Report to the Minnesota State Legislature: Definitions and Thresholds for Negative Impacts to Surface Waters

Minnesota Department of Natural Resources

January 2016

This report was prepared in response to Laws 2015, 1st Special Session, chapter 4, article 4:

Sec. 143. NEGATIVE SURFACE WATER IMPACTS; RECOMMENDATIONS.
By December 15, 2015, the commissioner of natural resources shall consult with interested stakeholders and submit a report to the Legislative Water Commission and the chairs and ranking minority members of the house of representatives and senate committees and divisions with jurisdiction over the environment and natural resources policy and finance on recommendations for statutory or rule definitions and thresholds for negative impacts to surface waters as described in Minnesota Statutes, sections 103G.285 and 103G.287, subdivision 2. Stakeholders must include but are not limited to agricultural interests; environmental interests; businesses; community water suppliers; state, federal, and local agencies; universities; and other interested stakeholders.

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Executive Summary

Background and purpose

This report was prepared in response to Laws 2015, chapter 4, article 4, which directed the Department of Natural Resources (DNR) to consult with interested stakeholders and develop recommendations for statutory or rule definitions and thresholds for negative impacts to surface waters.

The DNR is charged with managing water resources to assure an adequate and sustainable supply for multiple uses. Minnesota has a modified riparian water law system, in which landowners have the right to make reasonable use of the abutting surface waters or the groundwater beneath their land, as defined and regulated by the water appropriation permitting program. The water itself is a public trust resource, and the state grants the right to water beyond personal use – above 10,000 gallons per day or one million gallons per year – through water appropriation permits. In recent years, it has become increasingly clear that Minnesota's water resources, while abundant in many areas, are not unlimited. In some areas, increasing water withdrawals are using more groundwater than is naturally being recharged. In other areas, groundwater supplies are limited due to the underlying geology. Groundwater contamination is also a limiting factor in many areas.

The variability of Minnesota's climate and geography mean that rainfall is not always available in the quantities we need at the times when it is most needed. Increasing demands on both surface water and groundwater supplies can cause negative impacts to the ecosystems and riparian uses of streams, lakes, and wetlands. While water levels fluctuate naturally throughout the year and across multiple years, water appropriations can push low levels lower, significantly reducing stream flows and more frequently putting fish, wildlife, plant communities and riparian uses at risk.

This report examines the effects of groundwater use on rivers and streams, lakes, and wetlands. DNR's analysis and recommendations are based on the fact that surface water bodies go through seasonal and multi-year cycles of high and low water levels. The seasonal patterns, known as the seasonal hydrograph, are primary drivers in creating and maintaining the unique ecology and associated aquatic and riparian habitats of each water body. To preserve the seasonal hydrograph, protected flows must be established for streams, and protection elevations for lakes and some wetlands. These protection levels can then be translated into a quantity of water that can be sustainably withdrawn. Multi-year dry cycles and extreme droughts also serve important ecological functions, but may require a different approach to determining sustainable water use—e.g., water use that is ecologically sustainable under the normal seasonal hydrograph may need to be reduced during extreme drought.

This report was prepared with input from a broad range of stakeholders, as described in the Introduction and Appendix A. This report also incorporates and summarizes scientific studies, including an examination of approaches used in other states and countries. The recommendations in this report represent the DNR's suggestions to further define and describe methods of determining protected flows and protection elevations. These recommendations are based on the DNR's assessment of available information, analytical tools and the practicality of applying them in Minnesota.

Recommendations

The recommendations in this report fall into three categories: 1) definitions to be added in statute; 2) integration of statutory provisions dealing with surface water and groundwater; and 3) approaches to determining the thresholds for streams, lakes, and wetlands.

Definitions

The following definitions are recommended to be added in statute:

- Negative impact to surface waters – in relation to water appropriations, a change in hydrology sufficient to cause ecosystem harm or alter riparian uses long-term.
- Ecosystem harm – in relation to water appropriations, to change the biological community and ecology in a manner that results in a less desirable and degraded condition.
- Sustainable diversion limit – in relation to water appropriations, a maximum amount of water that can be removed directly or indirectly from a surface water body in a defined geographic area on an annual basis without causing a negative impact to the surface water body.

Statutory changes

The DNR also recommends combining many of the provisions in section 103G.285, which deals with surface water appropriations, and 103G.287, which deals with groundwater, into a single "Water Appropriations" section. This revision would recognize the interconnected and interdependent nature of surface and groundwater resources while removing the circular references between the two sections of statute that make it difficult to identify and assess 'negative impacts.'

Approach to determining thresholds

A "threshold" is essentially the point at which negative impacts occur. Thresholds can be estimated based on data and scientific literature. Calculating thresholds at a statewide scale is not appropriate or practical, however, given the number of variables involved – e.g., which species or which riparian uses are negatively impacted. The diversity of Minnesota's surface water and groundwater resources, land use, and climatic factors would make a single number misleading and inappropriate for many locations and conditions. The precautionary principle would require that any such statewide threshold be set to be protective of the most vulnerable resource, thereby unnecessarily restricting water use in many areas. Therefore, the DNR proposes establishing specific thresholds for specific watercourses, water basins, watersheds, or hydrologic areas in those parts of the state where water use is at risk of causing negative impacts.

Streams: The DNR's research and a review of scientific literature indicate that a 20% change in hydrologic regime (relative to the August median base flow) will negatively affect the ecosystem, while a change less than 10% is not likely to be detectable. Setting a diversion limit of no more than 10% of the August median base flow will preserve the seasonal variability of the natural hydrology under all but the most extreme drought conditions. A 15% diversion limit would preserve much of the seasonal variability, but is not adequate to protect ecosystems during periods of drought. We recommend a 10% limit in most circumstances, but recognize a diversion limit of up to 15% may be appropriate in some areas where water uses are less dependent on a consistent supply.

Lakes: The DNR recommends an approach that establishes sustainable diversion limits for two categories of lakes.

Lakes connected to stream systems that outflow most of the time. For these lakes, the outflowing stream's diversion limit would be applied to the lake and a separate protection elevation for the lake would not be necessary.

Lakes with infrequent surface outflow. For these lakes, protection elevations specific to the lake could be established based on key considerations related to hydrology, ecology, and riparian uses. Water levels at and above the protection elevation are expected to maintain the characteristic hydrology, ecology, and riparian uses of the lake most of the time. Water levels below the protection elevation put one or more of the water body's resources or uses at risk. The protection elevation is used to establish the sustainable diversion limit.

Wetlands: Different types of wetlands have distinct and characteristic seasonal water levels that maintain their characteristic plant and animal communities. Most wetland types in Minnesota depend to some extent on groundwater for at least some part of the growing season. Some wetland types, such as fens, are highly connected to and dependent on groundwater, while others, such as floodplain forests, are more directly influenced by surface-water. However, as yet there is no systematic method for evaluating potential negative impacts on wetlands due to groundwater appropriations, due to limited wetland-related hydrologic data.

The DNR is proposing to establish a comprehensive wetland hydrology characterization and monitoring program statewide. An initial step in this process is to begin testing the feasibility of establishing target hydrographs for the various wetland types, with a particular focus on areas of the state experiencing a heavy demand for groundwater appropriation. A target hydrograph is a range of acceptable water levels throughout the year for each various wetland types, extending from "normal" levels to infrequent or rare low levels that stress the characteristic plant and animal communities. The target hydrograph would be used as a guide for developing allowable diversion limits throughout the growing season to maintain the characteristic hydrologic regime.

Impacts to wetlands are also regulated under other authorities, primarily the Minnesota Wetland Conservation Act and the Public Waters Permit Program. The DNR's goal under this approach would be to avoid wetland drainage that would trigger regulation under those programs.

Methodology

The DNR would focus its efforts to set thresholds for negative impacts primarily in those areas of the state where the intensity of groundwater use and/or scarcity of groundwater supplies is causing concern, such as the groundwater management areas or individual water bodies known to be negatively affected by groundwater use. In these areas, the DNR will implement the following steps:

1) establish negative impact thresholds for surface water bodies;
2) establish sustainable diversion limits that will maintain protected flows and protection elevations of those water bodies;
3) conduct groundwater modeling to determine the effects of groundwater withdrawals on the surface water bodies; and
4) assess to what degree individual groundwater withdrawals may need to be adjusted.

Applying this approach to water use permitting

Water users, whether they are public suppliers, agricultural irrigators, industry, businesses or golf courses, need reliability and predictability. Establishing negative impact thresholds and sustainable diversion limits should ultimately improve the predictability and consistency of water appropriation decisions. It should also reduce the need to modify permits during drought and thus allow water users to rely on a fixed quantity in most years, although extreme drought conditions extending over multiple years may still call for emergency water use restrictions.

Establishing negative impact thresholds and sustainable diversion limits is the first step in the process of allocating water resources among individual appropriators. Further discussion is needed as to how best to engage current and prospective water users in allocation decisions once we have determined the amount of available water in a given hydrologic area.

Minnesota's water appropriation statutes were formulated in an era when groundwater resources were viewed as essentially unlimited. Allocating water resources in an environment where those resources may in fact be limited calls for additional research and discussion. Our statutes and rules may need to be revised to provide better guidance. The DNR is currently researching potential models of water allocation systems used in other states and regions as part of this larger discussion.

Local governments also play a significant role in the water allocation process through their planning and land use controls, which help to determine the number and nature of residential, commercial, and industrial water users in a given community. In planning for future development, local governments should carefully consider the sustainability of their water supplies and the extent to which new water-intensive uses should be allowed or encouraged. A planning process that considers the needs of all water users, future needs, and opportunities for water conservation can help to sustainably manage existing and proposed water use.

Conclusions

- **Minnesota is in the "urgency room," not the "emergency room," in terms of water use management.**
- **The state's water management policies, statutes, and rules are strong and conceptually sound. However, the state's water management statutes could be improved by clarifying terminology and better recognizing the interconnected nature of surface water and groundwater.**
- **There is a strong scientific basis for maintaining the natural dynamic patterns of surface water bodies by establishing protected flows for individual streams, protection elevations for individual basins, and target hydrographs for wetlands.**
- **Over the next five years, the DNR intends to set protected flows, protection elevations, and target hydrographs for water bodies in places where demand for water may be exceeding sustainable supplies. The changes to statute recommended in this report would help support that work.**

I. Introduction

This report was prepared in response to Laws 2015, chapter 4, article 4, which directed the Department of Natural Resources (DNR) to consult with interested stakeholders and develop recommendations for statutory or rule definitions and thresholds for negative impacts to surface waters.

In recent years, it has become increasingly clear that Minnesota's water resources, while still abundant in many areas, are not unlimited. Water supplies are at risk of overuse in some locations, and poor water quality limits use in others. The DNR is responsible for developing and managing water resources to assure an adequate supply to meet long-range seasonal requirements for domestic, municipal, industrial, agricultural, fish and wildlife, recreational, power, navigation, and quality control purposes from waters of the state (MS 103G.265). Minnesota's water appropriation law is based on the English common law doctrine of "riparian rights" and the concept of "reasonable use." Under this system, the owner of land abutting a surface water source or overlying a groundwater source has the right to make reasonable use of the resource. Minnesota statutes and rules have modified the riparian doctrine into a "regulated riparian" system, in which water appropriation permits define "reasonable use." The water itself is a public trust resource, and the state grants the rights to water beyond personal use – above 10,000 gallons per day or one million gallons per year – through water appropriation permits.

