Research Assessment

MINNESOTA'S WATER RESEARCH NEEDS are described within the four general categories of:

Ground Water;
Surface Water;
Fate and Reduction of Environmental Pollutants; and,
Integrated Water Management.

These categories are subdivided into 22 areas of important research need. A brief description of each research need is presented, as is the reason an item is needed (i.e., its link to Minnesota's management and policy issues), and the nature and context of the need (i.e., its probable duration and the current extent of related research). In addition, each category is introduced by "Questions from the policy side" and "Recommendations" from the Minnesota Water Plan (MWP). These illustrate the link between identified research needs and the MWP.

This section of the report provides the detailed survey and assessment from which the 14 project-level priorities were developed.

Ground Water

Conceptual Framework

GROUND WATER RESEARCH IN THE STATE should proceed within the following general framework: 1) An assessment of the current situation — "State of the state's ground water"; 2) Historical reconstruction of how the state's ground water changed in time to reach its current condition; and 3) Analyses to predict how its ground water will change in the future in response to both natural environmental change and impacts of human activities.

In all three temporal frameworks — past, present and future — the following issues should be addressed: **ground water quantity** (distribution and flow); **ground water quality**; and **ground water "processes"**.

By the latter term, we mean phenomena that cause an attribute of a system (e.g. ground water recharge) to change in time or space (usually time). When we study processes, we are interested in understanding the mechanisms by which change occurs so that we can quantify and if possible predict these changes. For example, one process of interest is the migration of a contaminant in an aquifer. To quantify and predict the origin (past) and future of the contaminant plume, we need to understand the mechanisms of plume migration.

Research in this framework will have applications for state handling of abandoned wells, wellhead protection, aquifer sensitivity guidelines, local water planning, best management practices, artificial recharge, ground water allocation, wetlands conservation, drinking water standards, and regulatory issues.

Research Area 1
Studies of the Unsaturated Zone

Research needs. Further research is needed to be able to characterize the flow and transport properties of this important zone between the ground surface and the top of the saturated zone (where ground water aquifers start). In addition, there is a need to catalog existing data on the flow and transport properties of materials in the unsaturated zone and to relate them to mapped units. Specific needs include:

- Better methods, including improved sensors, to measure flow and transport properties in this zone — both invasive and noninvasive (e.g. ground penetrating radar) methods;

- Improved understanding of the effects of mixed geology on pathways and fate of contaminants;

- Efficient computer models of flow and transport processes in the unsaturated zone, including mixed systems involving liquids and vapors (e.g. water and petroleum products);

- Improved understanding of the chemical interactions of contaminants with soil and subsoil particles in the unsaturated zone; and

- Evaluation of the potential for biological decomposition in this zone.

Why needed. The unsaturated zone is the key link between contaminant-producing activities at the ground surface and water quality in underground aquifers. Major transformations and loss mechanisms are associated with the subsoils in this zone, but we still have a poor understanding of these processes and are unable to accurately predict rates and extent of contaminant transport through unsaturated zones. Rates of recharge through the unsaturated zone also are a key link between climate change and water table levels.

Time and space. Many phenomena in the unsaturated zone (e.g. leaching of agricultural chemicals in sand plains) appear to occur rapidly. Studies on such processes can be conducted effectively within the biennial funding framework. Other situations, such as adsorption of petroleum products on fine-grained soils, require longer-term studies. Agricultural areas and landfills are obvious potential research sites. There is a statewide need to incorporate an understanding of unsaturated flow in wellhead protection plans.

Research Area 2 Hydrogeologic Characterization of Ground Water Resources

Research needs. Minnesota is making progress in gathering and interpreting basic hydrogeologic data on its ground water resources through the county geologic atlas and regional assessment mapping programs. These programs should be augmented in several ways, and research is needed on several key topics.

Research is especially needed on several aspects of Quaternary stratigraphy — the complex layer of glacial deposits (unconsolidated sand, gravel, silt and clay) that overlie bedrock in much of the state (e.g. the Anoka Sand Plain). Research on Quaternary stratigraphy should be expanded to determine ground water distribution and flow characteristics and residence times in glacial deposits. Hydrogeologic research needs include:

- Development of improved seismic and downhole geophysical methods for detailed three-dimensional imaging of Quaternary stratigraphy;

- Characterization of borehole samples (e.g., bulk density, porosity, permeability, resistivity, mineralogy, texture) to enhance interpretation of the geophysical signatures of Quaternary materials;

- Exploration by these and other geophysical techniques, followed by test drilling, for possible major aquifers in ancient bedrock valleys buried under the deep Quaternary deposits of western Minnesota;

- Characterization of flow and transport properties of low permeability materials in Paleozoic and Cretaceous bedrock aquifers;

- Development of a library of physical property data (porosity, permeability, resistivity) for use in improving empirical and computer flow models in bedrock formations;

- Expansion of county atlas and regional assessment programs to include more water quality information (e.g. concentrations of agricultural chemicals, geochemically determined water residence times);

- Determination of vertical permeability and contaminant transport characteristics of confining units, possibly by using thermal/geochemical methods to study the effectiveness of the confining unit; and

- Accelerated development of efficient, user-friendly and reliable Geographic Information Systems (GIS) for geologic and hydrogeologic data.

Why needed. Researchers, management agencies, and private consulting firms all rely on quality baseline data to ensure accurate and meaningful results. Of all our water resources, ground water is the least understood. We simply need more information on the distribution of ground water and the hydraulic properties of aquifers to make wise planning decisions. Research on unconsolidated glacial deposits is important because aquifers in them are shallow and susceptible to contamination. Also, most of our lakes and wetlands lie in these deposits and are directly connected with the ground water system.

Time and space. Gathering and cataloging information on ground water aquifers is a task of daunting scope. Ultimately, the task is statewide and long-term. Work on glacial deposits is more urgent because of their susceptibility to contamination. Work on bedrock confining layers is required to ensure clean ground water in the metropolitan Twin Cities area. Gradually, data should be gathered on a county-by-county basis as part of the geologic atlas series.

RESEARCH AREA 3
GROUND WATER TRANSPORT AND RESIDENCE TIMES

Research needs. As the emphasis in ground water research shifts more and more toward questions of protection of aquifers from contaminants, we are increasingly confronted with predictive questions such as "Where will a spill of trichloroethylene go?" or "What are the pathways from a buried landfill with unknown contents of toxic chemicals?" Answers to such questions will require knowledge of flow paths and residence times. Some ground water may be clean at present but in the path of migrating pollutants; given enough time pollutants could reach even a deep well. We need ways to predict whether an aquifer or well will produce sustainably clean water, or whether it is only a matter of time before contaminants reach a well.

Typical flow paths should be determined for a variety of hydrogeologic settings. We need to know sources of recharge water, flow paths, residence times of water, and subsequent points of discharge. What are the pathways of contaminants that enter these ground water systems? When will contaminants remain in the shallow, local flow systems, and when will they enter the deeper, regional flow system?

Fundamental to this research is knowledge of the age of ground water, inferred geochemically. Stable and radio-isotopes that occur in ground water are invaluable tools to determine ground water age. Is the water in deep aquifers of glacial age, and did recharge depend on high hydrostatic heads at the base of the glaciers? Can modern recharge rates supply water to these aquifers to match current withdrawals?

Regional aquifer systems need to be modeled to answer the above questions. First, modeling will aid our understanding of the natural cycle of ground water in an aquifer, i.e. the length of time and flow paths between recharge and discharge. Second, modeling will allow an estimate of how human-induced stresses on the system (e.g. pumping of wells) can alter the flow paths and residence times.

Also fundamental to progress on this topic is the development of better methods of three-dimensional imaging of subsurface aquifers and contaminant pathways. This may be termed "subsurface or Quaternary tomography" for regions where ancient, buried glacial channels and valleys act as conduits or networks with feeder shortcircuits. Subsurface meter-scale sedimentary structures are not easily defined by conventional core-drilling techniques, and most existing remote-sensing methods are unable to resolve important features in subsurface deposits. The following two techniques should be investigated further as potential improvements in aquifer imaging.

