Ecosystem Services
Technical Work Team Report

Minnesota Water Sustainability Framework
January 2011

Team co-chairs
Dave Wright, Monitoring & Control Unit Supervisor
Minnesota Department of Natural Resources Division of Ecological Resources

Lucinda Johnson, Senior Research Associate
Center for Water and the Environment
University of Minnesota, Duluth Natural Resources Research Institute

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A. Key Findings

- Impacts to ecosystem services from human activity vary across Minnesota due to differences in climate, geology, soils, topography, and vegetation.
- Ecosystems are interconnected and complex. In addition, various stressors impact ecosystems in a cumulative and interacting fashion, not all of which are due to humans.
- Because ecosystems are complex and interconnected, and regional differences occur across the state, water resource management and policies need to be tailored to regional and watershed scales rather than be shaped statewide at the site level.
- It is essential to develop and implement a strategic data acquisition and management system that provides knowledge of the condition of aquatic ecosystems, an understanding of how those ecosystems are changing over time, and information for identifying indicators and thresholds for decision-making.
- Investments to protect aquatic ecosystems that provide desired ecosystem services are as important, if not more important, than investments to restore systems where ecosystem services have been significantly diminished.
- Our capacity to engage Minnesotans at any scale in decisions about how land and water users need to modify their practices to help ensure the protection of ecosystem services can be strengthened by increasing their general knowledge of what ecosystem services are and how those services are related to existing or proposed land- and water-use decisions.
- There is an urgent need to improve the methods used to estimate the value of ecosystem services.
- It is important to define the goals in a framework that will guide the design or choice for on-the-ground decisions.

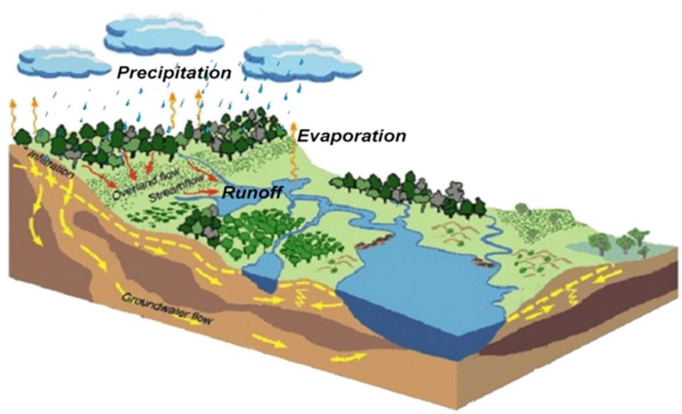
B. Introduction

Minnesotans appreciate and value water for the services it provides, including water for drinking, water for growing crops, and water for recreation. Such services are essential to the Minnesota way of life. What is probably less obvious are the multiple services Minnesotaœs citizens, communities, businesses, and ecosystems derive from the flow of water across and under Minnesotaœs landscape. These ecosystem services can be defined as ñthe conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human lifeò (Daily 1997); alternatively, ecosystem services can be viewed more broadly as simply the resources produced by ecosystems (Ecological Society of America 2000). This latter, broader definition of ecosystem services is the focus of this report.

The water cycle provides a basis for understanding the ecosystem services derived from water (Figure 1). The water cycle illustrates where water is found (e.g., atmosphere, streams, lakes, groundwater) and describes the various processes that move water through the cycle. As water moves through the cycle across Minnesotaôs watersheds, it interacts with and modifies the landscape. Humans are key actors that use and modify the condition of water, the physical landscape, and the plant and animal populations found on the land and in the water. As water moves through the landscape, the chemical composition and physical properties change. In addition, the landscape is often modified by human activities. To understand the ecosystem services provided by water it is necessary to understand these complex interactions.

Ecosystem services provided by water must be viewed with an understanding of how ecosystems function. In the study of biology the concept of a food chain is often used to help convey the concept of how energy, nutrients, or contaminants move through a natural system. However, since natural systems are made up of a myriad of interacting food chains, a food web is a much more accurate visual image of how the system really functions. The same is true in the linkages among individual ecosystem functions and ecosystem services. In real ecosystems, multiple services may depend on a specific function, and a ñwebò is a more realistic depiction of how an ecosystem operates.

Figure 1. Hydrologic cycle



The goal of this report is to identify key issues that must be addressed to progress toward sustainability[1] of services provided by aquatic ecosystems. To achieve this, the ecosystem services technical committee outlined how anthropogenic stressors may alter the function[2] and/or structure[2] of aquatic ecosystems and the ecosystem services they provide. The purpose of this exercise was not to describe all possible interactions or create a decision-making framework but rather to search among the diversity of aquatic ecosystem types and complexity of interactions that occur, for pathways or activities that had primary importance, factors that rose to the rank of being a ñkey issue.ò

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[1] Sustainable water use is when the use does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs.

[2] For the purpose of this exercise ecosystem 'structure' is defined as the biotic and abiotic attributes of ecosystems including community composition and structure, specific habitat features, and the physical and chemical structure of the system (MRAG & UNEP-WCMC, 2007). Ecosystem 'function', on the other hand, refers primarily to the "flow of energy and materials through the biotic and abiotic components of the system" (Diaz & Cabido (2001) in MRAG & UNEP-WCMC (2007) p. 8)

C. Process

To identify the primary issues influencing water sustainability in Minnesota, the co-chairs of the Ecosystem Services Technical Work Team along with project leader and project coordinator developed a list of professionals to participate in a two-day workshop. The participants were chosen to provide technical expertise about the major water body types (e.g., groundwater, streams/rivers, wetlands, lakes), the functions (e.g., food web support, nutrient cycling) associated with them, and the key land-use stressors (e.g., temperature alteration, sedimentation). Water management expertise came from the local, state, tribal, and federal perspective. Appendix A provides the list of participants, their affiliation, and the expertise they provided. Workshop participants were asked to engage in a series of exercises designed to help identify key issues affecting the sustainability of the ecosystem services delivered by aquatic systems in Minnesota. Workshop exercises focused on identifying the underlying ecosystem functions that must be protected or restored, to ensure the delivery of key ecosystem services. The workshop included the following components:

1. Identification of Key Aquatic Ecosystem Types and Functions

Workshop participants used the overarching aquatic ecosystem types, which included rivers and streams, lakes, groundwater, and wetlands, in their discussions for assessing aquatic ecosystem functions and services. The categories used are:

- rivers and streams - headwaters streams (orders 1ï 3) and rivers (larger than order 3)
- lakes - deep (stratified) and shallow
- wetlands - depressional, peatlands, riverine, and lake-fringe
- groundwater - shallow and deep aquifers

Due to the short duration of the workshop, participants were asked to focus discussions on key ecosystem functions and ecosystem services; factors controlling ecosystem structure were not explicitly addressed. For the most part, policies that protect ecosystem functions will also protect ecosystem structure.

2. Identification and Ranking of Stressors on Key Ecosystem Functions and Associated Ecosystem Services

Participants were grouped by ecosystem type expertise and engaged in a small-group process to:

- Identify important human activities and resulting stressors that influence a particular ecosystem function.
- Indicate the direction of the ecosystem response (positive, negative, neutral).
- Assess the confidence of the relationship based on the quality and quantity of supporting scientific data.

To qualitatively evaluate and summarize their discussions, participants identified and ranked the importance of anthropogenic stressors using different cell colors, arrows, and numbers. Appendix B includes a brief description of this exercise and the resulting matrices for each of the ecosystem types.

3. Identification of Services in Relation to Functions

In a follow-up exercise, groups composed of experts from the different ecosystem types were given two to three functions to review. Participants were grouped this way in order to ensure that key interactions between functions and stressors were not missed and to emphasize the interconnections between ecosystem types. During this process, they linked the functions to the services with which they were potentially associated. Members were also asked to indicate whether protection of that function would also protect the associated service. Appendix C includes the tables for each of the functions.

4. Discussion on How Effectively Minnesota's Current System of Policies, Regulations, and Rules Minimize Future Threats to the Sustainability of Minnesota's Water Resources

The workshop concluded with a free-form discussion on key issues and potential strategies *for achieving sustainability in the ecosystem services provided by Minnesota's water resources*. These are included in Appendix D.