Appropriation permits are based upon the water allocation priorities and the sustainability requirements established in statute. Minnesota Statutes 103G.261 establishes the allocation priorities. Domestic water supply is the highest priority, while other uses are classified based on amount, and whether the use is consumptive or nonconsumptive, or is considered "nonessential." Minnesota Rule 6115.0740 describes procedures to resolve water use conflicts, defined as "competing demands among existing and proposed users which exceed the reasonably available waters." While beyond the scope of this report, the state's system of allocation priorities is a concern for some water users and may merit future consideration.

A DNR water appropriation permit authorizes a total annual volume of water and also specifies the timing and rate of withdrawal. All permits include restrictions that may limit or reduce authorized amounts based on drought conditions. In practice, lows flows that develop during drought conditions are used to limit or restrict surface water use; however, these restrictions have rarely been applied to groundwater permits. In fact, agricultural irrigation from groundwater is exempt from changes in appropriation permits between April 1 and November 15, unless it endangers a domestic water supply (MS § 103G.271, subd. 3). This has led many water appropriators to seek a "more secure," less vulnerable source, which has typically been groundwater. However, increased use and reliance on groundwater has generated increasing concern about the negative impacts to surface waters. It is becoming increasingly clear that, in some areas of the state, avoiding negative impacts to surface waters will limit the amount of water available for appropriation and use.

The need to develop definitions and thresholds is tied to several provisions in Minnesota Statutes.

- Minnesota Statutes § 103G.287, Subd. 2, states that "Groundwater appropriations that will have negative impacts to surface waters are subject to applicable provisions in § 103G.285." This provision was originally added to the statute in 2010, with the terminology "groundwater appropriations that have potential impacts to surface waters…." The language was revised in

2014 to the current "will have negative impacts." Legislators' interest in further clarifying this term resulted in the legislation directing DNR to prepare this report.

- The "applicable provisions" in Minn. Stats. § 103G.285 include a number of provisions that limit withdrawals from surface waters:
    - Withdrawals from streams ("natural and altered natural watercourses") must be limited so that "consumptive appropriations are not made from the watercourses during periods of specified low flows. The purpose of the limit is to safeguard water availability for in-stream uses and for downstream higher priority uses located reasonably near the site of appropriation."
    - Withdrawals from water basins are limited in two ways: 1) a limit to the collective volume of annual withdrawals of one-half acre-foot per acre (i.e., 6 inches across the basin); and 2) a protective elevation for each water basin, which the DNR is to establish based on several factors:
        - "the elevation of important aquatic vegetation characteristics related to fish and wildlife habitat;
        - existing uses of the basin by the public and riparian landowners; and
        - the total volume within the water basin and the slope of the littoral zone.
    - Withdrawals from smaller basins, less than 500 acres in size, require increased scrutiny based on the needs of riparian property owners: an applicant must obtain a statement of support for a withdrawal from as many riparian owners as possible.
    - Withdrawals from trout streams are limited to temporary appropriations. (This provision has been in place since 1977 and pertains to permit decisions made after that date.) Trout streams are protected from surface water appropriations because they are particularly dependent on steady flow, stable cold water temperatures, and sufficient oxygen levels. However, these conditions depend on a steady supply of groundwater from springs or diffuse seepage. Therefore, groundwater appropriations can potentially have negative impacts on trout streams, triggering the "negative impacts" standard in 103G.287, subd. 2.
- In addition, the DNR is guided by other provisions in Minn. Stats. § 103G.287:
    - Subd. 3 states that the commissioner may establish water appropriation limits to protect groundwater resources, considering "the sustainability of the groundwater resource, including current and projected water levels, water quality, whether the use protects ecosystems, and the ability of future generations to meet their own needs.
    - Subd. 5, titled Sustainability standard, states that permits may be issued only if the commissioner determines that "the groundwater use is sustainable to supply the needs of future generations and the proposed use will not harm ecosystems, degrade water, or reduce water levels beyond the reach of public water supply and private domestic wells…"

- In addition to streams and lakes, which are specifically referenced in § 103G.285, this report also considers negative impacts to wetlands. While 103G.285 does not specifically reference wetlands, Bulletin 25, "An Inventory of Minnesota Lakes," includes a number of basins that are wetland-like in character, including some public waters wetlands identified on the Public Waters Inventory. In addition, wetland protection standards are contained in several statutes, including § 103G.222, which prohibits draining of wetlands, wholly or partially, without replacement. Calcareous fens are a type of wetland that is dependent on upwelling groundwater, and are specifically protected under § 103G.223. While responsibility for wetland protection is shared among several state agencies and local governments, it was considered important to recognize the resource values and functions of wetlands in this report. Wetlands are treated here as a particular category of ecosystems with differing degrees of connection to groundwater, although they also overlap the “lakes” and “streams” categories.

Preparing this report has provided an excellent opportunity to engage a wide range of individuals and organizations in a discussion of an important natural resource challenge: long-term sustainable use of water for drinking water, irrigation, livestock, and industry. Minnesota is in transition from an era in which water was viewed as uniformly plentiful to an era of increasing demands on limited supplies, at least in certain regions of the state. We are working to meet water users’ expectations for predictable, high-quality water supplies that support local economies while protecting those water supplies and the ecosystems they sustain from overuse.

Stakeholder Engagement

The DNR established a Project Stakeholder Advisory Group that included representatives of the interests identified in the legislation. The following organizations participated in the process:

- American Water Works Association – MN Section
- Association of Minnesota Counties
- Clean Water Action (for MN Environmental Partnership)
- Coalition of Lake Associations
- Ducks Unlimited
- Freshwater Society
- Irrigators Association of Minnesota
- Izaak Walton League
- League of Minnesota Cities
- MN Ag Water Resources Center
- MN Association of Soil and Water Conservation Districts
- MN Association of Watershed Districts
- MN Cattlemen’s Association
- MN Corn Growers Association
- MN Golf Course Superintendents’ Association
- MN Lakes and Rivers Association
- MN Rural Water Association
- MN Soybean Growers Association
- MN Water Well Association
- MN Waterfowl Association
- MN Well Drillers Association
- The Nature Conservancy
- Trout Unlimited

Five Advisory Group meetings were held in the western suburbs of the Twin Cities between August and December 2015. All were open to the public and were publicized via an email bulletin and the DNR's website. In addition to Advisory Group members, attendees have included members of local watershed districts, representatives of local governments and businesses that use groundwater, well drillers, legislators, and legislative staff.

- **Meeting 1, August 26**: orientation to the project; advice on project issues, focus, design, and participation.
- **Meeting 2, September 30**: presentation of technical team analysis and response to questions.
- **Meeting 3, October 21:** stakeholder perspectives about technical team draft products and possible approaches to determining thresholds.
- **Meeting 4, November 12**: review and discuss preliminary report draft.
- **Meeting 5, December 10:** review final draft report; discuss implementation steps

Technical Teams and Peer Review

The DNR established four technical work groups focused on stream systems, lake systems, wetland systems, and policy and procedures. The technical teams consisted primarily of staff from multiple DNR divisions, but also included experts from the University of Minnesota, other state and federal agencies, and the private sector. Participants are listed in Appendix D. Each team met at least twice, with small-group discussions in between or following meetings. Their work is summarized in several sections of this report and additional technical analysis is referenced in Appendix B.

Additional Outreach

Presentations to and feedback from the following groups have also helped to shape the recommendations in this report:

- Metro chapter, Minnesota Association of Watershed Districts
- Clean Water Fund Interagency Drinking Water - Groundwater Workgroup
- Clean Water Council
- Minnesota Water Resources Conference
- Minnesota Association of County Planning and Zoning Administrators conference
- Legislative Water Commission
- Groundwater Management Area Project Advisory Committees (North & East Metro, Bonanza Valley, Straight River)
- Minnesota Agricultural Water Resource Center
- Irrigators Clinic, Glenwood, MN

II. Background

The recommendations presented in this report are based on scientific research and monitoring of Minnesota's climate and surface and groundwater by the DNR and other agencies and organizations, using extensive historical records, geologic atlases, and networks of observation wells, stream gages, and lake level data. Highlights of this research include the following:

Our lakes, wetlands, rivers and streams are connected to and influenced by groundwater to varying degrees.

- In most locations, the natural flow regime in surface waters is connected to and interacts with associated groundwater aquifers. For example, most streams gain water from inflow of groundwater and lose water by outflow through the streambed. Many lakes and wetlands reflect the elevation of the surrounding water table aquifer. Many of the aquifers we draw water from are connected to surface waters. Those aquifers in turn are connected to varying degrees to other aquifers above or below them.

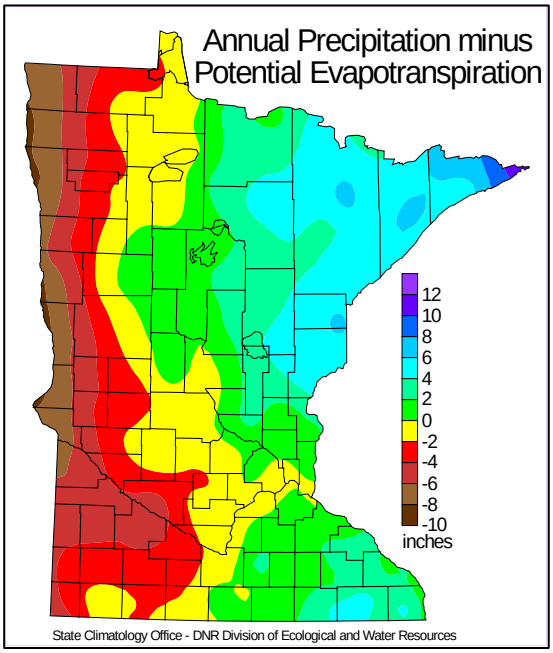

Figure 1. Annual precipitation minus potential evapotranspiration

Climate is a primary driver of Minnesota's water supply, dictated by the balance between input from precipitation and losses due to evapotranspiration (water lost to the atmosphere due to direct evaporation and transpiration by plants).