- **High resolution (sub-meter scale [e.g. 3.5 kHz]) seismic imaging techniques that allow profiling.** These include "Georadar", although its penetration is limited. Improved techniques might be developed from a combination of computer treatment methods used for on-land oil exploration, such as vibroseis, and marine seismic profiling methods and computer deconvolution;

■ **Interactive two-dimensional (seismic, georadar, profiling) and one-dimensional data banks.** Much of the recent research in parallel processing computers has gone into programs that can produce smoothed, three-dimensional imaging of large data sets. Basic research on this topic is underway in several groups at the University of Minnesota. Research is needed to produce adaptations for interactive imaging of all combined subsurface data (drilling, logging, georadar, seismic, ground water chemistry, isotope tracers, etc.)

Why needed. The flow path of ground water normally determines the flow path of contaminants and their residence times in aquifers. To protect our aquifers from contamination, especially the deep aquifers that currently provide high quality water, we must know the source and flow paths of ground water. The ultimate fate of contaminants such as agricultural chemicals and volatile organic compounds will be better predicted, and the transformation of pollutants along flow paths can be better studied. We need modeling expertise to help predict the consequences of waste disposal landfills and ground water pumping. Knowledge of ground water ages will provide information on the sustainability of our ground water resources. Are some wells "mining" old (and not-easily-replaceable) water, or are they simply tapping a renewable resource?

Time and space. There is an urgent need to be able to predict the effects of deep-aquifer pumping in the Twin Cities area and to be able to evaluate alternatives for landfill sites. Agricultural areas with generally shallow flow systems, which occur in several regions of the state, should be examined for the potential of fertilizer and pesticide residues to migrate to surface waters and deeper aquifers.

Research Area 4 Wellhead Protection

Research needs. Wellhead protection is one of the cornerstones of the ground water management/protection strategy defined in the state's comprehensive 1989 legislation, but it is a relatively new concept and research is needed to develop practical approaches.

Methods/models to delineate wellhead protection areas need to be developed and tested.

The sensitivity of such models to input parameters needs to be evaluated with regard to effects on the size, shape, and orientation of wellhead protection areas.

A hierarchical scheme of applying wellhead protection methods should be developed, allowing for quick initial employment of simple methods to be followed by more accurate methods later as time permits.

The sensitivity of delineation methods to variability in geologic and hydrologic properties should be assessed. Data on the geologic and hydrologic properties of important water supply aquifers in the state must be collated in order to make this assessment.

A research need related to the concept of wellhead protection concerns the life expectancy of pathogenic organisms, especially viruses, in ground water. The hydrogeologic conditions that permit extended survival of pathogens need to be delineated so that well code isolation distances are adequate to prevent the spread of disease through ground water.

In addition, research is needed to help define an approach that would adopt protection on an *aquifer* basis (specifically for the Prairie du Chien-Jordan Aquifer) rather than for the 500 individual wells currently used by municipal water suppliers in the Twin Cities area.

Why needed. Development of simple methods to delineate wellhead protection areas will allow rapid and inexpensive deployment, which will afford moderate wellhead protection until more accurate methods can be used. Wellhead protection, even if not perfect, is better and less expensive than aquifer remediation or relocation of entire well fields. Public awareness of the connection between land use and ground water pollution will be heightened as municipalities rezone wellhead protection areas for restricted land use.

Federal and state wellhead protection efforts seem to be focusing on individual wells rather than whole aquifers for program implementation. Application of the individual well approach in the Twin Cities region means that tremendous overlap would occur with almost any of the protection ring definitions being considered because of the high density of wells in the region.

Time and space. Wellhead protection is an urgent, mandated need. The most immediate application sites are shallow aquifers in sand and limestone, because of the possibility of rapid movement of contaminants in these aquifer types. Ultimately, however, the application must be statewide and long-term.

RESEARCH AREA 5
SURFACE WATER-GROUND WATER INTERACTIONS

Research needs. Lakes, wetlands, and streams generally have a hydraulic connection with aquifers, and consequently ground water plays an integral role in the hydrologic and ecological functioning of these water bodies.

Lake-ground water and wetland-ground water interactions. Water levels in lakes and wetlands depend on both surface and ground water hydrology. Ground water is the least known component in the water budgets of lakes and wetlands, and the effects of ground water recharge and discharge on amounts and rates of water-level changes in surface-water bodies are poorly understood. Transient fluxes of water between aquifers and surface waters affect short-term water levels. Regional changes in ground-water recharge can alter the regional water table, causing long-term water-level changes in lakes and wetlands.

■ Environmental isotopes are powerful tools to study residence and travel times, source attribution, and biotic/abiotic interactions between ground and surface waters. Research on aquatic systems in Minnesota can profit greatly from their broader use, as we improve our ability to interpret their signals. Recent successes in using stable isotopes to determine ground water-lake interactions and mass fluxes should be expanded on selected systems to determine long-term residence and response times of lakes.

■ Lakes and wetlands deposit sediment layers each year that *en toto* represent an integrated environmental history of the drainage basin. Interpretation of lake and wetland sediments is a key to understanding past patterns of regional climate, hydrology and vegetation. Furthermore, understanding how lakes and wetlands responded to past climate changes is important in predicting how they may respond to future climate changes. Stable isotopes preserved in biotic and chemical species in lake sediments archive important information on the dynamics of past environmental changes and the stability of ecosystems. A systematic study of a series of hardwater lakes across climate gradients is needed to calibrate these signals so that we can interpret the sedimentary record. In particular, the combined signals of carbon, oxygen, and deuterium deserve more investigation, and we need to develop or improve dynamic models to simulate the behavior of these isotopes in lake systems. Other isotopes also deserve attention. For example, the stable isotopes of strontium can be sensitive to watershed erosion, lake water salinity, and ground water inputs. The isotopic composition of ground water and the flux of water between the lake and aquifer are of fundamental importance in all isotopic studies on lakes.

■ Hydrologic modeling of interactions between ground water and surface waters should be done in tandem with isotopic studies. We need linked models to understand the effect of future climate change on water levels in lakes and wetlands. We need to know how fast lakes may respond to a climate change, and how much water levels will change. We need to know whether a climate change will cause the water table to drop enough to cause widespread drying and destruction of wetlands. Modeling is also fundamental in the hydrologic interpretation of sedimentary records, including those of isotopes, that harbor signals of past climate.

Stream-ground water interactions. Work should be done to understand seepage of water between streams and aquifers. The distribution of seepage along stream channels is poorly understood but is critical to determining ground water flow paths in adjacent aquifers. Knowledge of ground water flow paths is essential to predict the movement and ultimate fate of aquifer pollutants. It is important to know whether a pollutant moving through soil and shallow ground water systems will be discharged into a local stream or enter a deeper, regional flow system. Also, the availability of stream water is often limited by low-flow conditions, at which time most or all of the stream water originates as ground water seepage. Greater insight into the variability in both flow rate and water quality during low-flow conditions would be gained by studies of stream-ground water interactions. Through this work the flow paths and residence times of ground water near streams will be better understood. The flow paths and travel times of contaminants and low-flow stream conditions thus will be better predicted. Management decisions on a watershed scale will be aided by improved knowledge of stream-ground water interactions.

Why needed. Lake-level change has caused much property damage and public outcry. Short-term, transient lake-level changes are of interest to potential shoreline property holders, who may wish to know what will happen to lake levels if next year's rainfall is greater or less than 30-year average values, and how long the anomalous lake level will persist after climatic inputs have returned to normal. Long-term lake-level changes resulting from changes in the regional water-table elevation are relevant in the face of potential climate change due to greenhouse warming. A better understanding of ground water-lake level interactions will help make better policy and management decisions. "Natural" water-level variability will be better defined. Criteria could be established to predict which lakes are "sensitive" to potential water-level changes. The response of lake levels to climate change scenarios could be predicted if further hydrologic studies were undertaken on this topic.

Time and space. Understanding the relationships among climate, ground water, and wetlands is urgent because of the recent emphasis on wetland preservation may conflict with the impending possibility of a drier climate caused by the greenhouse effect. Study sites are needed in transects across climatic gradients. Particular attention should be paid to prairie wetlands, where many restoration efforts are underway.

Research Area 6
Sustainability of Minnesota's Ground Water Resources

Research needs. Both the quantity and quality of Minnesota's ground water resources need to be maintained. Ground water quantity is determined by rates of aquifer recharge, which are affected by changes in climate and land use, as well as by rates of water withdrawal for human use. Ground water quality can be maintained only by developing a thorough understanding of aquifer sensitivity to contamination and the flow paths of contaminants in aquifers.