D. Case Studies

The central need identified through the small group discussion process was:

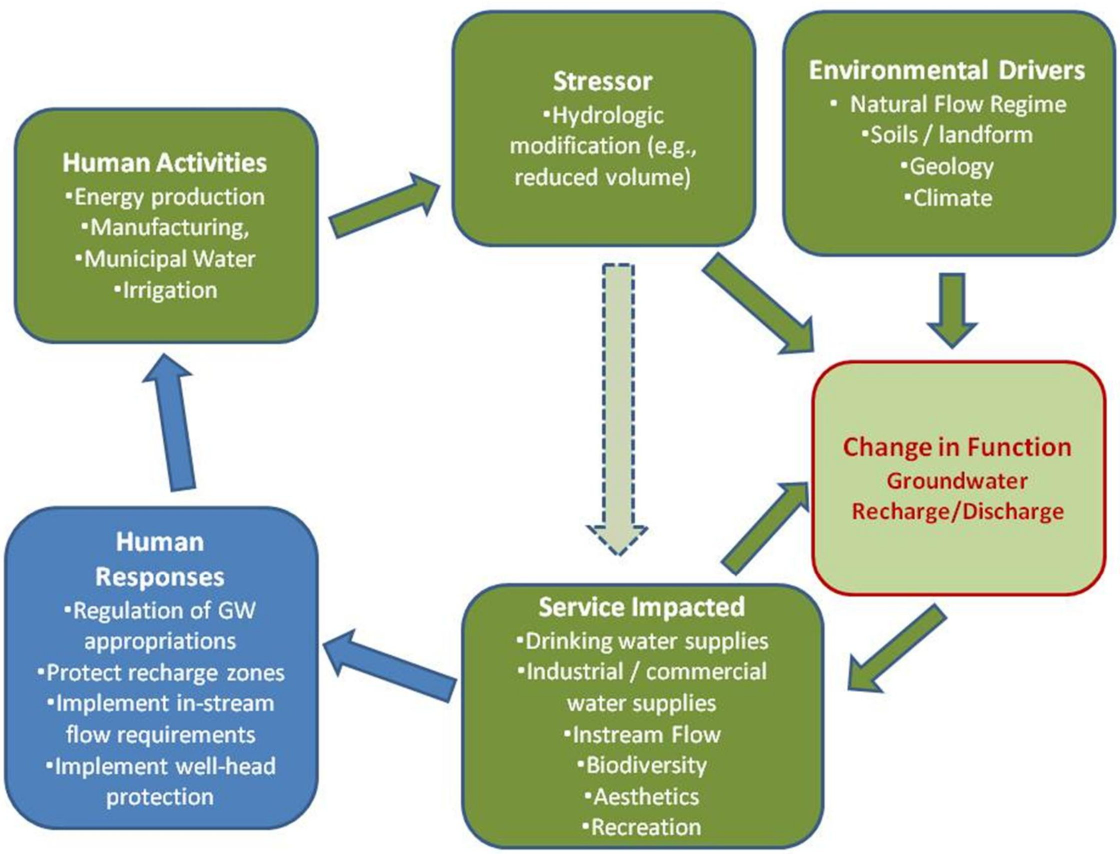
> *To protect key services, it is important to have an understanding of the associated ecosystem types and processes, the primary environmental drivers that regulate the ecosystems, and the human activities and resulting stressors that threaten them.*

Because aquatic systems are highly interconnected (e.g., groundwater discharges to surface water, which in turn recharges groundwater), participants found it difficult to consider threats to functions and services in isolation. In addition, key functions were often associated with multiple services, and were threatened by multiple and cumulative stressors operating at multiple spatial scales. Figures 2 and 3 illustrate the workshop process and its outcomes using flow diagrams for two ecosystem functions, groundwater recharge/discharge and sediment retention, to depict the complexity of choices involved in protecting ecosystem services.

Groundwater recharge and discharge is a function associated with the movement of surface water into the ground and groundwater out of the ground. It is an ecosystem function associated with temporary to permanent ñwet spotsò on the landscape, including lakes, rivers, wetlands, and floodplains. The location and rate of groundwater recharge and discharge is regulated by large-scale processes (occurring over long timeframes) related to climate, geology, and soils, and regional to local scale processes (occurring or regulated over shorter timeframes) including local topography, weather patterns, and vegetation cover (Figure 2, Environmental Drivers box).

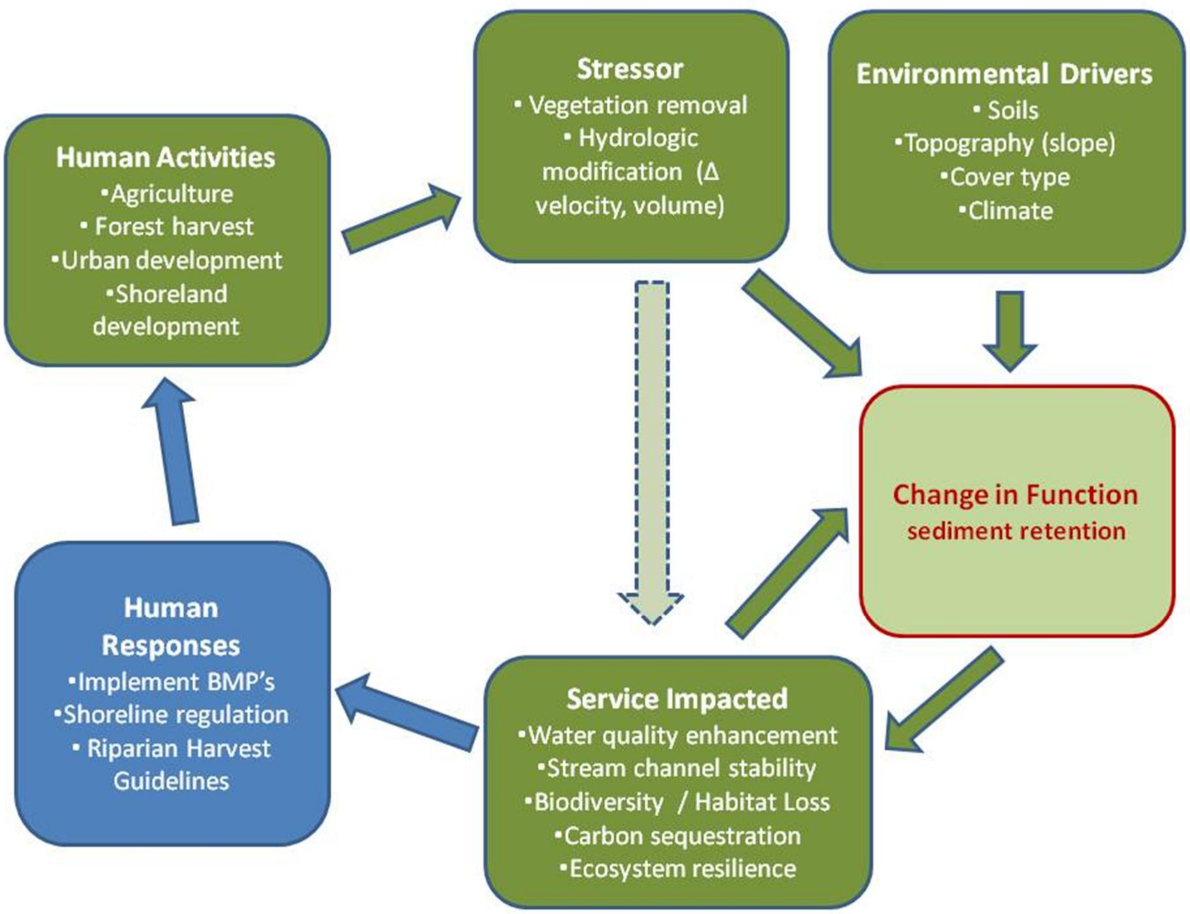
Human activities occurring within a watershed, such as municipal, commercial, or industrial water extraction and crop irrigation from surface or groundwater, can severely impact the amount and location of water available for recharge and/or discharge (Human Activities box). Furthermore, these and other human activities can influence the quality of water that is recharged to the groundwater. Under scenarios of excessive groundwater withdrawal (Stressor box), a reduction in groundwater recharge/discharge may degrade associated ecosystem services such as availability of drinking water or water availability for other uses (e. g., manufacturing, irrigation), as well as the capacity to support sufficient in stream flow or wetland water levels for maintenance of biodiversity, recreation, or aesthetic values (Services Impacted box). Since these services are of value to humans, efforts to protect these ecosystem services would be enhanced by determining protective groundwater or surface water use allocations, quantifying groundwater contributions to instream flow requirements, and developing wellhead protection policies (Figure 2, Human Responses box). Groundwater resources are distributed unevenly across the state, making areas such as southwestern Minnesota vulnerable to the impacts of excessive water withdrawal and reduced groundwater recharge. Such vulnerabilities could be addressed in the development of statewide policies that allow for the consideration of watershed-specific or ground watershed-specific issues.