- Human activity aside, surface and groundwater quantity is driven by the balance between input from precipitation and losses due to evapotranspiration. Minnesota is a headwaters state. Nearly all of the state's surface water or groundwater resources are the result of precipitation that fell directly upon our landscape. With relatively minor exceptions, water does not flow in from elsewhere. Therefore, knowledge of Minnesota's climate provides important insight into water availability.
- Due to its position in the continent, Minnesota is located on the boundary between the semi-humid climate regime of the eastern U.S., and the semi-arid regime to the west, as shown in the gradient in Figure 1.
- The patterns of precipitation that we have seen over the past several decades are likely to continue for the next few decades. However, extreme variability can occur locally. Abrupt changes within a given year or season can have significant impact on the landscape (Figure 2).
- In certain geographic areas, intensive and concentrated use of groundwater is increasing. These are the places where the DNR's groundwater management efforts are

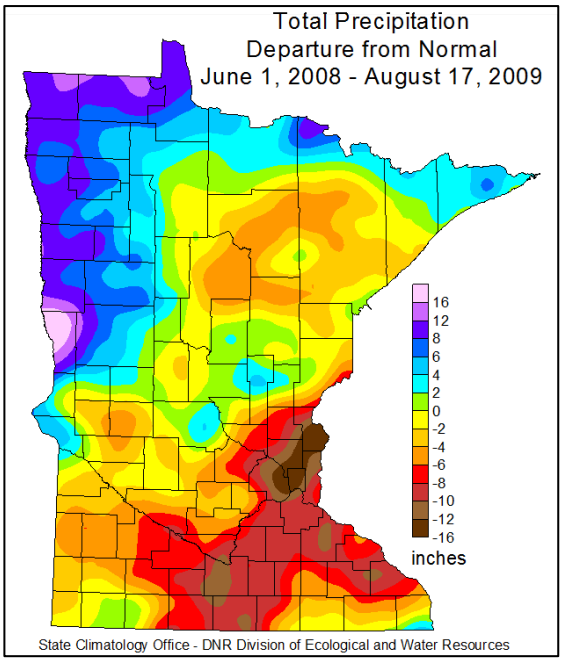

Figure 2. Precipitation departure from normal, 2008-2009

focused. Groundwater use is increasing in Minnesota largely for municipal water supply and irrigation (including domestic and other types of irrigation as well as agricultural irrigation). Figure 3 indicates a number of areas where the use of water represents a significant fraction of the total available precipitation and runoff, raising the issue of the sustainability of those water resources.

- The extent and capacity of aquifers vary across Minnesota. In Southwest and Northwest Minnesota and in the Arrowhead, aquifers yield very little water and do not recharge quickly. (In the Arrowhead, although Figure 4 shows a high potential for recharge, the shallow depth to bedrock does not allow much water to actually reach aquifers.) This relative scarcity of groundwater is not captured in Figure 3, which instead simply highlights those areas where reported water use may be exceeding available supply.

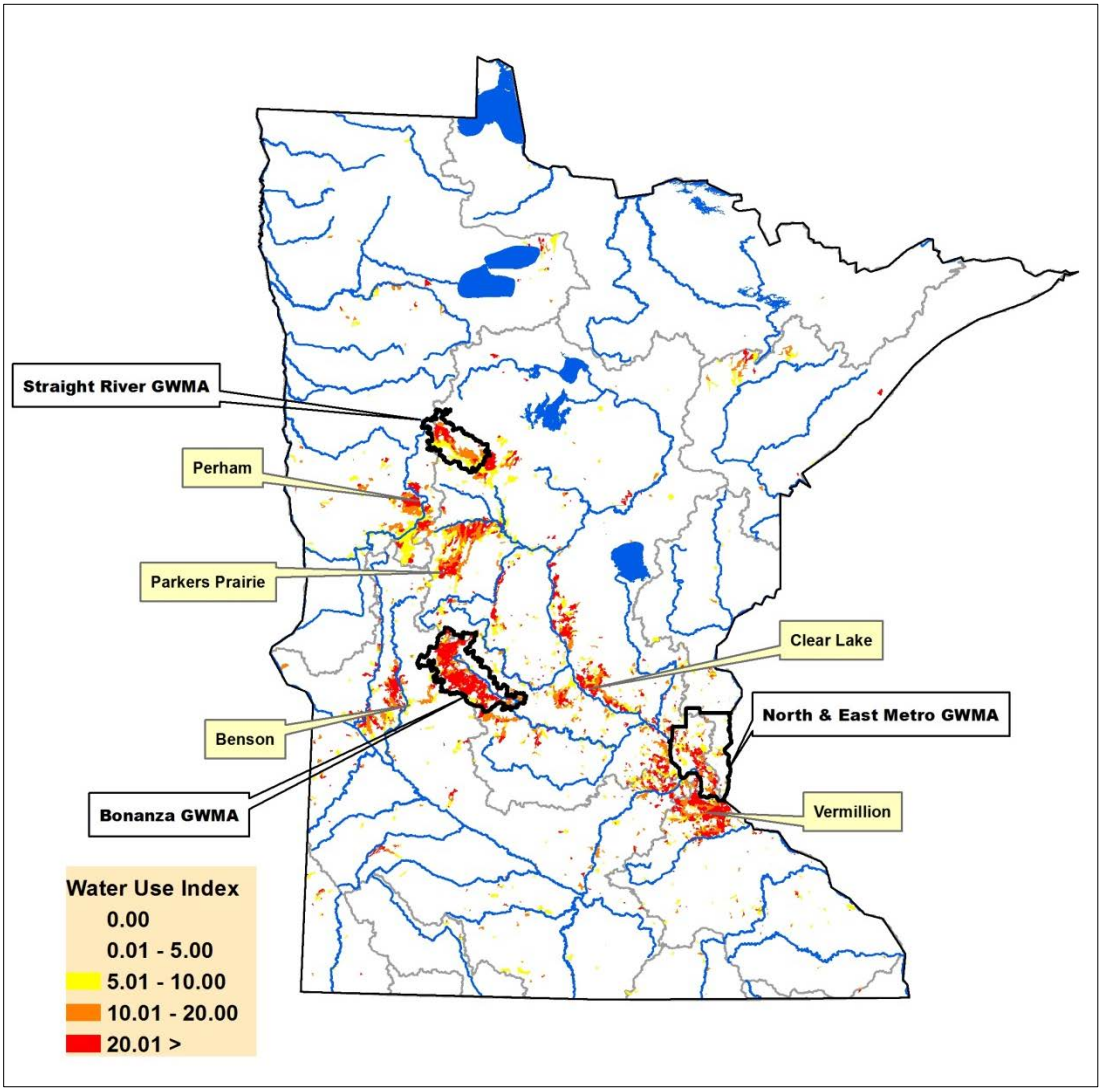

Figure 3. Catchments showing intensive reported use compared to available water resources. The Water Use Index is a ratio of reported water use to the mean annual surface water discharge from each catchment. A ratio of 20.01 means that more than 20% of the mean annual discharge is being withdrawn. The analysis was completed at the watershed scale of DNR Level 09 catchments (average catchment size = 491 Ac). Note that this ratio is not the same as the suggested stream threshold of 10% of the mean August flow. For further information on how this index is calculated, see DNR's Watershed Health Assessment Framework, http://www.dnr.state.mn.us/whaf/about/scores/hydrology/waterwithdraw.html#datamap

Recharge capacity also varies across the state. The U.S. Geological Survey (USGS) has produced a statewide estimate of potential recharge for Minnesota (Figure 4). The estimate is presented as a 1-km grid of potential recharge, averaged from 1996-2010, using the USGS Soil-Water-Balance (SWB) model (Figure 5) and including land use and daily climate data. Estimates of groundwater recharge are one of the key parameters used to construct groundwater flow models that can be used to manage appropriations.

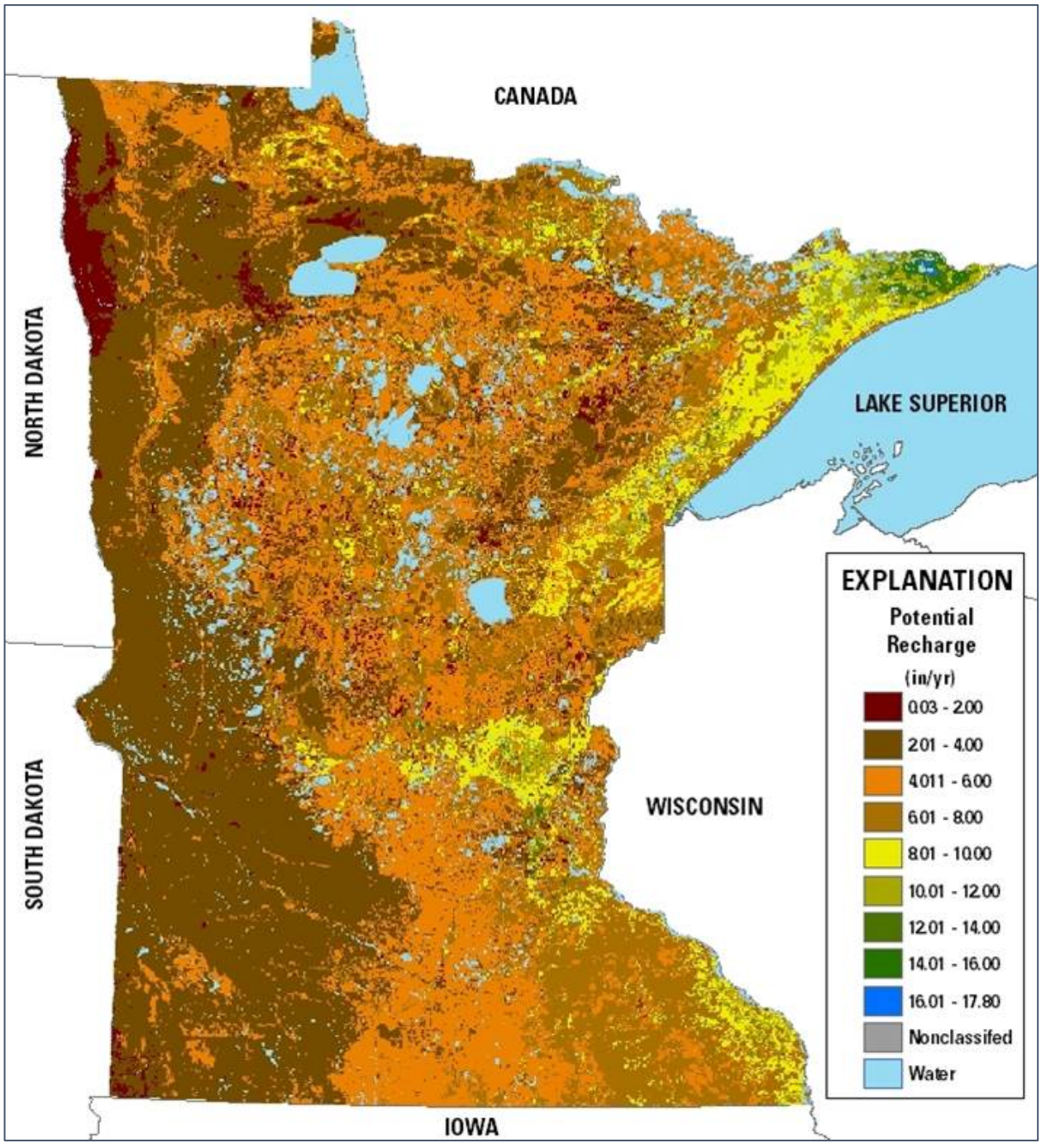

Figure 4. Estimated potential recharge, 1996 – 2010. Source: USGS.

The USGS's SWB model used to calculate recharge potential is based upon a simple formula: **Recharge = (precip. + snowmelt + inflow) – (interaction + outflow + evapotranspiration) – change in soil moisture**

For the last element, change in soil moisture, the model uses available soil water capacity: the amount of water each soil type can hold.

The hydrology of surface water features fluctuates naturally with seasonal and multi-year changes in climate.