Recharge. There is a need for improved understanding of the relationship between precipitation and aquifer recharge, and the seasonal and longer term variability in recharge. The importance of depression-focused recharge should receive further attention. Likewise, there is an educational need for better public understanding of the concept of recharge.

Water-table response to land use. Water-table elevations change in response to changes in recharge that result from land use changes. For example, urbanization increases the impervious area of the land surface and results in re-routing of runoff; agricultural practices affect evapotranspiration and runoff. However, we do not have good information to accurately predict the magnitude of water-table changes in response to specific land-use changes, and research on this topic should be pursued.

Modeling. Water managers need a readily available, accurate ground water model of the entire metropolitan region to address the water supply questions that are expected to arise in the next 20 years. The currently available U.S. Geological Survey (USGS) model for the region meets neither of the above criteria. The model should be able to model subregions within the metropolitan area within, which particular questions must be answered. The development of such a model for the region and its test application is a high-priority ground-water need.

Aquifer sensitivity to contamination. Efforts should continue to determine aquifer sensitivity. Research is needed on the potential for contaminated ground water to move into deeper aquifers. Interdisciplinary experiments should be conducted to develop optimum methodologies to determine ground water sensitivity in diverse geologic settings in Minnesota. This research should involve experiments that would field test and scientifically evaluate the various methods presently in use to determine sensitivity. New sensitivity mapping approaches also should be tested and their applicability determined at various mapping scales. Such techniques as studies of nitrate migration and determination of ground water residence times through radiometric age dating techniques should be evaluated. Geologic settings should include Quaternary aquifers and bedrock aquifers such as the Jordan and Prairie du Chien.

Ground water Sensitivity to Climate. Research should be done to understand the linkage between climate and ground water, including the variability of the processes involved. The variability of ground water recharge over time should be assessed over several time scales. The linkage between climate and ground water should be modeled mechanistically to help assess how possible future changes in climate could alter ground water recharge. Research should assess:

- Ground water availability and its variability in response to climate change;
- Sensitivity of water levels in lakes and wetlands to climate change;
- The effect of climate change on the hydrologic function of wetland;
- Variability in ground water gradients for improved delineation of wellhead protection areas; and
- Variability of ground water contributions to streamflow (for better understanding of low-flow stream-water availability during drought conditions).

Why needed. Climate determines the precipitation-evapotranspiration balance of a region and thus potential recharge. Ground water recharge in turn strongly influences water-table levels and ground water gradients, in turn causing a change in lake levels and drying up many wetlands. A climate-induced change in such gradients could alter both the direction and magnitude of ground water flow, affecting contaminant transport and residence times. A change in recharge would translate directly into changed availability of ground water for both human use and natural discharge into streams, lakes, and wetlands.

Time and space. Sustainability of Minnesota's ground water in terms of both quality and availability is important today and for future generations. In areas where use of ground water is high (such as the metropolitan area), the need for research to define sustainable yields and develop ways to maintain water quality are immediate, so that existing supplies are not jeopardized.

Research Area 7
Efficiency and Effectiveness of Remediation Technologies

Research needs. Ground water remediation technology has been an active area for research in the state for the past decade and substantial advances have been made, particularly in the area of bio-remediation. Additional research is needed in the following areas:

- Evaluation of contaminant reduction by *in situ* remediation technologies as well as "pump and treat" methods for saturated and unsaturated zones;

- Termination of cost-effectiveness of contaminant reduction technologies; and

- Development of new contaminant remediation technologies based on engineering of new microbes.

Why needed. Although Minnesota's ground water management strategy emphasizes protection and prevention, many aquifers or parts of aquifers already are contaminated, and positive action must be taken to reverse this degradation. Therefore it is appropriate that research be conducted on efficient and effective remediation methods. The prevention/protection strategy can be implemented fully only if adequate management tools are available.

Time and space. Remediation work must be done on contaminated sites, where the need is urgent. Research also must be conducted in laboratory settings and on aquifers in a variety of hydrogeologic settings to prepare for possible future clean-up needs.

Surface Water

INTRODUCTION

THE MOST VISIBLE and multi-dimensional category of water occurs at the land surface. Although a large amount of research has been conducted on this facet of the resource, we have only begun to understand its complexity. Moreover, new stresses and problems arise continually that require new information for proper decision making and resolution. "Surface Water" includes not only the standing and flowing bodies of water (lakes and rivers) for which Minnesota is famous, but also the land-water interface zones that occur in wetlands, the complex biological communities under the water surface, the atmospheric inputs that help determine the composition and quality of the water, and much more.

The following paragraphs list the needs for research on surface water issues developed by the committee. It in no way pretends to be a complete list of the things we need to know, but rather is a list of research areas that the water professionals on the committee think should be addressed soon.

Some general concerns can be summarized from each area. Wetland functions, values and use are subjects of increasing interest among water managers and policy makers, as "mitigation" efforts expand on degraded and threatened wetlands. However, we still know little about how wetlands work, and fundamental research is needed on wetland hydrology and ecology. Perhaps the biggest threat to the state's water resources, as they currently exist, is global climate change. The time to join others in collecting data on the phenomenon and evaluating the possible impacts is now. Minnesota has witnessed the invasion of many exotic species over the past century, and some serious problem species have appeared in just the past few years. We need to know how such invasions occur and what methods will work to control the unwelcome visitors.

Improved knowledge of our lakes and the driving forces behind their behavior continue to be research needs. Gathering basic limnological information on the state's largest inland lakes, which curiously have been neglected in past studies, should be a high priority. Of special research interest is Lake Superior — a unique state treasure about which we know so little and need to know much more to ensure the continuation of its beauty and high water quality. Because Minnesota's waters are our primary recreational assets, we need to know what impacts our use of these waters for recreational pursuits has on them. Many previous water monitoring and research efforts have ignored the biological sciences, leaving some large voids in our knowledge that need to be filled. Finally, our rivers have long endured our abuse but show promise of rebounding to be the valuable resource they once were. To assure their recovery, we need basic data on the condition of the rivers, the materials flowing into them, and effective tools for analyzing their behavior.

RESEARCH AREA 1
WETLAND VALUES, FUNCTIONS AND USE/MISUSE

Research needs. Further research is needed to better define the functions and values of wetlands, and the beneficial roles they should play as surface-water resources for society. In particular, there is a need to devote research efforts to:

- Identify and quantify the *values* (both ecological and economic) of wetlands of different types for a broad cross-section of beneficial uses, including water quality enhancement, wildlife and fish habitat, control of water flows, ground water-surface water interaction, and open space preservation;

■ Better understand wetland *ecosystem* functions and how to restore that function;

■ Characterize and categorize Minnesota wetlands according to hydrologic functions (i.e. the fluxes of the different components of the water budget);

■ Relate wetland vegetation quantitatively to hydrologic function;

■ Better understand and develop improved techniques for pollutant removal by wetlands and evaluate the ultimate fate of such pollutants (for example, do they remain in wetland sediments or are they transported downward into ground water aquifers?);

■ Identify impacts of commonly used pesticides on wetland biota; (for example, can the decline in waterfowl be related to increased chemical contamination of wetlands?);

■ Define the role of mitigation in proper wetland regulation;

■ Define the role that wetlands play in overall watershed management and pollution reduction for receiving waters, particularly lakes; and

■ Study the hydrology and water chemistry of restored/created wetlands to gather data for application to future wetland restorations.

Research also is needed to define how long and under what conditions the functions and values will continue to be valid. Certainly we cannot continue to release untreated urban runoff into wetlands and expect them to remove contaminants and infiltrate water forever.

Why needed. Because of the location of wetlands relative to the movement of water in drainage basins, both urban and rural wetlands commonly have become focal points for disposal of collected runoff. The disposal usually occurs without any pretreatment or attempt to minimize the load of damaging pollutants being carried in the runoff. Although we have come a long way in protecting wetlands over the last decade, they continue to be lost because of draining and filling associated with development and utility projects. In an effort to minimize impacts, mitigation is proposed, but we really know little about the functions that "mitigated wetlands" are trying to replace. (We use "mitigation" as a term for a suite of approaches that include, among other things, construction, alteration, enhancement or enlargement.) As a result, we might end up with a far less valuable wetland system. We need basic research to help define whether the mitigation approach is a desirable course to pursue. Should we be trying "no net loss" without a mitigation program?