Figure 2. Groundwater recharge/discharge stressor-function flow



In contrast to groundwater recharge, *sediment retention* is an ecosystem function that is controlled by watershed-scale processes across the landscape. Key features that regulate sediment retention are vegetation cover types, soil types, topography, and climate (Figure 3, Environmental Drivers box). Human activities that are most likely to impact this function are agriculture, silviculture, and urban development, especially in vulnerable areas such as lakeshores, stream corridors, and floodplains (Human Activities box). The key stressors that result from these activities include vegetation removal and hydrologic modifications (e.g. , changes in water volume and velocity) that promote or enhance erosion. Subsequently, ecosystem services such as water quality, stream channel stability, biodiversity, habitat loss, carbon sequestration (in organic sediments), and ecosystem resilience (the ability to recover from disturbance) are degraded. Policy changes that may mitigate such impacts include implementation of best management practices (BMPs), shoreline regulations to prevent vegetation removal, or more stringent riparian harvest guidelines. The sediment retention function is ubiquitous across the state; however, impacts within a watershed may be cumulative, so it may be necessary to address potential threshold effects on a regional scale or within specific landscape types.

Figure 3. Sediment retention stressor-function flow diagram



E. Major Themes

Three key messages emerged from the stressor-function flow diagrams and the resulting themes from the workshop. In addition, the brainstorming session generated a wide range of ideas and strategies (see list in Appendix D); some were extensions of the major themes that emerged from the small group discussion process, while others were new. The eight themes below include the three key messages from the workshop, followed by five themes listed identified by the authors as key issues that should be forwarded for broader discussion.

1. The Impact to Ecosystem Services From Human Activity May Differ Across Minnesota Due to Differences in the Climate, Geology, Soils, Topography, and Vegetation

a. **Geography matters.** There is significant variation in landscapes across Minnesota, and the steps taken to minimize the impacts of human disturbance and protect ecosystem services may need to be fine-tuned to reflect landscape-specific attributes. For example, policy and practices adopted for groundwater withdrawal in the southwest will likely be different than in the northern part of the state since the aquifer systems and surficial geology of the two regions differ.

2. Ecosystems Are Interconnected and Complex. In Addition, Various Stressors Impact Ecosystems in a Cumulative and Interacting Fashion

Efforts to protect ecosystem services need to be built from an understanding of underlying ecosystem processes and should reflect the cumulative impact of multiple stressors. The cumulative table in Appendix B, one of the outcomes of the workshop process, illustrates this point. The table is a qualitative summary of the stressor/functions exercise that the ecosystem services technical team completed. While hydrologic modification is highlighted by all groups in the tables in Appendix B, the cumulative table reflects the diverse group of stressors that impact key functions in aquatic ecosystems. Therefore, to be successful, management practices or protection efforts will need to account for this complexity.

3. Because Ecosystems Are Complex and Interconnected and Regional Differences Across the State are Apparent, Management and Policies Need Be Tailored to Regional and Watershed Scales Rather Than Site-Level Planning That Is Assumed to Work for the Entire State

Planning efforts need to move past thinking about site-specific BMPs that address a single stressor. Tools are needed that address the multiple stressors that impact landscapes in a cumulative way. The watershed-scale models and planning efforts that are proposed as part of the stateœs new clean water initiative are a step in this direction. Likewise, efforts to explicitly link surface water and groundwater use planning reflect this landscape/watershed perspective.

4. It Is Essential to Develop and Implement a Strategic Data Acquisition and Management System That Provides Knowledge of the Condition of Aquatic Ecosystems, an Understanding of How Those Ecosystems Are Changing Over Time, and Information for Identifying Indicators and Thresholds for Decision-Making

The abundance, complexity, and intra- and inter-annual variability of aquatic ecosystems means that decision makers will seldom have the luxury of complete knowledge of how their decisions will impact ecosystem services when decisions need to be made. However, to protect ecosystem services, the assumption cannot be made that ecosystem services will be maintained if BMPs are broadly implemented or the amount of land-use disturbance is maintain below a certain threshold. Our knowledge of how human activities impact aquatic systems and the ecosystem services they provide is incomplete, but we have a very good general understanding of how humans have affected the water cycle. Instead of assuming that a series of actions are not sufficient to cause impact or that certain levels of investment will insure protection, active knowledge acquisition is critical so that key ecosystem attributes can be identified and described (e.g., thresholds/goals defined), changes over time can be tracked, and human actions can be modified to protect and preserve Minnesota's aquatic ecosystems. This monitoring and assessment system should collect strategic information to:

- understand system processes, rates, capacities
- identify current status and trends
- identify indicators and thresholds
- identify restoration endpoints
- define protection action levels
- implement adaptive responses when necessary.

5. Investments to Protect Aquatic Ecosystems That Provide Desired Ecosystem Services Are As Important, If Not More Important, Than Investments to Restore Systems Where Ecosystem Services Have Been Significantly Diminished

We have all heard the proverb about an ounce of prevention being worth more than a pound of cure, but the rationale here is based on more than just the cost. Our ability to make accurate predictions about how the delivery of ecosystem services will be altered by changes in land-use practices or changing climatic conditions is limited. As a result, protecting systems that are currently delivering the desired suite of ecosystem services is a high priority. Investments to maintain the structures and functions that provide valued services are likely to be far less costly than the resources necessary to restore those that have
been lost.

The use of land and water in Minnesota is essential for our state's economic, social, cultural, and ecological health. This means, *we need to provide land and water management policies that meet the variety of economic and social goals critical for*

Minnesota while ensuring the equally critical ecosystem services are provided to enhance quality of life. Because multiple-use goals will be pursued and those uses will modify the quality or availability of water on the landscape, data needs to be collected to reflect our success in meeting multiple goals while simultaneously attaining desired ecosystem services on altered landscapes.

6. ***Our Capacity to Engage Minnesotans at Any Scale in Decisions About How Land and Water Users Need to Modify Their Practices to Help Ensure the Protection of Ecosystem Services Can Be Strengthened by Increasing Their General Knowledge of What Ecosystem Services Are and How Those Services Are Related to Existing or Proposed Land- and Water-Use Decisions***

This topic is complex, and many of the outcomes reflect the dynamic nature of ecological systems. There is significant value in finding ways to clearly articulate desired future conditions that incorporate goals for our ecosystem services. For example, our group pointed to ñno net loss of wetlandsò as such a communication tool and wondered whether ñno net increase in runoffò might be a concept worth considering. Likewise, the concept of ñstream right-of-waysò was offered both for its policy implications and for its communication value.

7. ***There Is an Urgent Need to Improve the Methods Used to Estimate the Value of Ecosystem Services***

The outcome of this exercise may not lead to easier decisions when there are use conflicts, since the outcome of decisions for multiple competing uses is not always to solely pursue the option that has the highest economic value. Understanding the value of ecosystem services being protected or restored will help inform how investment decisions are made, when they are made, or who makes them. They will allow citizens, policy makers, and managers to evaluate trade-offs when use conflicts arise. Protection of ecosystems will be enhanced when Minnesotans understand the relationship between healthy ecosystems and the ecosystem services we receive, and depend upon, for social, economic, or personal benefit.

8. ***It Is Important to Define the Goals in a Framework That Will Guide the Design or Choice for On-the-Ground Decisions***

Existing language in state statute identifies conservation policies that will contribute to the sustainability of ecosystem services (Appendix E - Minnesota Statutes, 103A. 205 and 103A. 206). The report from the policy technical work team addresses this topic more thoroughly. These statutes, however, set broad goals to be attained as the sum of all of our actions on a landscape; they do not identify the minimum thresholds or standards that need to be met as individual land or water management decisions are designed and implemented. Methods are needed that allow us to evaluate the cumulative effects from many individual stressors and the interactions among different types of stressors that can impact ecosystem services. It is critical that we both describe the broad landscape outcomes desired and acknowledge that land and water management for particular locations may need to be modified to attain these desired outcomes. In order to manage water resources holistically (provide a suite of economic, social, and recreational services) while maintaining essential ecosystem services, decision-support tools are needed to inform local decisions. We cannot afford to wait until our knowledge of ecosystem processes and services are fully developed. Protection of ecosystem services involves both understanding how land and water need to be managed to achieve those goals and developing the capacity to work together on all levels (e.g., local, county, watershed, state) to implement those practices on the landscape.

F. Additional Research Needs

Our knowledge of ecosystem services is incomplete and few methods that allow the cumulative impact of multiple stressors on the landscape to be assessed to guide decision making are currently available for use. Minnesota needs to continue to encourage and support research efforts that help develop understanding and enhance decision-making capacity and work to incorporate these new products into demonstration projects as they become available.

G. Resources

Minnesota Dept of Natural Resources, Ecological Classification System, http://www.dnr.state.mn.us/ecs/index.html.

Setting the Course for Improved Water Quality Streamflow, Stream Shape and Connectivity in Watersheds, Minnesota Pollution Control Agency. *A TMDL training program for local government leaders and other water resource managers – Session 5b.*

Minnesota ï Healthy Rivers Water Course, http://files.dnr.state.mn.us/assistance/backyard/healthyrivers/course/home.htm

Forest Encyclopedia Network, Stream Ecosystem Processes, http://www.forestencyclopedia.net/p/p1/p1369/p1446/p1482/p1490

EPA's Regional Vulnerability Assessment (ReVA) program, http://www.epa.gov/ord/sciencenews/scinews_reva.htm

River Continuum Concept. Biological Stream Functions. Eve Brantley. http://www.aces.edu/waterquality/streams/watershed%20academy/presentations/Biological%20Stream%20Functions,%20Rvr%20Continuum.ppt. Alabama Cooperative Extension System.