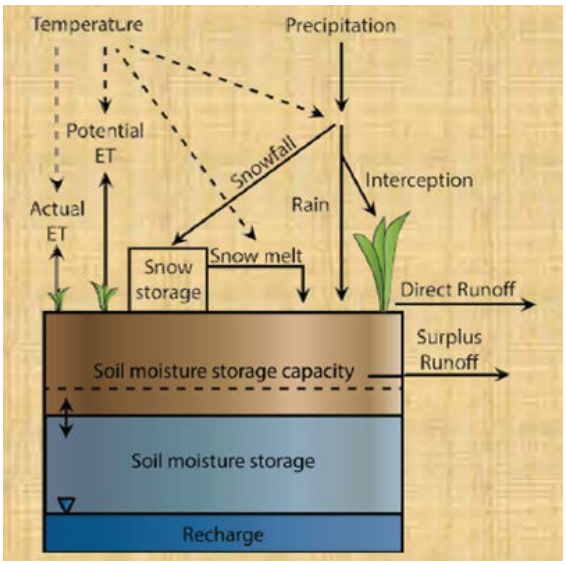

Figure 5. Diagram of USGS Soil-Water-Balance model. Source: USGS.

- For example, a pattern of higher precipitation has been observed in northwestern Minnesota since 1991, contributing to high water level problems in lakes that have limited outflows. At the same time, we have observed relative dryness in central and northeastern MN.
- We are seeing more precipitation in spring and summer, falling in heavier rainfall events, such as the rainfall events that produced flooding in June 2012 and June 2014.
- We are currently in a relatively wet period that began in the 1990s, yet measured groundwater levels are showing declines in more locations and increases in fewer locations.

The Palmer Hydrological Drought Index (PHDI) is a regional measure of the hydrological impacts of drought. It reflects the long-term effects of drought on systems affected by long-term precipitation deficits. These impacts, such as reservoir levels, groundwater levels, etc., take longer to develop and it takes longer to recover from them.[1] The PHDI is calculated on a monthly basis for sections (termed "divisions") of each state. Minnesota includes eight divisions; Division 5, shown in the bar graph below (Figure 6), is a multi-county area of central Minnesota. The month of August in this graph marks a point after our typical wet period of the year, as well as important part of the growing season for crops and fish and wildlife. August represents a month with relatively high water use, and corresponds with low flows and low lake levels.

The Minnesota Statewide Drought Plan[2] identifies a range of drought indicators based on the U.S. Drought Monitor. Under the plan, water use reductions may be required depending on the extent or severity of drought in each of several defined watersheds.

[1] Described in https://www.ncdc.noaa.gov/temp-and-precip/drought/recovery/ under "Defining Drought."
[2] § 103G.293 and http://www.dnr.state.mn.us/climate/drought/index.html

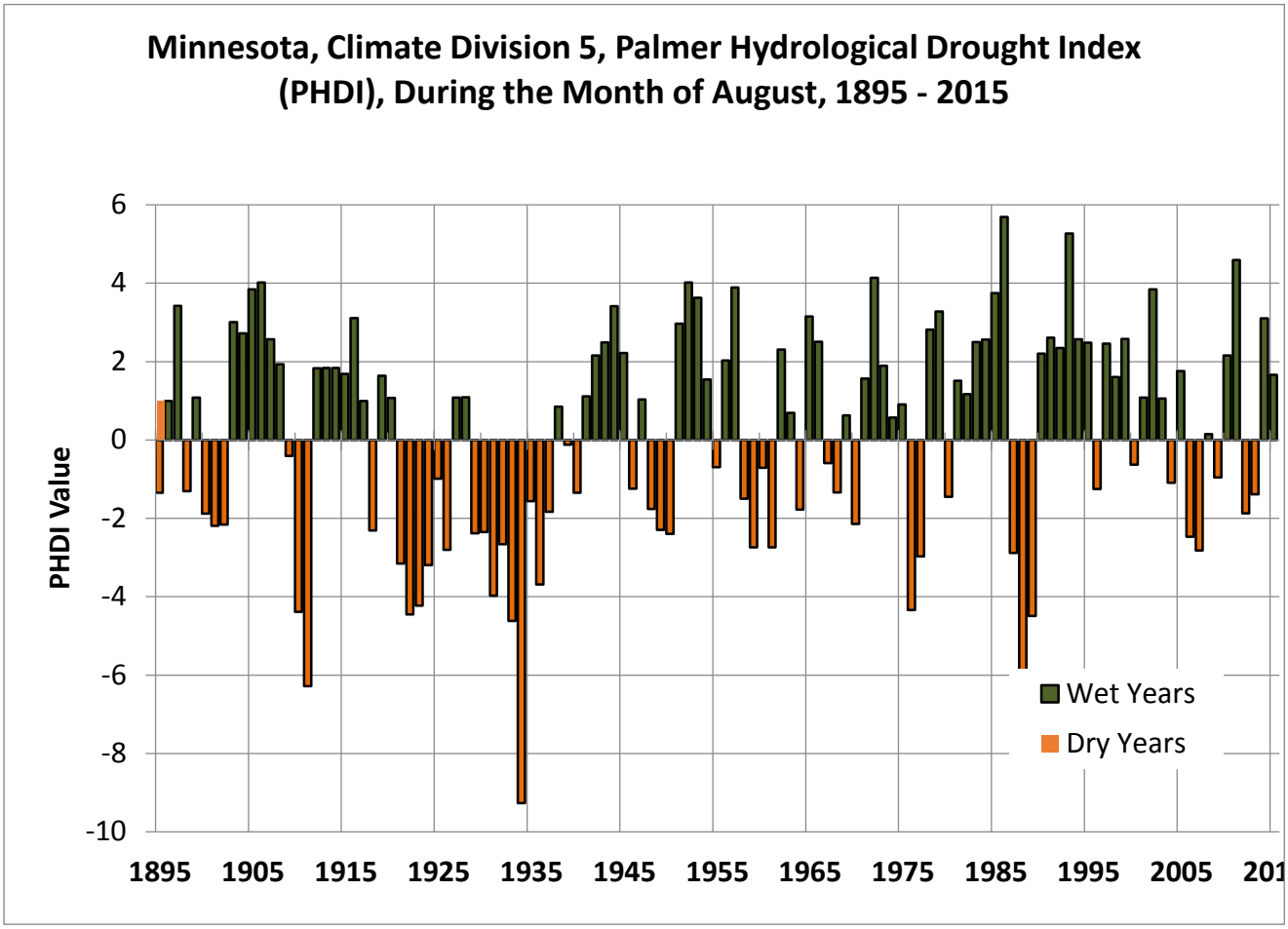

Figure 6. Palmer Hydrological Drought Index example

The full range of high and low water levels, along with the associated timing and duration, create the unique ecology of each water body.

- All parts of the seasonal hydrograph are equally important. For rivers and streams, flows that vary over time create and maintain dynamic channel and floodplain conditions, create essential habitats for aquatic and riparian species, and directly regulate numerous ecological processes (Figure 7). For some types of wetlands, naturally variable water levels are critical for maintaining certain defining features, such as habitat and water quality characteristics. In terms of ecology, there is no "excess" water.
- For natural systems, **hydrology is a key driver of ecology**. Hydrology affects all elements of a water body, from biology to water quality and geomorphology (the configuration of the stream or basin in the landscape).

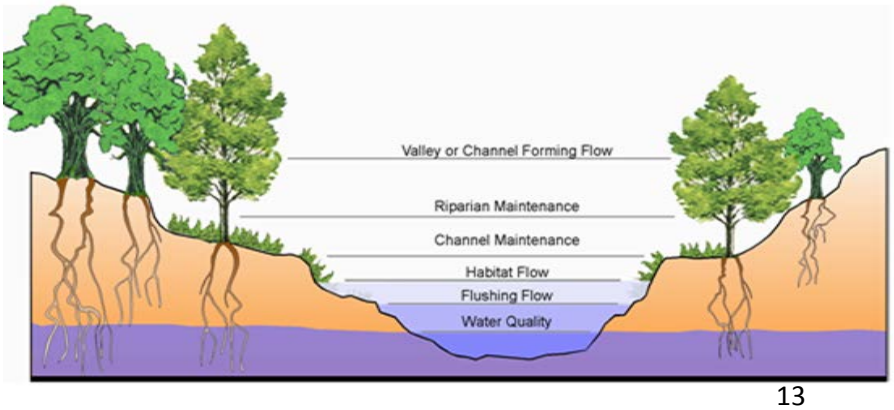

Figure 7. Range of flows essential to stream ecology. Source: Hill et al.

- **This report focuses on balancing consumptive use with maintaining a natural flow regime and limiting water use impacts at low flows** – since our water use comprises such a small fraction of higher flows, and our use of water is highest when water levels tend to be naturally lowest. The timing and duration of these low periods is critical to ecosystem health.
- **Our use of water may push the low levels lower. During extended dry periods, water use may push water levels so low that water quality and biology are fundamentally changed.** The challenge is to determine "how low can the water levels go, and for how long?" before it alters the characteristic long-term biological community?

By limiting the volume of diversions (of both ground and surface water), we can protect the natural annual hydrograph, including both the high and the low flows and levels. During low water periods, protection of a minimum flow or level is especially important to sustain the water body's unique ecology and water quality (see Figure 7).

The relationship of groundwater to surface water bodies, and the impacts on those water bodies, must be assessed through long-term modeling and monitoring.

- Because groundwater quantity and movement are not directly visible to us and because shifts in groundwater patterns occur over different time scales, from days or weeks to years or centuries, the impacts of groundwater diversions on surface water features generally cannot be observed in real time, but must be modeled.

The great diversity of hydrologic regimes, groundwater resources, and climatic conditions across Minnesota points to a need for **thresholds that are specific to water bodies, watersheds, or other defined regions where surface waters are at risk from groundwater use.**

III. Definitions and Thresholds

The essence of this report is to recommend definitions for negative impacts and thresholds. The following describe the DNR's recommendations along with some very significant considerations about setting numeric thresholds.

The following statutory definitions are proposed:

- Negative impact to surface waters – in relation to water appropriations, a change in hydrology sufficient to cause ecosystem harm or alter riparian uses long-term.
- Ecosystem harm – in relation to water appropriations, to change the biological community and ecology in a manner that results in a less desirable and degraded condition.
- Sustainable diversion limit – in relation to water appropriations, a maximum amount of water that can be removed directly or indirectly from a surface water body in a defined geographic area on an annual basis without causing a negative impact to the surface water body.

We are proposing a definition of "ecosystem harm" (a term currently used in statute but not defined) to better characterize impacts specific to ecosystems. This would be distinct from "negative impact," which would be defined more broadly to encompass both ecosystem harm and negative long-term impacts to riparian uses of surface waters. Ecosystem or riparian use factors may take precedence in setting thresholds for a particular water body. The terms "less desirable" and "degraded" refer to the diminished ability of the water body to support indigenous plant and animal species and communities that would otherwise be present, as well as desirable introduced species such as gamefish.

The term "diversion" rather than "withdrawal" is used to describe the collective, cumulative withdrawal of groundwater as it affects a surface water body. "Withdrawal," when applied to groundwater, generally refers to a limit established in an individual appropriation permit, not to the cumulative effects of multiple withdrawals.