The biology of wetlands depends on their hydrologic function. A slight change in the recharge or discharge function of a wetland might cause a large change in vegetation. Some rare wetland types may be the result of a delicate balance in hydrology. We should have some means to understand the impact of a change in hydrology caused by climate change or by wetland mitigation efforts on various wetland types. Wetland restoration will then become more feasible and predictable and less of a trial-and-error procedure. Knowledge of the hydrologic functioning of wetlands will permit more rational management decisions to be made. Surveys of wetland vegetation could have predictive value in determining the hydrologic function of wetlands.

Time and space. The research on wetlands is by nature a long-term proposal. Much of the problem with past wetland research is that data collection was cut short by a biennial funding scheme. We need long-term field studies on wetlands to observe changes and evaluate their ability to cope with our abuse. Spatially, wetland character is highly variable, but almost anything we can learn about wetland functions and values should be applicable statewide.

RESEARCH AREA 2
GLOBAL CLIMATE CHANGE

Research needs. Global climate change research is a far reaching topic with a broad range of research efforts being conducted internationally. The effect of global climate change on the water resources of Minnesota and the impact of this change on our ability to develop is also a very broad topic. The best we can hope to do is to define the likely results for different scenarios of climate change and fit these findings into the larger global research scheme. After this is done, state scientists and water managers will be in a better position to propose solutions within the broader global research community. Any efforts undertaken in Minnesota could leverage research funds from other funding sources; studies by the U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S. Forest Service, and National Science Foundation are examples of on-going programs. Also some recent, small-scale research efforts in Minnesota can be used as a basis for further definition of effects.

Research specifically is needed on:

- The effects of climate change on available river flows, water supplies, stream and lake quality and fisheries resources;
- The nature of climate variability and how this variability might impact water; and
- The validity of prediction models for aquatic and wetland ecosystems.

Also, monitoring data with a solid biological component are needed to document the effects of climate change on aquatic systems.

Why needed. Perhaps no other environmental issue has so much potential to impact our water resources as global climate change; yet we know so little about what really could happen. There is so much uncertainty about the impacts and they are of such a large scale that the temptation exists to ignore them altogether. The needs listed above would begin to look at Minnesota's piece of the puzzle and answer some preliminary questions on impacts. With all the federal research underway, state scientists have a good chance of coordinating with these efforts and leveraging outside funds for the state.

Time and space. As mentioned above, the time and space scales for global climate change are extremely large, but the effects will be felt most acutely at the local level when water resources are affected. We need to initiate efforts in the state and tap into international research to answer those questions most pertinent to us and our vital water resources.

RESEARCH AREA 3
EXOTIC SPECIES

Research needs. Exotic plants and animals are now having or have the potential to cause a considerable impact on aquatic and wetland ecosystems in Minnesota. Research is needed to:

- Identify and locate exotic species in the state, including those that have been here for the long-term;
- Determine characteristics of sites that make them susceptible to invasion by exotic species;
- Determine the impact of exotic species in order to prioritize management needs;
- Find environmentally-safe techniques to control or eliminate specific exotic pests such as purple loosestrife, zebra mussel, and Eurasian water-milfoil; and
- Develop plans to manage the impact of invasions by the species of the greatest current or potential concern.

Why needed. The invasion of exotic species such as the three mentioned above threaten to eliminate much of the diversity of our aquatic resources. The rapid proliferation of these species points to the immediate need to better understand them and develop approaches to control their spread. Control of some exotic species is being studied by programs elsewhere, thus presenting some opportunity for leveraging funds. The committee notes that the term "exotic species" should apply also to stocked species, such as steelhead, as well as to species such as carp that were introduced in the more distant past.

Time and space. The need to begin work on the above research items is immediate, since every delay means further spread of the exotic species of concern. Solutions, however, will likely be long-term since information has to be gathered and digested before we can proceed with management programs. The research results are of statewide importance and application. Leveraged funds might be available from federal programs.

RESEARCH AREA 4
LAKE QUALITY

Research needs. Although Minnesota has over 12,000 lakes that are crucial to the economic well-being of the state and lifestyles of its citizens, we find that much remains to be known about these resources. Research needs include:

- Basic limnological studies on the physical, chemical, and biological characteristics of the state's large lakes such as Mille Lacs, Pepin, Red, and the Mississippi river headwaters lakes, which have been neglected in past studies by limnologists and water management agencies;

- Analysis of attainable water quality, functional behavior, and optimum management techniques for shallow lakes;

- Evaluation of the effectiveness of lake manipulation techniques, such as inflow nutrient control, aeration, biomanipulation, artificial circulation, and other newly proposed techniques;

- Evaluation of the effects of shoreland development and water level fluctuations on aquatic habitat;

- Evaluation of the geographic dimensions of the mercury contamination problem in game fish, improved understanding of the mechanisms leading to enhanced bioaccumulation of mercury in some lakes and species of fish (environmental factors leading to enhanced bioaccumulation), and evaluation of possible mitigative measures for mercury contamination of game fish, including the possibility that mercury bioaccumulation is enhanced by a deficiency in the essential element, selenium, or by elevated levels of cobalt;

- Delineation of the organic compounds that pose potential health hazards by bioaccumulating in fish and review of the differing health advisories issued by different sources;

- Analysis of the hydrologic effects of using abandoned Mesabi Iron Range pits for water supply or aquaculture;

- Further development of stable isotope techniques to determine and model ground water-lake interactions, mass fluxes, biotic interactions, and the impact of precipitation trends on the hydrologic system of lakes; and

- Further development of paleolimnological techniques to analyze the effects of human disturbance and global climate change on lakes.

In addition, efforts should be undertaken to determine the best method to build a readily accessible state database for lake information.

Why needed. The importance of lakes to the state of Minnesota cannot be overstated. Nonetheless, we know so little about many of these valuable water bodies. Large gaps in our knowledge exist especially at each end of the size spectrum — large and small/shallow. Also, many of the techniques used to manage lakes are poorly understood, and their long-term effectiveness is not well documented. We are constantly learning about new threats to our lake resources from such stresses as mercury, Eurasian water milfoil, and acid precipitation; yet we often find ourselves guessing about the impact that these threats pose because we have insufficient data and understanding upon which to build objective conclusions. Building upon other studies is possible because of some on-going metropolitan area and statewide efforts to collect data. Minnesota has long been recognized as a leader internationally in limnological research, and several recommendations build on existing research strengths.

Time and space. Any attempt to evaluate lake character and behavior will be a long-term effort because lakes are slow to respond to external factors. However, we must begin to document what is occurring in our lakes if we ever hope to fully understand them. Statewide application of specific studies focused on problems in a given lake might be difficult, but applications of categorical lessons learned, management techniques proven to be effective and the character of various lake types are useable over a wide geographic range.

RESEARCH AREA 5
LAKE SUPERIOR

Research needs. Lake Superior is a unique state resource that should be considered separately from other (inland) lakes as far as research needs are concerned. Research is needed on Lake Superior to:

- Quantify watershed and atmospheric loadings of pollutants, with emphasis on toxic substances such as heavy metals and PCBs;

- Determine the transport, fate and effects of the pollutants in the lake; and

- Establish baseline water quality and biological databases, which currently do not exist.

In addition, studies are needed related to the St. Louis River remediation, the impact of harbor dredging on the lake and the impact of economic development proposals for the drainage basin on the lake. We also need basic information on the effectiveness of management approaches on the lake.

Why needed. Although Lake Superior is in many respects Minnesota's greatest natural resource, we know little about it. Routine data collection is essentially nonexistent other than for fisheries. Recent studies have shown that the western portion of the lake is distinctly different from the rest of the lake and merits our attention if we intend to protect its unique character.

Time and space. Current efforts to conduct research on Lake Superior are very small in comparison with the size and complexity of the lake, and we must begin a long-term effort to explore the lake and the environmental features affecting it. Spatially, information collected for Lake Superior probably are not transferrable to the rest of the state. Nonetheless, it is in the state's interest to gather information to better understand this most valuable resource so that it is not adversely altered.