Maps of Minnesota Water Resources
http://www.dnr.state.mn.us/watershed_tool/data_layers.html

http://gisdmnspl.cr.usgs.gov/cgi-bin/mapserv.exe?map=c:/Program Files/ms4w/Apache/htdocs/watershed/major_basins.map

Key Findings From Recent National Opinion Research on ñEcosystem Servicesò
David Metz, Fairbank, Maslin, Maullin, Metz & Associates
Lori Weigel, Public Opinion Strategies, April 25, 2010

Ecological Society of America, 2000 [defn of ecoservices],Ecosystem Services: A Primer
http://www.actionbioscience.org/environment/esa.html

Balancing Water for Humans and Nature ï The New Approach in Ecohydrology
Malin Falkenmark and Johan Rockstrom. Earthscan, London and Sterling VA, 2004, pg 4 (Gretchen Daly reference to ecoservices, 1997) ISBN 1-85383-927-2

Appendix A. Ecosystem Services Technical Work Team

Name	Expertise	Organization
Rich Axler	Lakes ï deep, Outreach	Natural Resources Research Institute
Kristen Blann	Landscapes, Conservation	The Nature Conservancy
Mark Dittrich	Ag lands	MN Department of Agriculture
Julie Ekman	Water permits	MN Department of Natural Resources (MDNR)
Paul Glaser	Peatlands	University of MN (UMN) - Geology
Mark Hanson	Lakes ï shallow, Wetlands	MDNR
Lucinda Johnson	Watersheds, Rivers	Natural Resources Research Institute
Rebecca Knowles	Tribal lands	Leech Lake Band of Ojibwe
Jan Keough	Wetlands, Ecosystem services	Environmental Protection Agency
Terry Lee	Groundwater/surface water interaction	Olmsted County
Doug Norris	Wetlands, Policy	MDNR Wetland Working Group
Daniel OõShea	Rivers	MDNR
Jim Stark	Landscapes, Hydrology	United States Geological Survey
Tony Sullins	Groundwater dependent species	US Fish and Wildlife Service
Kevin Stroom	Streams ï invertebrates	Minnesota Pollution Control Agency
Deb Swackhamer	Policy, Contaminants	UMN Water Resources Center
Henry VanOffelen	Policy, Wetlands	Minnesota Center for Environmental Advocacy
David Wright	Lakes ï deep, Policy	MDNR

Appendix B. Ranking Matrices for Impacts of Stressors on Aquatic Systems

Note: The cellõs color (red ï high, orange ï moderate, yellow ï low) indicates the importance of that stressor relative to other stressors impacting a structure/function. The arrows indicate the strength and direction (positive, negative, neutral) of impact of a stressor to the structure/function. An ñupò arrow indicates a strong positive impact, an upward diagonal arrow and moderately positive, a horizontal arrow a neutral impact, a down arrow a strongly negative impact, and a ñdownò diagonal arrow a moderate negative impact. The numbers (1 - high, 2 - moderate, 3 - low) next to the arrows are indicative of the level of confidence given to the arrow and color of the cell. The level of confidence is generally based on the quality and quantity of supporting scientific data.

Legend: change in hydrology reflect deviation in patterns compared to the natural flow regime with respect to timing, periodicity, flow duration, and flow volume); NPS = non point source pollution; Light change and temperature change as a stressor reflects changes in the light and temperature regime relative to the natural regime.

<u>Figure 4. Shallow lakes</u>

Shallow Lakes

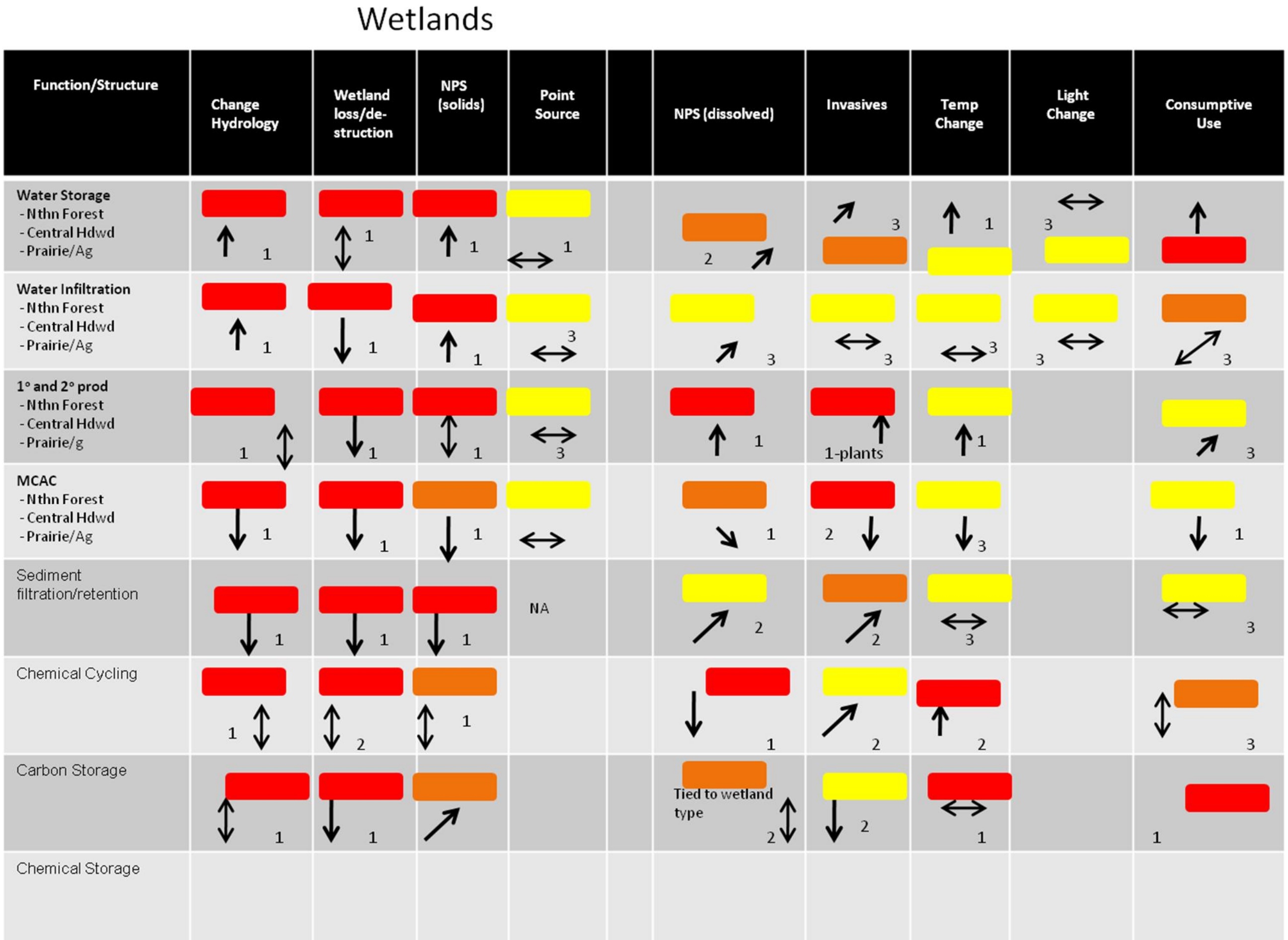
Function/Structure	Change Hydro-logy	Habit at loss	NPS	Point Source	Metals	Solids	Inva-sives	Temp Change	Light Change	Consumptive Use
Food Web Support - Nthn Forest - Central Hdwd - Prairie/Ag	1	1	1	1	1	1	1/3 depends on spp	1	1	3
Connectivity - Nthn Forest - Central Hdwd - Prairie/Ag	1	1						1		
Carbon & Nutrient Storage - Nthn Forest - Central Hdwd - Prairie/Ag	1		1			1		1		1
Provide Thermal Habitat - Nthn Forest - Central Hdwd - Prairie/Ag	1	1	1	1		1		1		1
Water Storage - Nthn Forest - Central Hdwd - Prairie/Ag										

Figure 5. Deep lakes

Deep Lakes

Function/Structure	Change Hydro-logy	Habitat loss	NPS	Point Source	Metals	Solids	Invasives	Temp Change	Light Change	Consumptive Use
Food Web Support - Nthn Forest - Central Hdwd - Prairie/Ag	2 1 1	1	1	1 existing 3 emerging	1	1	1/3 depends on spp	1	1	3
Connectivity - Nthn Forest - Central Hdwd - Prairie/Ag	1	1						1		
Water Storage/Infiltration - Nthn Forest - Central Hdwd - Prairie/Ag	1		1			1		1		1
Provide Thermal Habitat - Nthn Forest - Central Hdwd - Prairie/Ag	1	1	1	1		1		1		1