A "threshold" is essentially the point at which negative impacts occur. Thresholds can be estimated based on data and scientific literature. Calculating thresholds at a statewide scale is not appropriate or practical, however, given the number of variables involved. For example, the threshold of change for some aquatic plants such as wild rice is quite different from the threshold for boat access or even navigation. Similarly, the threshold established to protect a healthy trout population in one stream may differ from that for other streams due to water temperature or water quality. The precautionary principle would require that any such statewide threshold be set to be protective of the most vulnerable resource, thereby unnecessarily restricting water use in many areas. Therefore, the DNR proposes establishing specific thresholds for specific watercourses, water basins, and/or watersheds in those parts of the state where water use is at risk of causing negative impacts.

The objective outlined in this report is to avoid "crossing a threshold" due to water appropriation, thereby avoiding or preventing negative impacts to surface water resources. In order to protect these biological systems, the DNR would need to establish protected flows and protection elevations that can be used to determine appropriation limits. A sustainable diversion limit would be established as a means of keeping water flows and elevations above the threshold. Diversion limits would be established with consideration for the type and seasonality of use, along with pumping rates and volumes.

However, setting a single diversion limit also presents significant risk because of the extreme variability of Minnesota's climate and precipitation patterns. This variability, coupled with the fact that we use more water when it does not rain, makes a single diversion limit more risky. Periods of extreme low-flows or extreme drought conditions, while rare, pose the most risk to surface water resources and will very likely require some reductions in appropriations. The risks associated with extreme drought are discussed below. ("Extreme drought" can be characterized as a level of -4 or lower in the Palmer Hydrological Drought Index, as shown on page 11, although the impacts of drought will vary depending on the time of year and the duration of those conditions.)

The DNR's intent is to establish protected flows that give water users sufficient certainty throughout the year in the majority of years so that they can use water allocations most effectively.

Streams (Natural and Altered Watercourses)

Thresholds: The DNR's research and a review of scientific literature indicate that a 20% change in hydrologic regime will negatively affect the ecosystem, while a change less than 10% is not likely to be detectable.

Given this range of impact, the following options are available to manage cumulative diversions from streams:

1. Setting a diversion limit of no more than 10% of the August median base flow will preserve the seasonal variability of the natural hydrology and maintain geomorphology, water quality, connectivity, and biology of the system the vast majority of the time. This relatively conservative approach would provide predictability for water users under all but the most extreme drought conditions. This approach is also suitable for highly groundwater-dependent ecosystems such as trout streams.

2. Setting a diversion limit of no more than 15% of the August median base flow, would preserve much of the seasonal variability of the natural hydrology and maintain geomorphology, water quality, connectivity, and biology of the system most of the time. This approach might be preferable in some locations where a larger but more variable water supply is desired. However, a diversion limit of 15% would not be adequate to protect ecosystems during periods of extreme drought. Among the limitations of this approach:
    - Water quality and temperature are at greater risk of being negatively affected during periods of low flow.
    - In conjunction with a 15% diversion limit, a low flow threshold, the annual Q90, would be needed to limit changes in the low flow extremes and to provide a buffer against water quality concerns. (The "annual Q90" is the stream discharge that statistically was exceeded 90% of the time during the period of record analyzed.) Surface water appropriations are already subject to suspensions when measured flows are at or below the Q90 for at least 120 hours[3]. However, applying a Q90 limit to groundwater appropriations would present significant challenges and may not be feasible. The

[3] Note that the "7Q10" standard used by the MPCA to maintain water quality equates to approximately a Q95-Q99 – that is, to even lower protected flows.

relative unpredictability of Q90 conditions means that real time stream flow data are needed. Assessing real time streamflow adds significant cost, and data are not available for a majority of the state. In addition, the delayed effect of groundwater diversions means that stream flows may go well below the Q90 even if appropriations are stopped. Statute also prohibits changes to groundwater appropriation permits for agricultural irrigation during the growing season, which would essentially negate the usefulness of a low flow threshold in agricultural settings.

These approaches are compared in Figure 8. Based on the Palmer Hydrological Drought Index from 1970 to 2014, for a given (hypothetical) area, a maximum of 450 million gallons (MG) could safely be appropriated for most years. However, during periods of severe drought (8 of 44 years, or 18% of the time, during this period), appropriation limits would be reduced by 50%. Thus, this "maximized" approach allows higher water diversions in most years but limits supply in drought years. By contrast, the "stabilized" approach sets appropriations at lower amounts (i.e., 10%), thereby conserving more of the water supply, which would allow those appropriations to be maintained through all but extreme drought conditions. (See Section II for a discussion of drought management under the Statewide Drought Plan.)

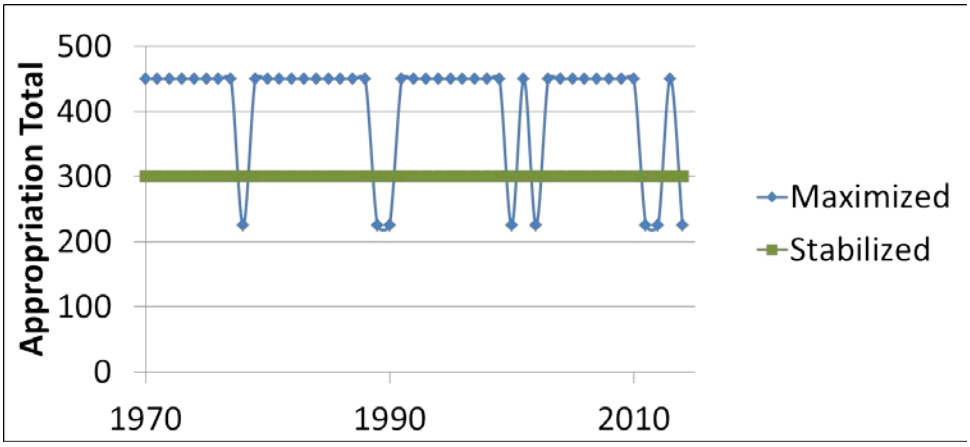

Figure 8. Hypothetical example of two approaches to setting diversion limits. One approach is to try and maximize the amount of water available from year to year, except during drought conditions, the other approach tries to stabilize the volume of water available from year to year.

Recommendation: The DNR recommends a 10% limit in most circumstances, but we also recognize a diversion limit of up to 15% may be appropriate in some areas where water uses are less dependent on a consistent supply. A higher diversion limit would require more intensive monitoring and management.

Rationale: In order to maintain the resource values of rivers and streams, we must preserve the structure and functions of the river ecosystem. The management options outlined above are designed to do this by accounting for five interacting components that are critical to structure and function: hydrology, biology, geomorphology, water quality, and connectivity (see Figure 9 and sidebar). Management of one element, such as the biology or status of a single species, is usually not effective because each element of a riverine ecosystem continuously interacts with the others.

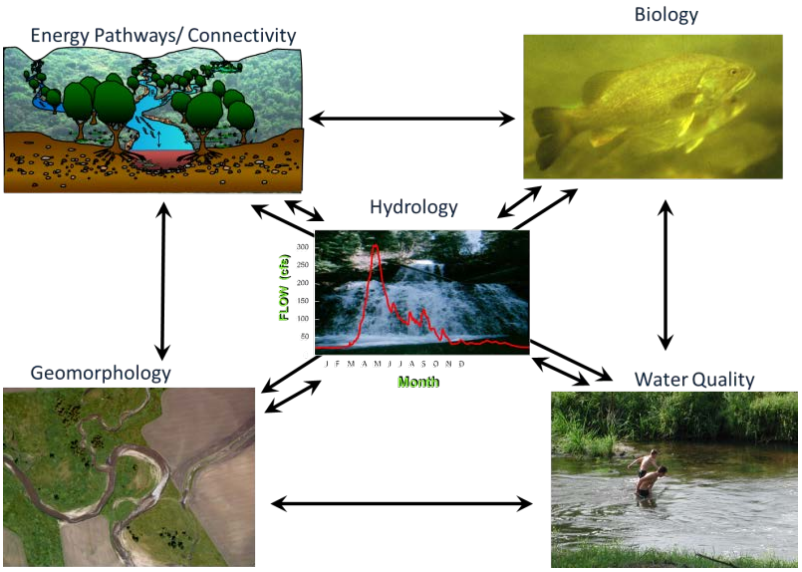

Figure 9. Five components of river ecosystems.

The Five Components of River and Stream Health

Biology: *Encompasses the plant and animal species present in the stream, riparian lands and contributing watershed.*

Connectivity: *The maintenance of pathways that move organisms, energy, and matter throughout the watershed.*

Geomorphology: *The topographic and bathymetric features of the stream, riparian lands, and contributing watershed and the processes that continue to shape them.*

Hydrology: *The inter-relationships and interactions between water and its environment in the hydrololgic cycle."*

Water Quality: *The chemical, biological, and physical characteristics of both surface water and interconnected groundwater.*

See the DNR's Watershed Health Assessment Framework for more information on the five components.

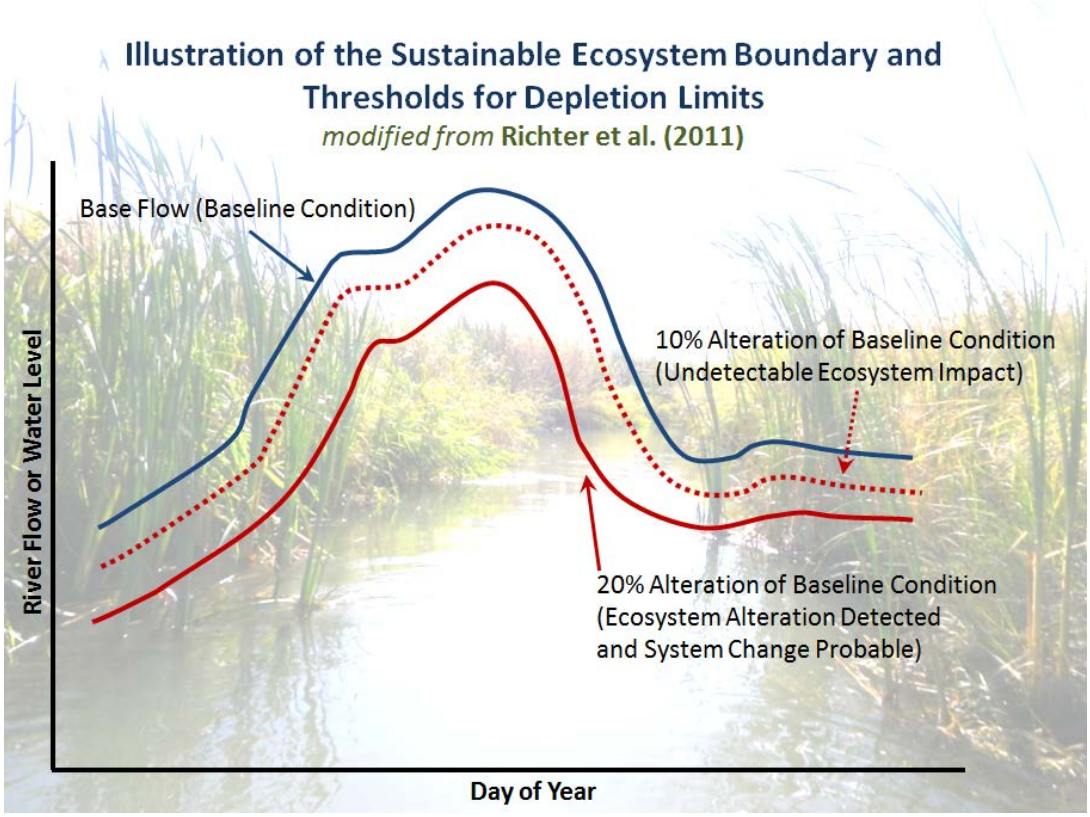

Figure 10. Sustainable ecosystem boundary and thresholds.