RESEARCH AREA 6
IMPACT OF RECREATIONAL DEVELOPMENTS

Research needs. There are many proposals for recreational site development in the state, and most involve water in some way. Research is needed to:

■ Quantify the impacts of recreational development and use on the aquatic ecology, water quality, sediment transport, and erosional features of affected water resources;

■ Define the water-based capacity of new recreational developments so that adverse impacts are minimized;

■ Quantify the economic considerations associated with recreational developments in terms of their impacts on associated water bodies.

Why needed. Recreational developments such as marinas, harbors, resorts and parks exert pressures (and often have negative impacts) on the water resources that usually are the attraction for the development. We know little about the direct and indirect, physical and economic impacts of recreational developments or the impacts of active recreational uses of the waters associated with these developments. Basic research would help us better evaluate the "benefits" of such proposals and assist agencies such as DNR in their efforts to evaluate impacts.

Time and space. This type of research has broad statewide application and could be conducted relatively quickly, as recreational development is quite active. Although each development is local in character, the techniques developed to evaluate impact are transferable statewide.

RESEARCH AREA 7
BIOLOGICAL MONITORING

Research needs. Although biotic integrity and ecological health are among the most important goals for protection of our surface waters, our ability to manage resources to achieve these goals is limited by the paucity of basic biological information on them. Fundamental research is needed to improve our technical abilities to obtain and use biological information in water management. Research specifically is needed to:

■ Evaluate the ecosystem health indices proposed to quantify biological impacts to water bodies; of special interext are those recommended by the Ecological Monitoring and Assessment Program (EMAP) of the U.S. EPA;

■ Evaluate the differences between rapid bioassessment techniques and the more complicated "Index of Biotic Integrity" relative to their effectiveness in detecting changes in ecosystem health;

■ Determine the value and credibility of the "ecoregion" concept and evaluate its use/misuse in water quality management. If this approach is found to be useful, improvements should be sought in the methods used to define ecoregions and develop water quality criteria based on each ecoregion;

■ Revise the instream-flow determination methodology to incorporate biological functions into the flow level determinations and explore whether common biological assessment methodologies are applicable to wetlands;

■ Develop techniques to differentiate between naturally occurring biological changes and those resulting from anthropogenic or cultural influences.

Why needed. Water monitoring and research programs frequently ignore biological parameters because they are more difficult and costly to measure than are chemical parameters and because the expertise needed to interpret the results is unavailable. Efforts to develop techniques that can be readily applied in aquatic studies, to evaluate recently developed procedures, and to educate those conducting such studies should help to increase the use of biological monitoring techniques in water quality management. The ecoregion concept is widely used to develop regionally-specific criteria for water quality and regional expectations of attainable water quality conditions, but the current approach is crude and not always an appropriately designed tool for generalizing information to unmonitored sites.

Time and space. Improving our capability to adequately conduct biological studies and accurately interpret the results will be of benefit statewide. Beginning such an endeavor is an immediate need.

RESEARCH AREA 8 RIVER PROTECTION AND MANAGEMENT

Research needs.

Minnesota River. Although there is a concerted research effort underway on many aspects of the Minnesota River through the Minnesota River Assessment Project (MNRAP), there remain many components of this system yet to be explored. Further studies would be useful to:

- Document and quantify the various sources of pollutants to the river;

- Determine the best mix of control alternatives available to reduce water quality problems;

- Identify the manner in which pollutants from the upper portion of the watershed affect water quality in the lower portion; in particular, the role that sediment oxygen demand (SOD) plays in the overall pollutant balance of the lower reaches needs to be determined;

- Document the effects of short-term, highly concentrated toxic runoff from rainfall and snowmelt events on the biotic community of the river; and

- Develop efficient modeling techniques by which the simulated water quality of tributaries can be used as input to river models to portray the impact of irregularly occurring nonpoint source pollution inputs.

Mississippi River. The drought of the late 1980s and the large oil spill near Grand Rapids in the winter of 1990-91 dramatically illustrated the vulnerability of the Mississippi River to both quantity (availability) and water quality problems. Research is needed to:

- Develop flow and contaminant dispersal models for the river;

- evaluate the most effective methods for detecting a contamination event and alerting downstream water users;

- Assess the risk of various industrial/commercial/transportation activities relative to the introduction of contamination to the river; and

- Define the institutional problems that have to be overcome to protect the river and devise an emergency alert plan.

Other Rivers and Riverine Impoundments.

- Need that is related to the efforts on the Minnesota River but extends to most rivers in the state is further exploration of streambank erosion processes. Impacts of subsequent sedimentation and the effectiveness of management practices to address the problem need to be evaluated.

■ An assessment of the way that release of water from storage reservoirs is coordinated should be undertaken and alternative strategies that consider external impacts should be developed.

■ The 1979 DNR study on dams needs to be updated.

Why needed. The Minnesota River has been characterized as one of the state's worst rivers with respect to water quality. The river serves as a means of transport for pollutants from both agricultural and urban areas. Ongoing efforts are attempting to document the complexities of this river system, but no single program will be able to address all concerns. There remain research needs that should be addressed to enhance ongoing activities. Some of the research items could leverage funds from larger-scale research efforts.

Users of Mississippi River include nearly one million people who rely on it for drinking water, a series of large power producing facilities that rely on it for a clean source of cooling water, and navigation interests who move commodities over its surface. All of these users need to know when the potential exists for a disruptive contamination event.

Some strategies for release of water from impoundments (especially those used for hydropower) may needlessly damage downstream riparian users. Not all Minnesota dams have operations plans. The last study of dams in the state is now more than 12 years old, and we don't know whether its information is still valid for management or how functional or safe all dams are.

Time and space. The Minnesota River flows through a large portion of central and southern Minnesota. Any program to improve its quality would yield direct benefits to a substantial fraction of the state's population. Many of the research needs described for the Minnesota River would likely be transferrable to other rivers in the state. Research on the nature of the non-point/point relationships in the river basin would be beneficial to other pollution control situations in the state, as would the results of related projects looking at best management practices (BMPs) and institutions. Solutions to the problems occurring on the Minnesota River will not come quickly, but research must continue if we hope to eventually reduce one of Minnesota's biggest pollution problems. The temporal scale of research needs on the Mississippi River is immediate and short-term. The application is specific to this river, but it affects a large segment of Minnesota's population.

Fate and Reduction of Environmental Pollutants

POLLUTION REACHES ground and surface water from a variety of sources, and for convenience they generally are grouped into point and nonpoint source categories. Point sources are direct discharges to lakes and streams via pipes or ditches. These discharges typically are from municipal sewage treatment systems and industrial or commercial operations. Much effort has been focused on controlling point source pollution during the last 20 years through state and federal regulations to require permits for such sources and a grant program to cover much of the cost of improving municipal sewage treatment plants.

Nonpoint source (NPS) pollution is often referred to as polluted runoff. The sources are the land-use or land-management activities that allow contaminated water to run off the surface of the ground, percolate into ground water, or seep from underground into surface water. The Council on Environmental Quality has estimated that pollution from nonpoint sources, such as feedlots, landfills, and agriculture, is five to six times the pollution load from municipal and industrial point sources.

Additional research is needed on both point and nonpoint sources of pollution entering Minnesota's surface waters and ground water aquifers. The growing recognition that nonpoint source runoff from urban and agricultural areas must be controlled has led to a need for better information on the design and effectiveness of "best management practices" or BMPs. Solutions to nonpoint source pollution problems involve a myriad of potential management practices that can be used in a "best" mix. To determine which practices should be used, we need much better information on the effectiveness of each to perform a desired function. Without this information, we will continue to hear claims that pollution is being handled by so-called BMPs that might not even be appropriate for the application of concern. Transfer of findings from BMP research is particularly timely as programs such as MNRAP and local water planners begin to look for solutions to nonpoint pollution problems.

One of the biggest problems with past BMP research is that the studies have been short-term. In many cases, we have an idea of short-term effectiveness, but we really do not know if this continues for more than a year or two. BMP research needs to extend into a long-term mode so that we can learn the reliability of the facilities we are building and practices we are recommending. The results of appropriately designed research should be applicable statewide.