Figure 6. Wetlands



MCAC= maintenance of characteristic animal communities

Figure 7. Groundwater

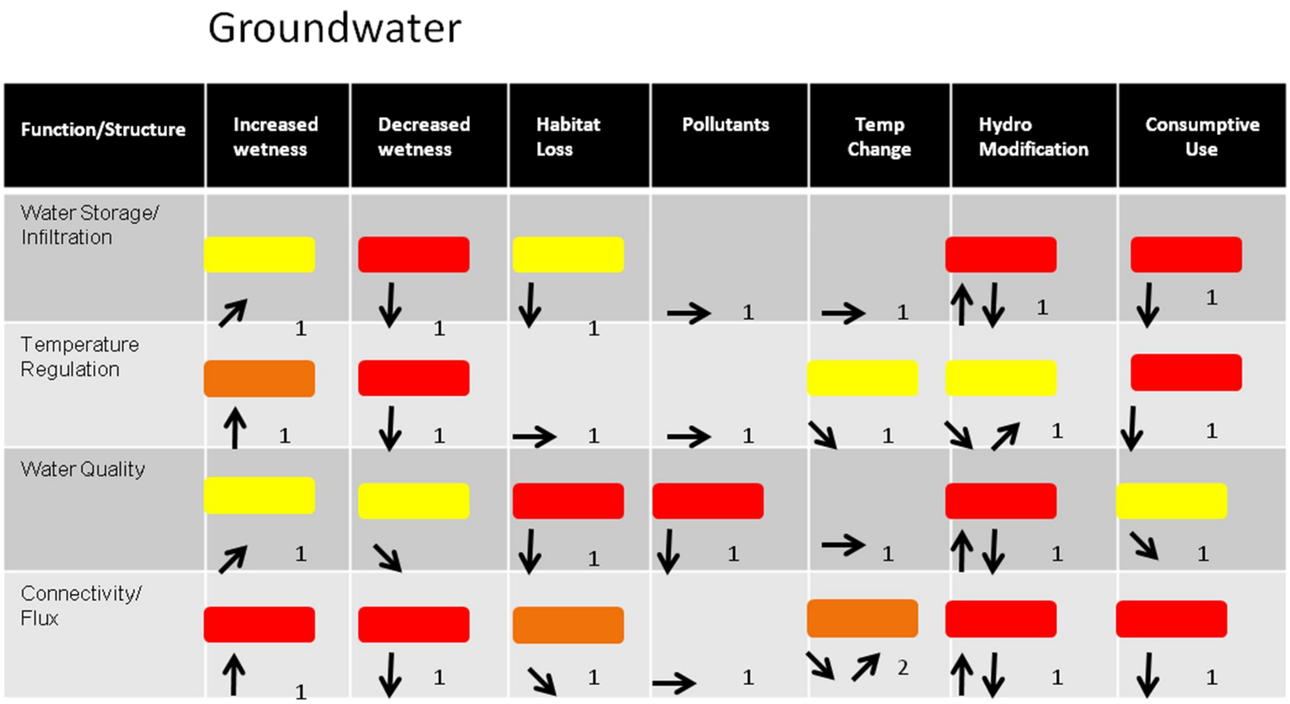


Figure 8. Ecosystem type

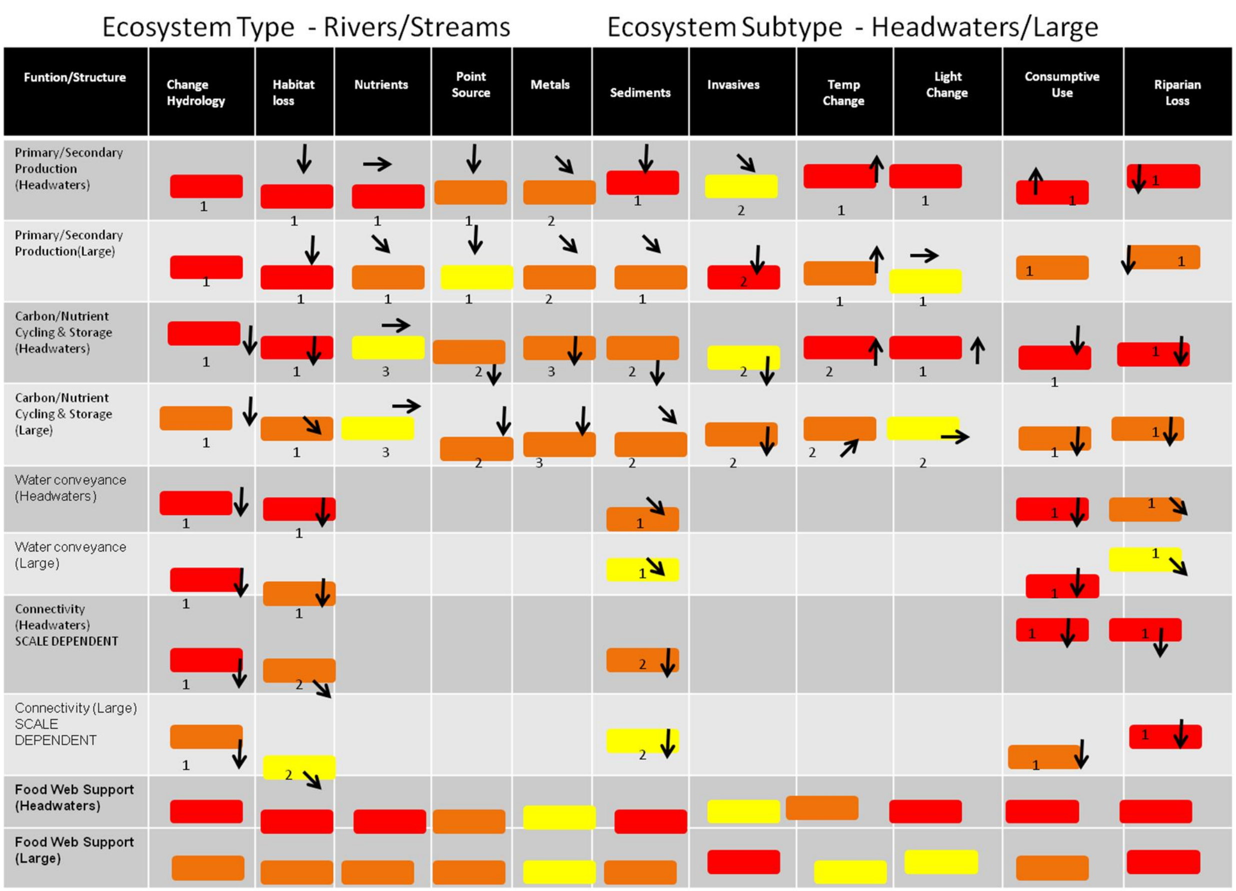


Table 1. Cumulative table - qualitative summary of the findings from all of the tables above

Stressor Function	Change in Hydrology (additional aspects)	Habitat loss	Nonpoint Source Pollution	Point Source	Invasives	Temp Change	Light Change	Consumptive Use	Riparian Loss
Primary/ Secondary Production	X R,W	X R,W	X W, L		X R	X R	X R	X R	X R
Food Web Support (Biodiversity)	X R, L	X R, L	X R	X L	X R	X L	X R,L	X R	X R
Carbon/ Nutrient Cycling & Storage	X W	X R,W	X L	X L		X R,W,L	X R,L	X R,W	X R
Water Storage/ Infiltration	X W,GW	X W	X W			X L		X W,L,GW	
Water conveyance	X R	X R						X R	
Biological/Habitat Connectivity	X R	X L		X L	X L	X L		X R	X R
Thermal Habitat Protection	X L,GW		X L			X L	X L	X GW	
Sediment filtration retention	X W	X W	X W						
Water Quality	X GW	X GW	X GW	X GW					
SW/GW interactions	X GW							X GW	
MCAC	X W	X W			X W				

X ï appeared as a high importance for that stressor on the function (red box)

Letters, R, W, L, GW ï appeared on the tables for rivers, wetlands, lakes, and/or groundwater, respectively

Appendix C. Services and Their Relation to Functions

Function: Biological/Habitat Connectivity

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	no			
Thermal Control	yes	dams riparian management zones	direct	yes
Flood Damage Reduction	no			
Low flow (Hydrologic Regime)	yes	dams ï negative habitat refugia ï positive	direct	yes
Sediment retention	yes	riparian management zone multiple habitat types	direct	yes
Nutrient Retention	yes	riparian management zone multiple habitat types	direct	yes
Water quality protection (for aquatic or human)	yes	riparian management zone multiple habitat types	direct	yes
Micro-climate control	yes	riparian management zone and wetland complexes multiple habitat types	direct	
Cost reduction to Invasive species	yes	riparian management zone multiple habitat types	direct	can have a negative impact on invasive - ??:pathways for invasives