Statutory language calling for sufficient flows to maintain fish in good condition inherently addresses all riverine components because a healthy fishery requires balance across the five components. The natural hydrograph of streams and rivers influences the biology of rivers through several inter-related mechanisms. The native biota have evolved in response to the overall flow regime.

In the past, stream flows were set based on fixed percentages of hydrologic variables and represented "minimum flows," – i.e., essentially, "what is the minimum flow required for the species of concern to survive?" The recommended minimum flow value was set for the entire year. However, under this approach, as demand for water increases, the result is simply a "flat line"—i.e., a static flow across the year at the minimum flow level. This management approach does not preserve key elements of riverine health, including the channel-forming high flows and variable flows needed to maintain habitat, and has been demonstrated to degrade the stream's ecosystem over time.

The DNR is proposing a percentage of flow approach for managing stream and river diversion, similar to that adopted by other water management agencies, nationally and internationally, as listed in Appendix C. In contrast to the minimum flow approach, the amount that can be diverted through surface water and groundwater appropriations – the sustainable diversion limit – remains constant across the seasonal hydrograph, and thus protects the stream's natural flow variability, as shown in Figure 10. The percentage of flow approach is based on identifying the allowable depletion limit – i.e., the negative impact threshold – and setting the diversion limit to avoid the negative impact. As discussed above, water diversions of 10% have a minimal impact on most species, stream types, and hydrologic conditions, while diversions above a 20% threshold produce moderate to severe ecosystem changes.

The August median base flow is selected as the standard because August is a biologically meaningful low flow month – protecting this month establishes a logical basis for protecting the entire hydrograph. It is also part of the growing season, for fish and wildlife as well as plants and crops, and is a determinant of species richness.

The DNR has developed a model for predicting the response of fish species to changes in discharge for Minnesota, using almost 800 samples of fish species and environmental data. For fish in streams, habitat is typically defined by the water velocity, depth, substrate, temperature, and cover that each life stage of a species uses.

The DNR and the MPCA have available one of the largest data sets in the country for this type of information. Since 1987, we have been collecting samples and developing mathematical representations of fish habitat preferences. Nearly 10,000 samples, with over 220,000 individual observations, have been collected and developed into habitat preference curves for 150 species-life stages.

The analysis shows a close relationship between richness (number) of fish species to low flow discharge. Smaller streams are more sensitive to flow changes. As we remove water, we remove species. The habitat preference curves strongly support the use of the August median flow as an index flow to use as a protection standard.

In addition to fish, there are many other components of aquatic ecosystems that are equally sensitive to the flow regime. Fish species provide a valuable surrogate for other facets of the ecosystem because of the breadth of our research on fish habitat preferences in Minnesota.

Lakes

Thresholds: The DNR's research and a review of scientific literature indicate that Minnesota's wide variety of lakes would be expected to respond differently to a loss of water because of appropriation activity. The threshold currently in Minnesota Statute (§ 103G.285, subd. 2) and Rule (6115.0670, subp. B (4)) limits direct appropriations from lakes to a set volume (one-half acre foot per acre of surface area) and requires a low-water level cutoff (the "protective elevation") threshold, below which no appropriation is allowed. This statute also identifies specific attributes of lakes – important aquatic vegetation characteristics, existing uses, total volume, slope of littoral zone – for consideration in setting a protection elevation. Finally, the statute identifies additional notification requirements if water will be appropriated from lakes that are less than 500 acres in size.

In practice, the one-half acre foot limit has been relatively simple to apply for direct surface water withdrawals from lakes. However, more and more groundwater appropriations are coming from groundwater wells in proximity to both large and small lakes. This raises questions of when these cumulative groundwater withdrawals will cause a negative impact to the lake, and whether the 6-inch threshold is relevant.

The DNR's research and review of the scientific literature indicates that a simple 6-inch threshold can remove too much water from some lakes, including certain wild rice lakes, shallow lakes, or lakes with small watersheds. A 6-inch threshold may also have significant effects on some riparian uses and access. On the other hand, for lake systems that have large watersheds or that outflow most of the time, a limit of 6 inches may be overly constraining and unnecessarily limit water available for use.

Recommendation: The DNR recommends establishing sustainable diversion limits for two categories of lakes in locations where surface and/or groundwater appropriations are of concern:

- Lakes connected to stream systems that outflow most of the time. For these lakes, the outflowing stream's diversion limit would be applied to the lake and a separate protection elevation for the lake would not be necessary.
- Lakes with infrequent surface outflow. These lakes are good candidates for the protection elevation-setting approach outlined below.

For lakes with infrequent surface outflows, the DNR recommends setting a protection elevation specific to the lake and determining the lake's sustainable diversion limit based on its water budget. This process would involve the following steps:

1. Examine water level records for the lake and evaluate the lake's characteristic elevations – the variability and range of elevations that are ideal for maintaining the lake's hydrology, ecology (including aquatic vegetation and habitat) and riparian uses (including lake access). Determine how often water levels drop below the identified elevations.
2. Develop a water budget that accounts for all water inflows into and water losses from the lake basin. Assess how much existing and/or proposed appropriations are diverting from the system, and how those might affect the lake's hydrology, ecology, and riparian uses.
3. Establish a protection elevation that will protect the key resource values of the lake while allowing a reasonable level of use. Public input should be considered in defining these resource values and setting priorities. Water levels at and above the protection elevation are expected to maintain the characteristic hydrology, ecology, and riparian uses of the lake most of the time.

Water levels below the protection elevation put one or more of the water body's resources or uses at risk.

4. Based on the water budget and the protection elevation, establish a sustainable diversion limit (a volume of water) that can be diverted from the lake throughout the year. The intent is to set diversion limits at a level that will remain effective across multiple "wet" or "dry" years. In extreme drought conditions that span one or more years, appropriations would likely need to be reduced (as with streams and other resources).

"Protection elevation" is already defined in Minn. Rules 6115.0630, subp. 13, as "the water level of the basin necessary to maintain fish and wildlife habitat, existing uses of the surface of the basin by the public and riparian landowners, and other values which must be preserved in the public interest."

It's important to recognize that for a given lake, the ideal elevation for boat accesses may be different than the ideal elevation for nearshore habitats, which may be different than the ideal elevation for a swimming beach. For lakes that are a drinking water source, an ideal elevation would need to ensure that appropriation-induced changes in lake-level patterns do not degrade the quality of the drinking water.

The protection elevation must be set with consideration of all key resource values, not based on a single management objective. Given the natural fluctuation of Minnesota lakes and the variability of our climate, the protection elevation does not represent the lowest level for a given lake – in fact, lake levels might 'naturally' fall below the protection elevation in any given year. Rather, the protection elevation would represent the elevation goal we aim to maintain while accounting for permitted water appropriation activity.

The protection elevation is used to establish the sustainable diversion limit for the lake. Establishing these parameters would be expected to maintain the natural pattern of lake levels in all but extreme droughts. (See Section II for discussion of the statewide drought management plan.) This approach would provide more predictability to appropriators and riparian users than the current approach that sets a fixed volume and implements a "shut-off" when water levels fall below a defined elevation.

Rationale: A fundamental assumption of this approach is that to maintain the resource values of lakes we must preserve the structure and functions of the lake's ecosystem. As is the case for rivers and streams (discussed earlier) and wetlands (discussed below), maintaining a lake's characteristic hydrologic (lake-level) pattern is a key requirement for preserving the natural resource and recreational benefits it provides.

A lake's long-term water level pattern can be represented by a lake-level exceedance curve (see Fig 11 below). The top chart depicts the water level history of the lake and helps identify the maximum historic range of lake level change. This chart also shows the runout elevation, a little above 1,016 feet. The bottom graph in Fig. 11 represents the frequency that a particular elevation is exceeded. For this example, the lake is above its runout about 50% of the time over the period of record and above 1,012 feet 90% of the time. The lowest levels correspond with extended droughts in the 1930's and late 1980's.

Appropriation activity will lower lake levels, since some water is removed from the basin, and alter the shape of the lake-level exceedance curve. To minimize negative impacts to lakes from appropriation

activities, the DNR would strive to maintain the general shape of the curve so that high-water, low-water, and average water level conditions continue to occur at about the same frequency over time.

The amount of change in water level that would be allowed would depend on a lake's specific natural resource and/or riparian resource values and how those values are affected as the water level declines. **Appendix B** presents an example of how the frequency of lake levels below a protection elevation might affect both riparian uses and aquatic plant habitat under two different diversion limits scenarios.