Research Area 1
Urban Runoff and Infiltration

Research needs. Relatively few studies have been conducted to quantify loads of nutrients, heavy metals and pesticides in stormwater runoff from towns and cities in Minnesota and to determine the effect of land-use and terrain factors on such loads. Research is needed to better define the relative importance of residential and commercial developments, extent of impervious land surface, various drainage practices and soil type on contaminant export in urban runoff. The environmental and human health impacts of urban runoff to surface waters and ground water resources need to be evaluated. Effects on human health and the urban environment from the use of fertilizers, pesticides and other toxic substances need to be quantified.

Research is needed to:

- Quantify the phosphorus and nitrogen loadings in urban runoff, locate sources and determine the impact each has on receiving surface water and ground water;

- Quantify the amounts of pesticides, and other toxic substances such as heavy metals, in runoff in urban areas, determine sources, and measure the impact on receiving waters;

- Determine the amount of chloride used as a road de-icing agent in urban areas and the impact it has;

- Examine soil erosion, suspended and dissolved solids, BOD, and sediment oxygen demand (SOD) in urban runoff to determine environmental effects;

- Establish demonstration sites consisting of small, instrumented urban watersheds to study landscape-runoff relationships and to investigate the effects of various landscape conditions and agricultural practices on the movement of chemicals in urban landscapes and watersheds;

- Evaluate the effectiveness of retention ponds for urban runoff;

- Develop urban facilities to better handle runoff from snowmelt;

- Develop design criteria for small-scale systems to treat runoff from fully developed urban areas, which eventually will come under EPA permit requirements;

- Evaluate the use of regional treatment facilities to avoid a proliferation of small, poorly maintained sites throughout a watershed;

- Analyze the real effectiveness of combined sewer separation (have we really solved any problems, or have we created more?);

- Determine the fate and disposal of contaminants that are trapped in BMP facilities (such as retention ponds); and

- Develop and evaluate best management practices for residential, municipal, and industrial sources of contaminants, including landfills, land disposal systems, deep injection/burial of wastes, and treatment of wastes at point of origin, to prevent the degradation of ground water quality.

Why needed. In spite of the large expenditures of public and private funds over the past two decades to clean up the state's surface waters, it is apparent that the task is far from finished. In large part, this is because control efforts and expenditures for treatment facilities have been focused on point sources of pollution. Both the quality and quantity of runoff in urban areas and their impact on receiving waters need to be defined better so that the proper level of control and treatment can be determined. The short- and long-term effectiveness of BMPs used to control and treat urban runoff needs to be examined; this will be achieved most efficiently by establishing a few long-term research/demonstration sites. If we are going to prevent adverse environmental and health impacts from urban runoff and infiltration, we need to do the research to understand the problem and its potential solutions.

Time and space. The need to begin work on the priorities listed above is immediate. Some monitoring has been done in the Twin Cities area, but this needs to be expanded to other urban areas in the state. Research projects need to be long-term to include varying climatic conditions and land-use practices and to evaluate the long-term effectiveness of proposed treatment techniques.

RESEARCH AREA 2
AGRICULTURAL RUNOFF AND INFILTRATION

Research needs.

Pesticides. Although significant research on the origin, fate, and transport of pesticides from *normal* field application is underway, research on the fate and transport of pesticides from *accidental and incidental* spills has not been conducted in Minnesota or nationally. Research should focus on environmental impact and cost containment issues regarding both normal agricultural use and spill cleanup. New technology needs to be developed and existing technology modified to control agricultural weeds without adversely affecting the environment. Such methods as competitive crops, allelopathy, and biological control should be studied. Specific research recommendations related to pesticides include:

- Determining the frequency of spills at agricultural pesticide mixing and loading sites and investigate their environmental impact;

- Determining climatic interactions between precipitation events, infiltration, and timing of chemical application;

- Investigating the bioavailability and long-term environmental implications of herbicide residues bound in soil;

- Developing and testing alternative weed management systems to reduce herbicide use, control soil erosion, and reduce losses caused by weeds in agronomic crops;

- Evaluating the interactions between crop and weed population dynamics;

- Determining degradation mechanisms and leaching rates of new low-rate herbicide chemicals;

- Developing ditches that actually treat runoff rather than simply transmit it (for example, conduct research on various cross-sectional configurations, vegetation, effects of meanders, detention time, berms, aeration);

- Establishing demonstration sites consisting of small, instrumented watersheds to study landscape-runoff relationships and to investigate the effects of various landscape conditions and agricultural practices on the movement of chemicals in rural landscapes and watersheds; and

- Developing and evaluating management practices to prevent ground water contamination from agricultural sources, including tillage and cropping practices, drainage and irrigation management, and chemical management.

Nutrients. Nutrient management needs to be evaluated. The impact and evaluation of nutrient BMPs on surface and ground water need to be quantified. Little research has been directed toward the impact of manure and legume nitrogen on nitrate concentrations in ground water. Specific research topics related to nutrients include:

- Establishing a systems approach to develop BMPs as combinations of practices to minimize the impact on surface and ground water, including large plot evaluation of irrigation practices on coarse-textured irrigated soils;

- Evaluating contributions of manure and other organic sources of nitrogen to the total nitrogen pool;

- Developing manure management plans based on soil, manure, and crop types and evaluate their effectiveness in managing nitrogen and phosphorus;

- Investigating contributions of legumes to the total amount of available nitrogen;

■ Evaluating use of cover crops to minimize nitrate movement;

■ Determining the effect of tile drains on nitrogen movement through soil profiles;

■ Evaluating new technologies that allow more precise fertilizer nitrogen applications on a soil by soil basis;

■ Continuing investigations to establish a nitrogen soil test that can be used in more humid areas in Minnesota; and

■ Determining the factors affecting denitrification rates within ground water aquifers and the significance of this potential sink for nitrate in sensitive aquifers.

Why needed. Agriculture is the largest nonpoint source of pollutant loadings to surface water and ground water. There has been virtually no research on the transport and fate of pesticides introduced to the environment near drinking wells as a result of either normal loading and handling practices or accidental spills. These could be large contributors to the degradation of ground water quality in small but significant areas.

The 1991 nitrogen report, prepared by the Department of Agriculture and Pollution Control Agency in response to a legislative mandate in the 1989 ground water bill, indicates that nitrogen reaches surface water and ground water from many sources. The contributions of agricultural practices to the "nitrogen problem" should be defined in further research. Elevated nitrate levels in drinking water supplies of some rural areas have been well documented. To reduce these levels will require an approach that accounts for all the nitrogen contributed to agricultural systems. This ultimately will result in lower contributions of nitrogen to the environment. Better ways to manage and use nutrients and pesticides in agriculture should be developed and demonstrated, both as a cost savings to farmers and to promote good environmental practices.

Alternative solutions to weed control besides mechanical cultivation and chemical control need to be established. Cultivation has resulted in soil erosion, and chemical control has resulted in contamination of natural waters. Biological forms of weed control that reduce soil erosion and movement of contaminants into receiving waters are under development; these methods need to be evaluated for efficacy and possible harmful effects before they are adopted by agricultural producers.

Time and space. These research needs affect large areas of the state. BMPs have been proposed to reduce nitrate loadings from agricultural areas, but undocumented assumptions have been made about their effectiveness in reducing surface water and ground water degradation. If producers are to be encouraged to adopt these practices, their effectiveness must be documented. The time frame required to make these assessments is 3-5 years (3-10 years for weed control research). The research should be conducted in sensitive ground water areas and high impact surface water areas first.

Research Area 3 Atmospheric Sources of Contaminants

Research needs. The contributions of atmospheric contaminants to Minnesota's surface waters need to be better quantified, and the importance of these contributions to ecosystem health needs to be determined. Pesticides, PAHs, PCBs, nitrogen forms, and mercury are pollutants of special concern in this regard. Specific topics in need of study include:

■ The relative contributions of atmospherically transported contaminants to total entering a lake determined as a function of lake size or watershed/lake area and geographic location in the state.