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Biodiversity contributes to resiliency	yes	riparian management zone multiple habitat types	direct	yes
Groundwater Recharge	no			
Recreation	yes	complexes dams both positive and negative	direct	yes
Food Production		landscape diversity multiple habitat types	direct	yes
Commercial Use	yes	dams for energy and water supply navigation ï positive	inverse/+	no
Aesthetics	yes	landscape diversity and multiple habitat types	direct	yes
Drinking Water	yes	riparian management zones, watershed processing (eq/ NYC water supply)	direct	yes
Traditional Resources/uses (wild rice/ spiritual/aquaculture/ cranberries)	yes		direct	yes
Quality of Life (related to essential services, but not the same, beyond essential)				

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Essential services to support life (more tangible)				
Resiliency to climate change	yes	migration corridors	direct	yes

Function: Carbon/Nutrient Cycling and Storage

This function is related to primary/secondary production so the aspects are reviewed twice. COMPARE these answers to primary/secondary production

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	yes	carbon storage is the same as sequestration. Nutrient cycling if too much will decrease carbon sequestration	direct	yes
Thermal Control	yes	in riparian zones, wetlands, peatlands	direct	yes
Flood Damage Reduction	yes	correct amount of plan production (neutral or increasing) changes the roughness coefficient and slows water velocity. varies with flood plain forests for storage? ï direct relation carbon storage in flood plain forests and flood damage benefitted	both	yes
Low flow (Hydrologic Regime)	yes (with a broad defn)	if you maintain vegetation to protect carbon storage and cycling then you are protecting the hydrologic regime. Ex. prairie differ cottonwood is SW MNJ trees suck up a lot of water. Regional differences matter ï human value use overall pitfall is if we define the relationship generally it implies we know specifics and can measure the relationship		
Sediment retention	yes	captures, filtrates, sedimentation	direct	yes
Nutrient Retention	yes	captures, filtration, sedimentation	direct	yes
Water quality protection (for aquatic or human)	yes	complex ï others more discreet related if can affect other chemicals in water (metals). soil processes develop w/ carbon and carbon &s and more biological remediation.	direct	yes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
		ex increased carbon/nutrient the more complete conversion of nitrate/nitrite but quality goes up to a certain level of car/nut cycling then you may reach a point of quality look at bring c/n c&s to and equilibrium		
Micro-climate control	yes	lakes ï relates to water storage, temp control, DO control, flow, humidity control micro ï local ï 1000 to 2000 ft of water vegetation, production of plant material is affected by C/N C&S and that influences microclimate. Ecosystem specific ï SW prairie stream the drier the climate, the more the ???	direct/indirect	yes
Cost reduction to Invasive species	yes	if you overload system you disrupt the system which benefits some invasives ï competition reduced, open space eutrophication favors invasives biodirectional ï if N increases, threatened w invasive, C decreases threat of invasives go up.	direct	yes
Biodiversity contributes to resiliency	yes	same logic as invasives. Contributes to threat of biodiversity. Ex ï marginal zone plants tough to restore if removed the biodiversity goes down. shallow lakes ï submerged plant community structure not well known.	direct	yes
Groundwater Recharge	no ï unless talking about 1000s of yrs and only nutrient part in water level and shallow lakes	the relationship may be generally known but not necessarily scientifically	indirect because root axn is related	yes

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Recreation	yes	fishing is related to water quality. Fish production green water is not good for recreation or swimming. If carbon/nutrient cycling there are benefits to a change in water clarity and nutrients affect recreational services	direct	
Food Production		This is what food production is and trophic status affects aquatic life if too much carbon/nutrients. You grow more fish and can see profound changes in carbon/nutrients with food production.	direct/indirect indirect to wildlife production by fostering cattails • if you want to maximize food production you might change the system from natural state • if you manage for one you see trade-offs	yes
Commercial Use	no ï a stretch	extraction of water for ag, manuf, livestock, energy, transportation is a minor commercial use		
Aesthetics	yes	social parameters will given to push for increased water clarity	direct	absolute
Drinking Water	yes	improved quality, reduced costs if sw quality you are protecting human health protected ï disinfect	direct	yes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Traditional Resources/uses (wild rice/ spiritual/aquaculture/ cranberries)	yes	wild rice is sensitive to a regime of nutrient loading. Maintenance of ecosystem is good relates to aesthetics, recreation, quality of	direct	yes
Quality of Life (related to essential services, but not the same, beyond essential)	yes	access to wild places, green spaces, and attractive water, mental health benefits, clean air. (Clean air ï ANOTHER SERVICE?)	direct	yes
Essential services to support life (more tangible)	yes	need a minimum level of water for life related to low flow, all forms of life, traditional uses, drinking water, food production, human health, plant food production needs, aquatic needs	direct	yes

Function: Food Web Support (Biodiversity)

REDEFINED AS: Maintenance of characteristic biological communities

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	yes	particularly forested wetlands, soils, peatlands	direct	yes
Maintenance of cold water habitat	no ï reverse			
Flood Damage Reduction	yes	floodplain water storage; plants in wetlands lows down water flows; plants in littoral zones maintain natural channels.	indirect	yes - not by itself (i. e. not primary driver)
Low flow (Hydrologic Regime)	yes - reverse	forested wetlands and riparian areas in rivers		yes - not by itself (i. e. not primary driver)
Sediment retention	yes	littoral zone, riparian zone	direct	yes - not by itself (i. e. not primary driver)
Nutrient Retention	yes	littoral zone, riparian zone	direct	yes ï not by itself (i. e. not primary driver)
Water quality protection	yes	littoral zone, riparian zone	direct	yes ï not by itself (i.e.

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
				not primary driver)
Micro-climate control	yes ï interactive, but micro habitats	interdependence of plants - climate	direct	yes ï not by itself (i.e. not primary driver)
Cost reduction to invasive species	yes	healthy ecosystems help prevent exotics from invading and taking hold	direct	yes
Biodiversity contributes to resiliency	yes	healthy ecosystems help prevent exotics from invading and taking hold	direct	yes
Groundwater Recharge	no			
Recreation ï fishing, boating, etc.	yes	healthy ecosystems maintain healthy fisheries	direct	
Food Production (natural sport fishery)	yes	healthy ecosystems maintain healthy fisheries	direct	Yes
Commercial Use (commercial fishery, aquaculture, bait, wild rice)	yes especially fishery	healthy ecosystems maintain healthy fisheries	direct	Yes
Aesthetics (photography, boating, etc.)	yes	Unhealthy ecosystems are not attractive	direct	Yes

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Drinking Water	no			
Traditional Resources/uses (wild rice, fishery)	yes, fishery not wild rice	healthy ecosystems maintain healthy fisheries	direct	yes
Quality of Life	yes		Direct and indirect	Yes, but many more also
Essential services to support life	yes		Direct and indirect	Yes, but many more also

Function: Primary and Secondary Production and Decomposition

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	yes	carbon fixation	direct	yes
Thermal Control (Water of appropriate temperature)	yes	shading groundwater recharge/infiltration	direct	yes
Flood Damage Reduction (storage, damage reduction to infrastructure)	no	water uptake, infiltration slows flow	direct ï minor	yes
Low flow (Natural Hydrologic Regime)	yes	transpiration	direct	yes
Sediment retention		held in place by primary producers, trap sediments	direct	yes
Nutrient Retention/ Assimilation	yes	trap nutrients	direct	yes
Water quality enhancement (includes nutrients, sediments, contaminants)	yes	filters particles and nutrients	direct	yes
Micro-climate control ñatmosphericò	yes (riparian management zone)	shading by riparian area and macrophyte vegetation	direct	yes
Resiliency to Invasive species	no			

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Biodiversity	no	relation varies ï positive to negative		
Groundwater Recharge	yes	uptake reduces recharge, increases infiltration	direct	yes
Recreation	yes	varies positive - fish, ducks negative - weeds	direct	depends
Food Production	yes	fishing, wild rice, etc.	direct	yes
Commercial Use (excludes commercial fishing, manufacturing, transport)	yes	degraded water quality is negative impact on commercial use of water		no
Aesthetics	yes	degraded ï negative natural ï positive	direct	depends
Drinking Water	yes	degraded	direct	depends
Traditional Resources/uses (wild rice/ spiritual/aquaculture/ cranberries)	yes	food, hunting, religion, medicine	direct	yes
Quality of Life (combination of many services)				
Essential services to support life (intro to document)				