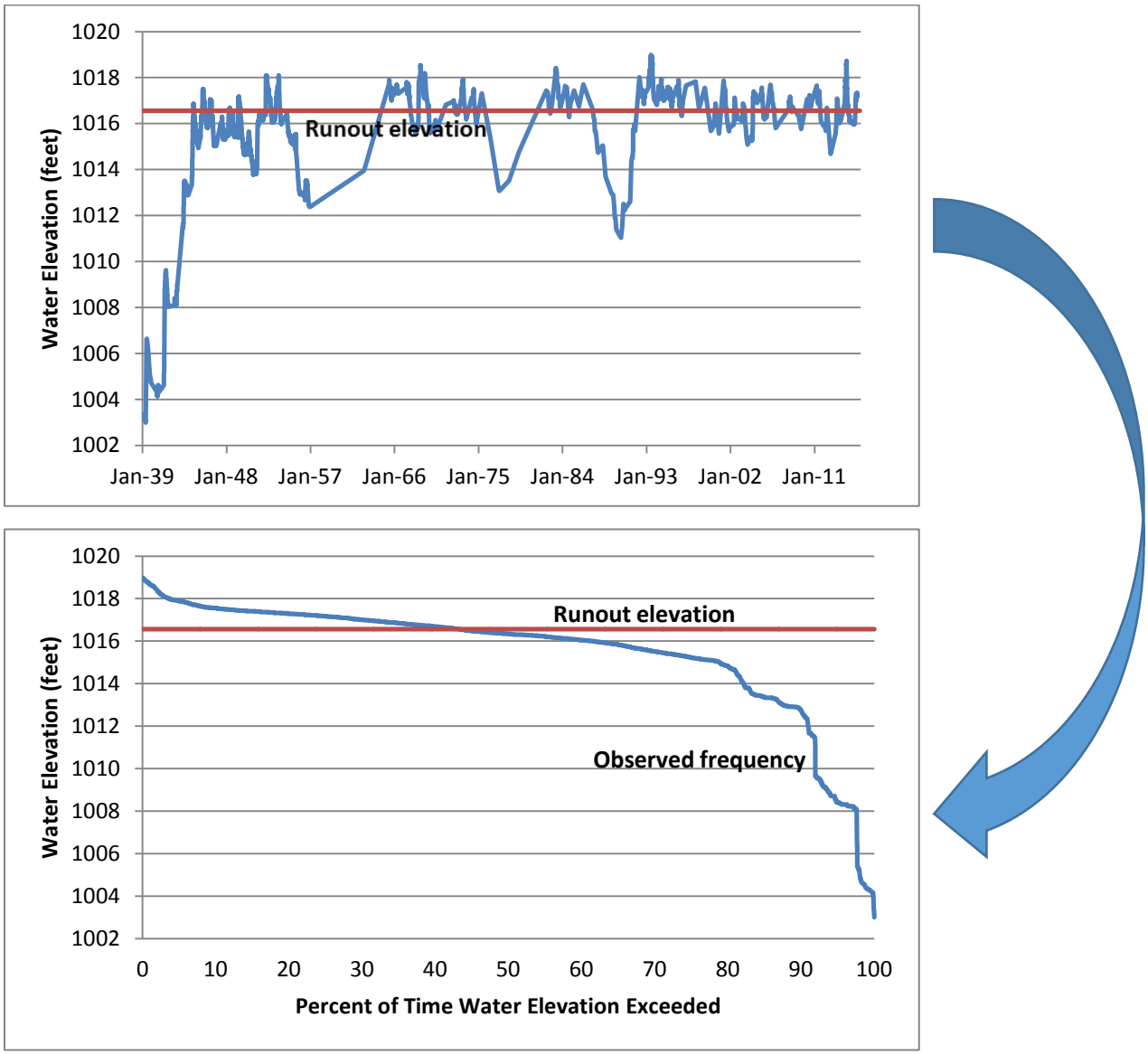

Figure 11. Example of conversion of water level observations to an exceedance curve.

By comparing how water level changes will affect the lake's key resource attributes, an appropriate protection elevation and an associated diversion limit to use in permitting decisions can be determined. As with many resource management activities, multiple resource values must be weighed, and public input should be considered in decision-making.

Two factors that influence the vulnerability of lakes to groundwater appropriations are:

1) **Watershed to lake size ratio:** This ratio is a strong predictor of how much water is flowing into the basin and therefore the amount of appropriation that can be allowed. All else being equal, lakes with larger watersheds, relative to the size of the basin, will receive more runoff from the watershed and will be more resilient to reductions in the amount of inflow due to appropriations. In Minnesota, once the watershed area to lake area ratio is greater than 20:1, the lake is likely to have a surface water outflow most of the time.

2) **Basin shape:** the shape of the lake's basin, particularly the portion of the basin that is less than 15 feet deep (those water depths where the growth of rooted aquatic plants is most prevalent) is also important. Basins that have broad, gently-sloped bottoms are likely to be more susceptible to water level changes compared to steeply-sloped basins, because small changes in lake depth result in proportionally larger changes in the surface area of the basin.

   The impact of water level changes may be particularly acute in shallow lakes (defined by the DNR as having a maximum depth of 15 feet or less) or shallow bays. In these situations, the amount of rooted aquatic plant habitat for important fish and/or wildlife populations may vary substantially as water levels move up and down. Likewise, the public's access to the lake for surface water recreation activities, either from private docks, public access points, or swimming beaches, will be impacted as water depths fall and the shoreline moves outward.

   In some lakes, especially smaller lakes with a steeply sloping nearshore, a reduction of one to two feet in water elevation would eliminate hypolimnetic habitat (the deep, cold, layer that will support cold-water species throughout the summer). Pillager Lake in Cass County is one example of such a lake. This effect can be modeled to identify susceptible lakes under current and future climate conditions.

   Table 1 compares lakes that outflow most of the time with those that outflow infrequently, as compared to lake depth. The comparison is not quantitative, but simply compares the level of sensitivity of these lake types to groundwater withdrawals. Shallow lakes with less frequent outflows show the highest level of sensitivity, as discussed above.

Table 1: Comparison of Lake Sensitivity to Groundwater Diversions

	Shallow Lakes	Deep Lakes
Frequent Surface Outflow	**Moderate**	**Lowest**
Infrequent Surface Outflow	**Highest**	**High**

Wetlands

Thresholds: Wetlands, like lakes and streams, go through typical seasonal cycles that support their characteristic plant and animal communities and other wetland functions. As shown in Figure 12, the seasonal hydrograph varies by wetland type. The extent to which groundwater contributes to a particular wetland's water budget varies, but most wetland types in Minnesota depend to some extent on groundwater, particularly the unconfined, surficial water table, for at least some part of the growing season. Some wetland types, such as fens, are highly connected to and dependent on groundwater, while others, such as floodplain forests, are more directly influenced by surface water.

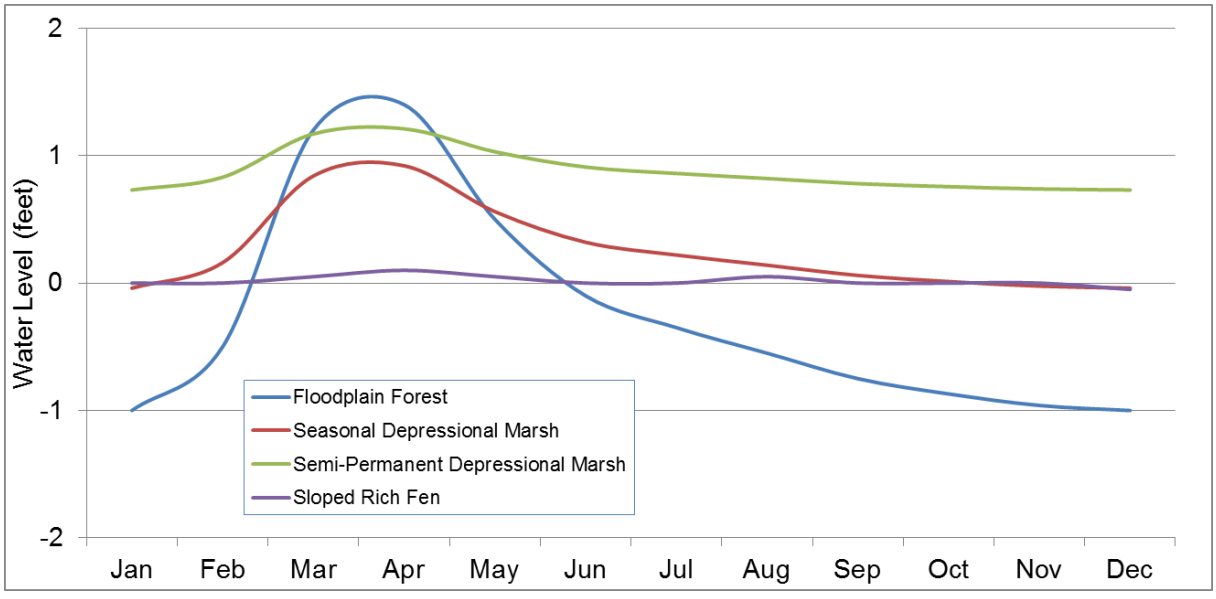

Figure 12. Example annual hydrographs for various wetland types in Minnesota. Note that the fen shows relatively little water level variation across the year, evidence of its heavy dependence on groundwater.

In regulating groundwater (or surface water) appropriations, the goal is to maintain the basic hydrologic regime for the particular wetland type, including long-term wet/dry cycling where appropriate, thereby helping to ensure that the wetland will maintain its characteristic plant community, wildlife habitat, and associated functions.

Wetlands potentially at risk of negative impacts from groundwater diversions are currently regulated through the DNR's appropriation permit review process. Aquifer testing and simple modeling of

drawdowns from nearby wells are used to assess potential impacts. If the wetland is a calcareous fen, a type which has elevated protection under statute, an appropriation permit may be denied if any change to the hydrology would result. For other wetland types, appropriation permits may be limited or denied based on the degree of impact. However, this approach is employed on a case-by-case basis, without a systematic process for setting thresholds for particular types of wetlands.

In place of this case-by-case approach, the DNR recommends identifying and applying more broadly applicable thresholds based on the concept of target hydrographs. Under this approach, which is adapted from a concept originally developed in the United Kingdom (Wheeler et al., 2004), long-term hydrologic data in the form of percent exceedance curves are used to develop annual hydrographs for various wetland types, or groups of wetland types, expressed as *ranges of water levels* extending from "normal," or frequently occurring conditions, to rare, but still naturally occurring, water levels that create stress on the wetland plant community (Figure 13).

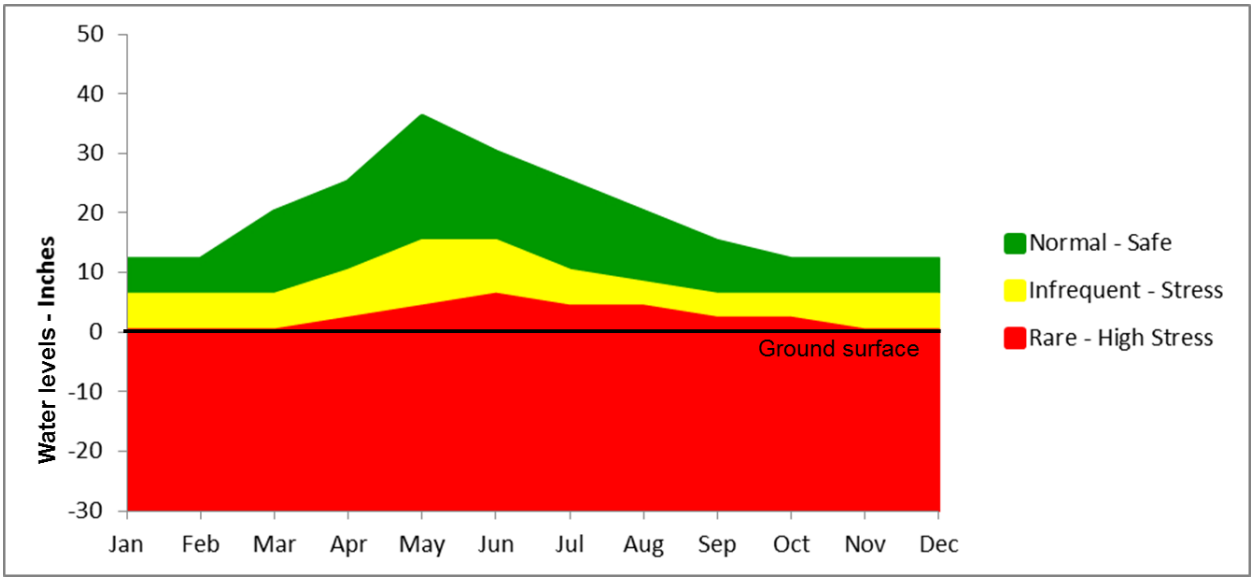

Figure 13. Example of a target hydrograph

Recommendation: While the target hydrograph approach has yet to be used in Minnesota, the DNR and the technical advisors to this report believe that it merits further evaluation as part of a broader wetland hydrology characterization and monitoring program. We recommend evaluating the available data regarding wetland hydrologic regimes and beginning to develop sample target hydrographs for the most common wetland types. This step would be followed by further field-testing to determine whether this approach is practical to implement more broadly.