- Attribution studies to determine the nature of the emission sources for atmospherically-transported contaminants, in particular the importance of in-state vs. out-of-state sources and of incinerators, stack emissions, pesticide application practices, wind-blown soil particles, and volatilization of chemicals from the land surface;

- The extent to which atmospherically derived contaminants are causing ecological damage in Minnesota lakes;

- The significance of atmospherically derived nitrate and ammonium in contributing to eutrophication problems of in-land lakes;

- The mechanisms whereby contaminants move through aquatic food webs into game fish, and in-lake factors that affect contaminant accumulation by fish;

- Cost-effective and environmentally safe methods to restore lake ecosystems that have been contaminated by atmospherically-transported chemicals.

Why needed. Recent studies have shown that atmospheric transport is responsible for widespread contamination of otherwise pristine lakes in Minnesota. However, the dimensions of this issue are poorly defined, especially for organic contaminants. In the case of mercury contamination, we know that the problem is widespread and potentially serious in northeastern Minnesota. However, we lack information on its extent in other parts of the state, on the in-lake factors that promote the accumulation of mercury in fish, and on feasible control and remediation strategies. In order to decide what regulatory, management, and remediation steps may be needed, if any, regarding airborne contaminants, research on the topics listed above is needed.

Time and space. Because of the high variability associated with climatic patterns in the state, studies need to extend over several years and need to examine a variety of lake sites throughout the geographic confines of the state.

RESEARCH AREA 4 TREATMENT AND DISCHARGE OF WASTEWATER

Research needs. The effects of certain types of pollutants in the discharges from municipal and industrial wastewater treatment facilities need additional research. In particular, the impact of toxic substances in effluents on the ecological health of receiving water bodies need to be evaluated. Additional work also needs to be done on the impact of individual sewage treatment systems on surface and ground water. Research is needed on the impact of trace-level contaminants and multiple contaminants in discharges on surface and ground water, and on their treatment and removal from the waste stream. Specific recommendations for further research include:

- Determining effectiveness of existing technologies in removing toxic substances;

- Developing new technology for the separation and removal of toxic substances from waste streams;

- Determining the economics of removing and recycling toxic substances from waste streams;

- Investigating the formation of additional toxic compounds in waste streams as a result of chemical and biological treatment processes.

Why needed. With the passage of the Clean Water Act in 1972, substantial amounts of federal funding were made available to build or upgrade municipal wastewater treatment facilities throughout the state. The Act also required industries to meet permitted effluent limits. Over 90 percent of the major cities and industries that discharge pollutants in the state are in compliance with their permit conditions. This means that conventional pollutants (e.g., suspended solids, oxygen-demanding organic matter, microorganisms) in municipal wastewater are treated and controlled before discharge to receiving waters. Analytical methods that can detect synthetic organic compounds at very low levels have led to new concerns. A variety of toxic and potentially toxic compounds have been discovered in both municipal and industrial waste streams. Because many of these compounds bioaccumulate in aquatic food chains, it is important to control and eliminate them from waste streams.

Almost one-fourth of Minnesota's population relies on individual treatment systems to treat household wastewater. In addition, most seasonal lake residences rely on this technology. These systems can be sources of contamination to both ground and surface waters (especially lakes). In addition, many small communities cannot afford technically complicated treatment systems. Oxidation ponds and other simple systems similar to those used for individual household wastewater treatment are used in such communities. The effectiveness of these technologies in removing toxic materials needs to be evaluated.

Time and space. This is a statewide problem that will require several years to complete. In some cases, it may be necessary to eliminate a substance from manufacturing processes to achieve its elimination from receiving waters. Areas with large concentrations of individual treatment systems (e.g. lakes with recreational homes) are priority areas for research on these systems.

Integrated Water Management

INTRODUCTION

INTEGRATED WATER MANAGEMENT recognizes the interconnections of physical resources and the human agencies that use, manage, and control components of the hydrologic cycle. Coordination among management agencies is needed to eliminate conflicts that result from decisions focused on part of a linked system. Efforts to integrate water management must acknowledge that big solutions do not exist, and success will come from many well-coordinated small solutions.

The objective of water managers must be to optimize resource attributes and benefits without diminishing the resource, i.e. maintain a sustainable resource. To implement the objective of resource sustainability, we must examine the feedback links among various water resource components under the full range of possible futures. Climate change and resource contamination are foremost among the uncertain futures. Sustainable management requires highly informed management agencies. The agencies need information about the magnitude and geographic pattern of resources and demand, about linkages among the resources, and about the sustainable capacities under changes in climate, land use, population, technology, and legal structures and regulations. Research must be focused to provide this information.

The variability of water resources in Minnesota may necessitate plans for adjusting water demands to safeguard resources for future needs. Such plans must provide a basis for prioritizing and scheduling demands. The adequacy of such plans depends on the adequacy of information about the resource and demands on it. Although we have much of this information for current conditions, we know little about sustainable capacities under changed conditions.

Definition of sustainability rests on how much we know about the anatomy of the hydrologic cycle at all places and times. To manage for the future, we must use tools that answer "what if" questions about an integrated system. We should start by asking the following questions about limits on our ability to perform the needed analyses. What are the limits on our resource data? Is there adequate data management to deal with the bulk of data and modeling demands? In what way are current modeling technologies limiting? What level of analysis now exists? How will the results of analyses be implemented? Taking stock of these limits gets at what we need to know and when we need to know it. Some tasks can be attacked in parallel, but some must logically precede others.

The state's goals of sustainability of quality and availability, as stated in the Minnesota Water Plan (MEQB 1991), focused the committee's attention on management that recognizes: the current and desired states of the resource; the connectivity of the hydrologic cycle; the geographic and temporal variability of the resource; and the need for integrated management of this complex resource — because overall solutions have to be derived from coordination of many small solutions. The committee addressed research and information needs in five areas relative to integrated water management issues:

- Water availability and conservation;
- Socioeconomic and legal issues in water rights and water policy;
- Analysis of trends in water availability, use and quality;
- Barriers to defining and managing sustainability; and
- Geographic Information System (GIS) and data base integration

Concern 1
Water Availability: Status of the State's Aquatic Resources

For an adequate understanding of water availability in the state, we need data on all components of the hydrologic cycle. The ability to make proper decisions in allocating the state's water resources rests upon the availability of such information. Decisions that over-allocate existing resources (because information on water availability is inaccurate or inadequate) may diminish the gains on economic investments and/or rob future generations of their rightful inheritance. Prediction of water supply availability under future climatic conditions will involve models and analyses that start with this information as a base. Collection of basic hydrologic data is not research, but many kinds of research studies depend on the availability of basic hydrologic data. Delineation of specific data needs regarding the physical attributes of Minnesota's water resources is beyond the scope of this document, but the committee noted that the state is not as "data-rich" as is commonly believed. Additonal monitoring information is desirable on nearly all components of the hydrologic cycle, including both supply and demand variable. In many specific cases, the current status of data availability hinders effective management decisions.

Concern 2
Socioeconomic and Legal Issues in Water Rights and Policy

The physical availability of water resources is a primary factor limiting its use in some cases, but social and institutional settings limit the access individuals have to the resource. These limits are neither well understood nor resolved for the entire state. Numerous information and research needs can be identified for each social and institutional issue listed below. Examples are included with each issue, but the list is not exhaustive.

Legal Issues

- Resolution of Native American water rights.

Research needs. Legal analysis of relevant treaties, federal and state laws, and legal precedents; comparative review of issues in neighboring states; economic analysis of benefits and costs of potential resolutions of water rights issues.

Why needed. To avoid misdirected capital investments and costly lawsuits.

- Implications of importing water for municipal supplies in western Minnesota.

Research needs. Impact on environment and institutional structures

Why needed. Import of water is recognition of water as an article of commerce. This opens the door to radical changes in the way we view water rights in the state.

Economic Issues

Research needs. The costs of maintaining water quality and adequate supplies generally are thought to be far lower than the costs of cleaning contaminated water, if that is even possible, and the economic losses (foregone benefits) of inadequate supplies. However, recent studies have produced large estimates for the total national cost of environmental protection (of which protection of water quality is just one facet), and decision makers are continually faced with difficult questions regarding the optimal use of limited financial resources to maintain or enhance environmental quality. We need to define the costs of clean and adequate water resources, determine who pays for them, and quantify their benefits to society in terms of quality-of-life, human health, and economic well-being. The findings of such studies need to be communicated effectively to decision makers and the general public. Research recommendations include:

■ Quantifying water quality improvement benefits.