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Resiliency to climate change	yes	carbon flow increases	direct	yes

Function: Sediment filtration/retention

NOTE: “Sediment removal” applies only to non-sediment limited system

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	yes	Water clarity; riparian management zone trapping	indirect	depends
Thermal Control	yes	turbidity	direct	yes
Flood Damage Reduction	no	Reduced storage due to wetland filling and decreased conveyance in streams. Not retaining sediment can increase flood if sediment causes flood.	direct ï inverse relationship	depends
Low flow (Hydrologic Regime)	yes	sediment characteristics relates to hydrologic regime	direct	hydrological controls sediment, not other way around
Sediment retention				
Nutrient Retention	yes	trapping and uptake	direct	yes
Water quality protection (for aquatic or human)	yes	water clarity and contaminant removal	direct	yes
Micro-climate control ñatmosphericò	no			
Cost reduction to Invasive species	yes	habitat quality	direct	yes

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Biodiversity contributes to resiliency	yes	habitat quality	direct	yes
Groundwater Recharge	yes	clogging interstitial spaces, decreasing hypothetic ??? flow	direct	no
Recreation	yes	turbidity	direct	yes
Food Production	yes	turbidity	direct	yes
Commercial Use	yes	turbidity	direct	yes
Aesthetics	yes	turbidity	direct	yes
Drinking Water	yes	turbidity, phosphorus, pollutants	direct	yes
Traditional Resources/uses (wild rice/ spiritual/aquaculture/ cranberries)	yes	turbidity, phosphorus, pollutants	direct	yes
Quality of Life (related to essential services, but not the same, beyond essential)				
Essential services to support life (more tangible)				

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Resiliency to climate change	yes (to a point)	through ecosystem degradation	indirect	may be a threshold

Function: Surface Water/Groundwater Interaction

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration (wetlands, peatlands)	yes	changes water level alters balance between carbon storage and carbon decomposition	direct but limited in scope across MN	yes
Thermal Habitat and Micro-climate control (streams)	yes	flow of groundwater impacts temperature, it minimizes temperature variations, less groundwater = more variable temperature	direct	yes
Flood Damage Reduction (didnẗ consider flooded basement from gw)	no			yes
Low flow (Natural Hydrologic Regime)	yes	Infiltration produces recharge	direct	yes
Sediment retention	yes	overland flow occurs when soils become saturated, the relationship between surface water and ground influence how rapidly saturated conditions occur	direct	yes
Nutrient Retention	yes	Because nutrient retention is directly linked to rates of carbon sequestration and because water availability influences microbial processes that impact the types of inorganic nutrient present.	direct	yes
Water quality protection	yes	Example: along Decorah aquifer edge in SE MN ï groundwater discharge leads to improved water quality before water re-infiltrates into the St. Peter aquifer *NOTE: Regional differences include depth of till (influences rate of surface water and groundwater recharge). For example, karst geology has very high recharge rate causing more concern for*	direct	yes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
		water quality impacts. There should be better protection (i. e. , zoning) on recharge areas.		
Micro-climate control (combined with Thermal Habitat)				
Cost reduction to invasive species	no			
Biodiversity contributes to resiliency	yes	Alters hydrology, increases complexity of habitats	direct	yes
Groundwater Recharge (combined with Thermal control)				
Recreation (trout streams)	yes	seasonal hydrograph influences recreational suitability for a variety of recreational uses	direct	yes
Food Production (rivers, aquaculture ï irrigated)	yes	seasonal hydrograph influences food production by altering the availability of water for irrigation and/or the habitat available for aquaculture or rate at which groundwater resources are recharged	direct	yes
Commercial Use (water withdrawal)	yes	surface water/groundwater interactions influence river flow and water availability and the capacity of groundwater to handle pumping demands	direct	yes
Aesthetics (rivers, lakes, wetlands, shallow water edge)	yes	The type and quality of shoreline habitat is dependent on water levels and the seasonal pattern of inundation	indirect	sort of many other factors affect
Drinking Water (wells, sw withdrawal)	yes	As described above, river flow/ groundwater level/recharge rates are dependent on GW/SW interactions	direct	yes

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
		NOTE: Regional differences include depth of till (influences rate of surface water and groundwater recharge). For example, karst geology has very high recharge rate causing more concern for water quality impacts. There should be better protection (i.e., zoning) on recharge areas.		
Traditional Resources/uses (wild rice)	yes	Traditional resource uses often require surface water levels that vary within natural seasonal patterns, groundwater and surface water inputs may generate departures from natural patterns that impact traditional resource status	direct	yes
Quality of Life (see Traditional Resources/uses)			direct (repeats across many surfaces)	yes
Essential services to support life	yes	Drainage, Impervious surfaces, & pumping (surface or groundwater extraction) are key issues that alter seasonal patterns of water availability. Too little or too much water may impact essential services	direct	yes

Function: Thermal Habitat Protection

Note: Considered this for two aquatic ecosystem types, lakes and groundwater – for Lakes, we defined this function as the thermal structure providing habitat maintenance for characteristic flora/fauna; e.g., thermal stratification in lakes that protects cold water fisheries. For groundwater, it is the cooling to surface streams provided by discharge that protects cool water biological communities.

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	no			
Maintenance of cold water habitat	yes ï lakes and gw, not wetlands	surface water ï cold water streams benefit to communities and lakes lakes ï yes	direct	yes ï but requires multiple functions
Flood Damage Reduction	no			
Low flow (Hydrologic Regime)	Yes, through gw flow	at low flows, less water warming rivers and streams	direct	yes, along with other functions
Sediment retention ï wetlands perform this benefit	no			
Nutrient Retention ï wetlands perform this benefit	no			
Water quality protection ï function includes too many parameters?????	yes ï temperatu re as a WQ parameter only	warm water is pollutant to cold water systems	direct	yes

Service	Is the service related to the function ?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Micro-climate control ï fens, bogs, large lakes ï thermal buffering shoreline	yes	temperature ï climatic relationship	direct	yes
Cost reduction to invasive species	yes	cold water systems only	direct maybe?	sort of ï need other protections besides temperature
Biodiversity contributes to resiliency	yes	cold water systems only		
Groundwater Recharge	no	opposite ï no connection		no
Recreation ï fishing	yes	causes problems for angling in cold water systems	indirect	yes ï protect cold water biota
Food Production (aquaculture, natural fisheries)	yes	causes problems for angling in cold water systems	indirect	yes ï protect cold water biota
Commercial Use (commercial fishery, aquaculture, bait, wild rice)	no			
Aesthetics	no			
Drinking Water	no			
Traditional Resources/uses (wild rice, fishery)	yes ï cold water fisheries	causes problems for angling in cold water systems	indirect	yes

Service	Is the service related to the function ?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Quality of Life	no			
Essential services to support life	yes	Specific to cold water systems		yes

Function: Water Conveyance (ability to convey water – mostly streams and rivers)

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	no			
Thermal Control	yes ï under certain circumstances	positive or negative	indirect	yes ï not primary driver
Flood Damage Reduction	yes	works both ways	direct	yes ï can be better or worse
Low flow (Hydrologic Regime)	yes	works both ways	direct	yes ï positive or negative
Sediment retention	yes	affects movements and settling rates	direct	yes
Nutrient Retention	yes		indirect ï based on flushing and sediment retention	yes
Water quality protection	yes	both ways ï waste moved downstream	both	yes
Micro-climate control	no			
Cost reduction to invasive species	yes	loss of riparian area through channelization, if increase connectivity of water bodies can increase vulnerability of invasions of exotics (e. g asian carp and Chicago River)	indirect	yes ï not only function, though
Biodiversity contributes to resiliency	yes	loss of riparian area through channelization, if increase connectivity of water bodies (e. g asian carp and Chicago River)	indirect	yes ï not only function, though
Groundwater Recharge	yes	both increase and decrease recharge, rapids, reservoirs	direct	depends on what direction function applied ï increased

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
				conveyance or decreased ï up or down
Recreation	yes	Can decrease conveyance with dams to create reservoir, increase recreation, but decrease white water rafting/kayaking and negatively impact fishery	direct	yes ï can be both ways ï conflict among recreational users
Food Production (sport fishery)	yes	same	indirect	maybe - (no)
Commercial Use (commercial fishery, aquaculture, wild rice)	yes ï wild rice	.		no ï although maybe finding out natural regionôs more resilient for production
Aesthetics	yes	Can lower or raise lake levels affecting property value and appearance; , structures used to alter conveyance may be unsightly	direct	yes
Drinking Water	yes	Building reservoirs for DW	direct	No ï the impact of maintaining or restoring natural flow would remove DW reservoir capacity
Traditional Resources/uses (wild rice, fishery)	yes ï wild rice	Flow regimes are altered to maximize wild rice production	direct	no ï historically an altered flow regime needed to protect rice production. However. , many tribes are now appreciating that allowing a more natural flow regime makes the rice lakes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
				more resilient for long term production
Quality of Life	yes	Affects recreation and aesthetics, natural resources, etc	Direct and indirect	Yes, but just one of many functions
Essential services to support life	yes	Water conveyance necessary for overall water cycle!	Direct and indirect	Yes, but just one of many functions