Why needed. This would make improvement costs more acceptable to the public and would help prioritize competing options.

■ Improved assessment of the economic and non-economic value of "water in place" (e.g. instream flow values) that includes its buffer stock value.

Why needed. Irrational water valuation will happen in the absence of a systematic effort to consider all costs and values.

■ Cost of managing and controlling farm use of nitrate and other chemicals, and the transaction costs of alternative control strategies.

Why needed. Such information will diminish inaction or incorrect actions that result from uncertainty.

■ Development of a liability assignment procedure for disasters that affect water quality. (Who pays what economic cost and how do we compute environmental costs and lost opportunities.)

Why needed. Externalizing such costs is contrary to the basis of sustainable resource management.

■ Identifying basis for sustainable agriculture in economic and environmental terms.

Why needed. We need to show tradeoffs in water resource availability and quality as a basis for decisions about agricultural resource management.

■ Developing contingency plans for water availability problems.

Why needed. To minimize the impact of shortfalls on economic conditions of individuals and the state, as well as the health and welfare of individuals in areas experiencing shortfalls.

Educational Issues

Research Needs. There is still a lack of public understanding of the unity of the hydrologic cycle, and in particular the role of wetlands and ground water in the cycle. We need to evaluate the effectiveness of our efforts to educate the public and policy makers on resource issues with which they must deal. Recommended topics for this area include:

■ Define the role of wetlands in the hydrologic cycle and educate the public and elected officials about their role.

Why needed. Because wetland preservation has become an emotional issue and as a result the scientific basis for their protection has become removed from the context of their environmental and economic values and functions.

■ Water conservation and prioritization of aquifer use.

Why needed. Use of high quality water to meet demands that low quality water can satisfy increases treatment costs and may result in shortage of high-quality ground water.

Time and space. These needs are statewide, long-term and immediate.

CONCERN 3
TREND ANALYSIS

Research needs. Keeping track of where we are with respect to water availability, quality, and demand requires that we collect, maintain, and *analyze* adequate data on climate, streamflow, ground water, water quality, land management, and water demand. Long-term monitoring of all hydrologic cycle components is needed. A comprehensive long-term monitoring program to assess the status of the state's water resources and temporal trends in water availability and quality needs to be designed and developed. Technical issues that need research before such a program can be implemented include:

- Spatial resolution and sampling frequency needed to detect trends at specified levels of sensitivity;
- Evaluation of parameters useful to determine biological integrity of surface waters;
- Compatibility of existing monitoring programs with new program (how to design program to take maximum advantage of historical and current data for trend analyses without compromising design relative to goals and criteria of new program);
- Usefulness of remote sensing techniques in long-term water resource monitoring.

Why needed. We need trend monitoring to provide benchmark data sets to evaluate our water resource management programs, to assess the impact humans have on resources, and to evaluate modeling and analytical procedures. We need to know the behavior of all resources that we use and manage to make sure that they are maintained as assets for future generations and not transferred to them as yet another debt.

Time and Space. Analysis of time trends in water resources requires maintenance of benchmark stations through long periods of time and for a wide range of localities, but the research needs identified above for design of a more comprehensive monitoring program could be completed in a two- to three-year effort.

Concern 4
Barriers to Defining and Managing Sustainability

There are three classes of barriers to managing water resources for sustainability:

- The complexities posed by the hydrologic cycle in time and space;
- The complexities of user activities and rights and the institutional structures that manage and regulate individual decisions; and
- Complexities of the available data and analytical tools.

Taken together, these complexities pose a formidable barrier to rational and truly integrated water management. We need to think carefully about how they work and interact in various settings and time-frames within Minnesota. Indeed, defining and managing our water resources for sustainability requires that we consider conditions beyond the collective ranges of our experience. Changes in population, technology, development patterns, and climate, will induce changes in water supply and demand that may be beyond our ability to project from retrospective trend analysis.

Simulation models are a major tool used to perform the necessary analyses, but their productive use depends on several limiting factors. We need research to unravel these limitations and expose the barriers described above. In particular, we need to:

- Define the barriers to implementation of integrated water resources simulation models and then develop or adapt such models;
- Evaluate the degree to which earlier analyses of segments of the hydrologic cycle for the state's water resources are valid or limiting; and

■ Examine the social and institutional barriers to integrated water management and the way they define responsibilities and implementation strategies.

The research approach most likely to be successful in resolving these issues would involve a pilot study area.

Limits on Modeling Technologies. For practical reasons, including the availability of data and a mismatch between the complexity of the problems and computational capacity, modelers historically segmented the hydrologic cycle. They developed separate models for open channel flow, rainfall-runoff relations, flow through porous media, evapotranspiration, crop water use, etc. Eventually they included more processes as computational techniques and our understanding of the mathematics of these processes improved. Flow-routing models eventually emerged, as did ground water transport models. Current modeling tools may need refinement, but their deficiencies are eclipsed by the inadequacies of input data. The computational power now exists to model highly complicated problems; computer technology is far ahead of the other components of the modeling process. Existing systems can provide answers to many questions for a region or watershed, but they cannot model the entire state. The spatial and temporal resolution of input data often is a large source of error.

Limits on Analysis. Previous efforts to analyze the state's water resources on a holistic basis provide only crude general picture for single variables at one point in time. There are some detailed studies of segments of the hydrologic system for a few localities over a short period of time, but the implicit assumption in such studies is that other components of the system remain constant. This assumption is tenable only over short time periods.

Limits on implementation of results of analyses. After determining that the results of a particular analysis make scientific sense and are necessary to meet the objective of sustainability, three factors control implementation of the findings:

■ Legal footing — does the best scientific forecast constitute adequate basis for action by the state;

■ Financial ability — can we raise sufficient money to do the task without jeopardizing other important responsibilities;

■ Political willpower — will the prescribed action on behalf of the state as a whole alienate sufficient individual interests to remove the political leadership?

Research need. Only through sustained efforts to fully develop an integrated water management system for small pilot project areas will we be able to achieve true integration.

Why needed. We need a better understanding of barriers to defining and managing sustainability for the state to address the changes needed to meet our objectives in water resource management.

CONCERN 5
GIS AND DATA BASE INTEGRATION

Geographic information systems (GIS) and data base integration barriers have been a concern of the state for over a decade. GIS is only one of several available approaches to data storage and management systems. GIS has more of a role in some water resources applications than in others, and no single data storage system will handle all needs. Some aspects of water management deal with point problems, and others deal with lines and areas. The optimal systems for each are fundamentally different. GIS files are complex and require complete data for dynamic variables such as precipitation. In tabular form these data are mostly non-occurrence for most places at most times. Thus the GIS file structure should be used for some computer modeling but not all.

However, we need to insure that adequate means exist for data exchange among users and suppliers and that data conversions do not introduce significant error.

Research need. Demonstration projects should be undertaken to design and develop model data storage and management systems suitable for holistic analysis of the water management issues in the study areas. This would allow us to define and work through the complexities of data management and institutional structures in areas large enough to allow upward transferability of the findings to the development of a statewide system but small enough to enable researchers to solve problems in a timely and cost-effective manner.

Why needed. We need a better understanding of GIS and data base integration problems because the analyses that are built from data are constrained not only by the structure of individual data bases but also by our inability to link related data bases. Data provide the basis of decisions about law, policy, and management. Better data integration is more important for integrated management than for management of single components of a system. Without it, the best analyses cannot be performed, and we can neither evaluate present data collection procedures nor assess the potential value of proposed data collection. Moreover, agencies cannot coordinate their actions or share data if their data systems are not integrated.

SUMMARY

Because integrated water management attempts to work with the way the hydrologic cycle functions, its implementation requires some fundamental changes in institution links. Thus, we recommend development of one or more integrated water management pilot projects that can evolve into a prototype for a statewide system. Only through the development of such pilot project(s) can we discover the barriers imposed by existing water rights, resource patterns, agency agendas, data limitations, and analytical capabilities.

A major goal of the project would be to define the barriers to integrated water management for sustainability. The pilot project should start with a thorough evaluation of efforts at integrated water management by other states, with a careful assessment of when their findings can be transferred to Minnesota. Its product should lay out a long-term agenda for the Legislature, state agencies, and public education through demonstration projects that articulate the costs and benefits of this approach.