Function: Water Storage/Infiltration

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Carbon sequestration (wetlands, peatlands)	yes	high water tables decreases rate of decomposition, increases carbon sequestration rates	direct	yes
Thermal Habitat and Micro-climate control (rivers)	yes	Because groundwater inputs to surface waters tend to minimize temperature fluctuations, more storage/infiltration may alter thermal habitats	direct	yes
Flood Damage Reduction (rivers)	yes	A flood represents excess water that is not being stored on the land ï increase storage/infiltration should reduce flood damage	direct	yes
Low flow (Natural Hydrologic Regime) (lakes, rivers, wetlands, groundwater, peatlands)	yes	storage/infiltration is directly related to the amount of base flow and the capacity of the system to provide enough water to meet low flow targets	direct	yes
Sediment retention (rivers, wetlands)		The rate/amount of sediment lose varies to response to the amount of overland flow; storage/infiltration impacts sediment movement	direct	yes
Nutrient Retention* (lakes, wetlands)	yes	water levels impact rate of denitrification, infiltration alters rates of nutrient retention/loss via overland flow; loss rates increase as infiltration rates declined	direct	yes
Water quality protection* (wetlands, rivers)	yes	An increase in water storage/infiltration increasing nutrient trapping/retention, and increase time available to break down pollutants	direct	yes
Micro-climate control (combined with Thermal Habitat)				

Service	**Is the service related to the function?**	**How are they related**	**Direct or Indirect relationship**	**If the function is protected, is the service protected?**
Cost reduction to invasive species	yes	Water storage (dams) creates new habitat that may be exploited by invasive species. Because healthy native plant communities may reduce invasive species, water storage/infiltration practices that encourage health native plant communities may reduce invasive species infestations	indirect	no
Biodiversity contributes to resiliency (wetlands, lakes, streams)	yes	Because the hydrology of an aquatic system is one of the factors that provides habitat complexity, and because water storage/infiltration alters hydrology, habitat complexity ï biodiversity is related	direct	yes
Groundwater Recharge	yes	Infiltration provides recharge	direct	yes
Recreation (lakes, streams, wetlands)	yes	Water level impacts recreational feasibility	direct	yes
Food Production (rivers)	yes	Need flow to provide irrigation needs, water storage/infiltration impacts availability of water during period when rainfall less than evaporative loss. The water storage/infiltration balance is purposely modified to drain land to facilitate crop production.	indirect	not sure
Commercial Use (rivers)	yes	Water storage/infiltration alters water levels and seasonal stability of flow when evaporative losses exceed precipitation inputs; stability water availability will enhance commercial use.	direct	yes
Aesthetics (rivers, lakes, wetlands)	yes	Modifications of natural water level patterns impact the characteristics of riparian habitats, shallow water habitats, and water quality.	direct	yes
Drinking Water	yes	Need to have sufficient volumes to meet use need. In general, enhancing infiltration increases water quality. Storage/infiltration alters groundwater recharge and seasonal available of water to meet drinking water needs	direct	yes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Traditional Resources/uses (wild rice)	yes	See answer to ñaestheticsò above Traditional uses often are impacted in natural water level patterns are altered	direct	yes
Quality of Life (see Traditional Resources/uses)				
Essential services to support life (peatlands)	yes	Provides natural patterns of hydrologic head on the landscape, the places where water accumulates, and the rate at which it is replenished.	direct	yes

Function: Water Quality

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Carbon sequestration	yes	lowland forests, peatlands, soils, provide carbon sequestration if water quality is good. Deep wetlands are a carbon storage. Shallow lakes are being investigated for carbon sequestration. Water quality affects the ability to increase metabolism and decrease storage need?.	direct	yes
Thermal Control	yes	If water quality decreases through turbidity, thermal control is affected, but wind will overwhelm any quality.	small indirect	yes
Flood Damage Reduction	no	If water quality is good, there is better assemblage of plants potentially affecting flood damage reduction	indirect	yes
Low flow (Hydrologic Regime)	yes (with a broad defn)	Quality of base flow benefits from good water quality.	indirect (vegetation is good if water quality is good)	yes
Sediment retention	yes	Water quality and sediment retention are the same. Sediment retention varies by aquatic system. River role is to move sediment through.	direct	yes
Nutrient Retention	yes	Sometimes it is and sometimes it is not. More often they are related until the water body becomes hyper-eutrophic. This is more typical with water level changes for shallow lakes. ñGreat Riversò are being studied for value of nutrient retention service.	direct	yes
Water quality protection (for aquatic or human)	yes	The function itself is a direct service. The function is every other thing (NOT water quality). Water quality has too many aspects to list it separately as a function. It is a service not a function.	direct	yes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Micro-climate control	yes	Nutrients in balance and natives would have a change of competition.	indirect	yes
Cost reduction to Invasive species	yes		direct	yes
Biodiversity contributes to resiliency	yes		direct	yes
Groundwater Recharge	no	if water quality means plant life is growing well, then this is a stretch to show a relationship to groundwater.	indirect	yes
Recreation	yes	Sometimes it is and sometimes it is not. More often they are related until the water body becomes hyper-eutrophic. This is more typical with water level changes for shallow lakes. ????? Sames as C/N R &S	direct	
Food Production		Cows die, food plants affected if water quality decreased. Wild rice/aquaculture is affected.	direct	yes
Commercial Use	yes	Low iron, low TSS, low sulfides, etc. implicate lower commercial costs. Power plant use - if too algae increase, affects costs.	not as direct	yes
Aesthetics	yes	Similar to C/N R & S	direct	yes
Drinking Water	yes	Strong relation to human health (Federal/State standards)	strove????	yes

Service	Is the service related to the function?	How are they related	Direct or Indirect relationship	If the function is protected, is the service protected?
Traditional Resources/uses (wild rice/ spiritual/aquaculture/ cranberries)	yes	This overlaps with aesthetics and recreation and drinking water	Ston dir???	yes
Quality of Life (related to essential services, but not the same, beyond essential)	yes	Similar to C/N R & S	direct	yes
Essential services to support life (more tangible)	yes	general ecological term as quality of life.	direct	yes

Appendix D. Key Issues for Consideration

- Decisions about changes in hydrological regimes do not consider both human and ecological needs.
- Management decisions often focus on only one function/stressor.
  - We cannot address one function or stressor and expect to achieve sustainable ecosystem services.
  - It is more complex because everything is interconnected.
- Thresholds for cumulative impacts at the watershed or water body scale
- Wetland protection has been successful because of a ñno net lossò perspective. Can this perspective be applied to water within a drainage system?
- A tiered aquatic use-value map would inform:
  - Protection of pristine areas
  - Prevent degradation of unimpaired waters, and
  - Inform restoration of impaired waters
  - We have ñright-of-waysò for roads that give roads precedence over other uses; can this concept be applied to water?
- We still need to define what comprises a healthy watershed and monitor the indicators.
- State water management is not set up to manage the water system holistically

Appendix E. Examples of Minnesota State Statute Language Applying Conservation Policies That Will Contribute to the Sustainability of Ecosystem Services

M. S. 103A. 205 CONSERVATION POLICY FOR RAINWATER

It is the policy of the state to promote the retention and conservation of all water precipitated from the atmosphere in the areas where it falls, as far as practicable. Except as otherwise expressly provided, all officers, departments, and other agencies of the state or political subdivisions having any authority or means for constructing, maintaining, or operating dams or other works or engaging in other projects or operations affecting precipitated water shall use the authority, as far as practicable, to effectuate the policy in this section.

M. S. 103A. 206 SOIL AND WATER CONSERVATION POLICY.

Maintaining and enhancing the quality of soil and water for the environmental and economic benefits they produce, preventing degradation, and restoring degraded soil and water resources of this state contribute greatly to the health, safety, economic well-being, and general welfare of this state and its citizens. Land occupiers have the responsibility to implement practices that conserve the soil and water resources of the state. Soil and water conservation measures implemented on private lands in this state provide benefits to the general public by reducing erosion, sedimentation, siltation, water pollution, and damages caused by floods. The soil and water conservation policy of the state is to encourage land occupiers to conserve soil, water, and the natural resources they support through the implementation of practices that:

(1) control or prevent erosion, sedimentation, siltation, and related pollution in order to preserve natural resources;
(2) ensure continued soil productivity;
(3) protect water quality;
(4) prevent impairment of dams and reservoirs;
(5) reduce damages caused by floods;
(6) preserve wildlife;
(7) protect the tax base; and
(8) protect public lands and waters.