Rationale: As discussed above, the hydrologic regime of wetlands, consisting of the depth, duration and timing of inundation or soil saturation, is a major factor in determining wetland structure and function, including the wetland plant community. Different types of wetlands, or groups of wetland types, have relatively distinctive hydrologic regimes, which can be expressed as annual hydrographs (Figure 12). For some wetland types, the water level may vary considerably over the year; others have relatively constant water levels. In addition, some wetland types, particularly prairie potholes, undergo wet-dry cycles that occur over periods of several years. These long-term cycles are important for maintaining certain characteristic wetland functions such as wildlife habitat and water quality maintenance.

Once the target hydrograph has been derived for a particular wetland type or group of types, the width of the Normal-Safe zone could be used as a guide for developing allowable appropriation amounts. A diversion limit based on some proportion of the width of the Normal-Safe zone (i.e., the range of water levels within the zone) at the critical part of the growing season (August, in most cases), would likely ensure that the characteristic hydrologic regime is maintained, regardless of when the appropriation is actually made, or where in the range of naturally occurring water levels the wetland happens to be at the time of the appropriation. A permitted appropriation might occasionally drive the wetland water level from the green to the yellow zone, or from the yellow to the red, but basing the allowable appropriation on the normal variablility in water levels would help ensure that water levels do not drop to stressful levels significantly more frequently *than what naturally occurrs*. However, as with the approaches outlined above for streams and lakes, it could be necessary to limit appropriations during extended dry periods, when continuing groundwater appropriation could add significant stress to already-stressed wetlands. It would also be necessary to consider important site-specific wetland functions, such as use by migratory waterfowl, in setting allowable appropriations.

It is important to recognize that wetland types having naturally variable water levels would have a wider Normal-Safe zone and a correspondingly larger allowable appropriation limit than wetlands that require relatively constant water levels, or that depend on constant upwelling of groundwater, such as calcareous fens. The Normal-Safe zone for the latter type of wetland might be so narrow that there is no safe appropriation amount – any appropriation is likely to drop the water level into the yellow or red zone significantly more frequently than what naturally occurs, with subsequent adverse effects on the wetland plant community and functions.

As noted in the Introduction, impacts to wetlands are also regulated under other authorities, primarily the Minnesota Wetland Conservation Act and the Public Waters Permit Program. Under M.S. 103G.222, wetlands must not be drained or filled, wholly or partially, unless replaced by restoring or creating wetland areas of at least equal public value. To date, there has been minimal coordination between DNR appropriation permits and the wetland regulatory programs. Moving forward, the DNR would seek to ensure that wetlands are not drained as a result of permitted water appropriations, thereby avoiding triggering regulation under the wetland regulatory programs. An appropriation permit would not be approved that would drain wetlands unless the applicant had an approved wetland replacement plan. Additional implementation details are provided in Sections IV and V.

IV. Methodology: Calculation of Thresholds and Groundwater Modeling

Pumping water directly from a lake or stream has a direct and immediate effect on flow or water level in that surface water body. When a surface appropriation is suspended there is an immediate effect on the water levels. The same is not true for groundwater appropriations. Determining whether groundwater appropriations have negative impacts to surface waters is complex. Generally, the effect on connected surface water features is both delayed and spread out or 'flattened' in time and is typically distributed among multiple water features.

As mentioned in the introduction to this report, the DNR would focus on setting thresholds for negative impacts to surface water bodies primarily in those areas of the state where intensity of groundwater use and/or scarcity of groundwater supplies is causing concern. In these areas, the DNR would implement the following steps:

1) establish negative impact thresholds for surface water bodies;
2) establish sustainable diversion limits that will maintain protected flows and protection elevations of those water bodies;
3) conduct groundwater modeling to determine the effects of groundwater withdrawals on the surface water bodies; and
4) assess to what degree individual groundwater withdrawals may need to be adjusted.

Calculating Thresholds

Thresholds would be calculated based upon an assessment of the hydrology, the long-term biological community, and the long-term riparian uses of the water body, as well as the needs of water users. A threshold would be specific to a stream, a lake, a wetland or a larger hydrologic area. Once a threshold has been established, groundwater modeling would be used to assess the relationship of groundwater diversions to the surface water body.

Calculation of thresholds would be based on available data as follows:

Streams: Data on streamflow is available from about 520 active stream gages around the state. Where data are not available, modeling techniques would be used.

Two types of flow would be calculated:

- **Base Flow:** Sustained, gradually varying or steady flow in a stream provided by groundwater discharge, the near surface soil profile, bank storage and wetland and lake storage.
- **August Median Base Flow:** Estimated base flow during August that is equaled or exceeded fifty percent of the time. It is typically determined through hydrograph separation of long term stream flow records – separation of direct runoff from precipitation/ snow melt events and the base flow.

When near-site data are available, the steps in the calculation process are:

- Examine monitored location data
- Perform base flow separation
- Develop duration assessment for August and identify the median base flow

When data are limited, a different series of steps is followed:

- Evaluate nearby monitoring location with similar hydrologic characteristics
- Transfer records using paired discharge measurements, evaluation of regional and seasonal climatic conditions and comparisons with historical groundwater data

Several standardized modeling tools are used in both processes: the Web-Based Hydrologic Analysis Tool and the USGS Groundwater Toolbox, which includes six standardized techniques.

Once the August median base flow is determined, the protected flow threshold would be set at 10% of that flow, unless adjusted upward in the 10-15% range based on local conditions and water user needs.

Lakes

The process for calculating lake-specific protection elevations would be undertaken in two phases. (This process applies to lakes that have regular periods without a surface outflow; for lakes that outflow most of the time, the outflowing stream's diversion limit would apply.) These phases are:

1) a preliminary landscape-level assessment of the relative risk of negative impact for a given basin, similar to that shown in Figure 14 below; and
2) where the potential for negative impact appears significant, a protection elevation for the lake would be developed. In this second more specific phase, a **model of a lake's water budget** would be constructed and calibrated to match the existing lake-level record, water appropriation losses would be simulated based on existing users and use patterns, and a protection level would be established based on an assessment of the key resource values, as discussed in Section III.

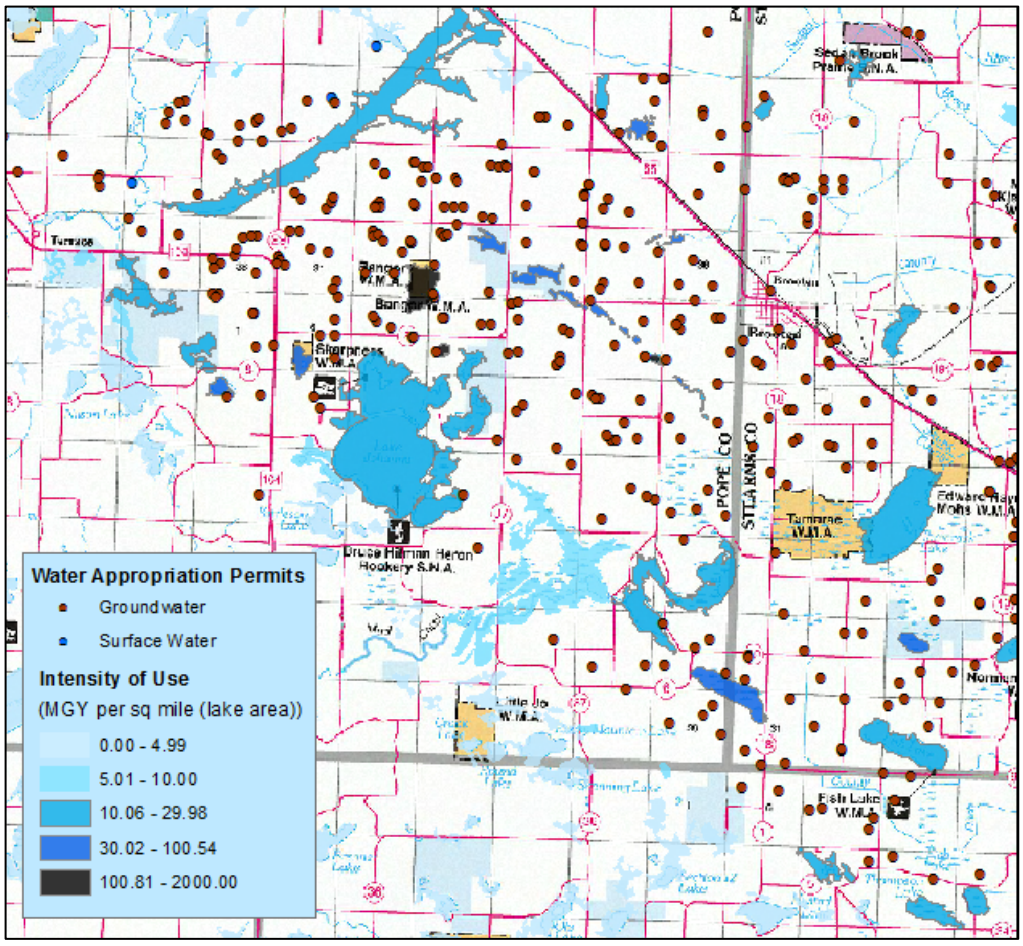

Figure 14. Map of Pope/Stearns county area shows permitted wells and water basins. The darker the shading of the basins, the higher the intensity of use and the relative risk of negative impact.

Reference Basin Approach: For lakes where little or no information on the lake's water levels is available, we recommend a reference basin approach. "Reference basins" would be lakes within the same landscape / watershed that have long-term lake level records. A simple water budget model would be constructed for the reference basin that replicates the observed lake level history for the reference lake. Using that model, protection elevations and water quantity diversion limits would be tested to determine the values that will protect the lake's important natural resource and riparian uses and the shape of the lake-level exceedance curve. The general relationship developed for the reference lake would then be applied to the lake basin with limited or no lake-level data.

Wetlands

The DNR is proposing to establish a long-term wetland hydrology characterization and monitoring program statewide. An initial step in this process is to begin testing the feasibility of establishing target hydrographs for the various wetland types, with a particular focus on areas of the state experiencing a heavy demand for groundwater appropriation. This effort would also draw on the extensive records of wetland native plant community data compiled through the Minnesota Biological Survey and the DNR's Ecological Classification System. If this method proves feasible, the sustainable diversion limit throughout the year would be established for each wetland type.

A related step would be to establish a monitoring network that would track the actual water levels under varying climatological conditions over time in selected wetlands that are representative of the various wetland types. This monitoring effort is currently being designed and funding is being sought.

Depending on the classification system used, there are from 8 to over 40 types of wetlands in Minnesota. However, many wetland types have similar hydrologic regimes, so it will not be necessary to develop target hydrographs for every distinct type of wetland. The Corps of Engineers, St. Paul District, has developed narrative target hydrology standards for various wetland types for use in assessing the performance of compensatory mitigation projects (wetland restoration/enhancement/creation). The Corps of Engineers' standards group the various wetland types into seven hydrologic categories as follows:

1. Seasonally Flooded Basins
2. Floodplain Forests
3. Hardwood Swamps, Shrub-Carrs and Alder Thickets (Mineral Soils)
4. Fresh (Wet) Meadows, Sedge Meadows and Wet Prairies (Mineral Soils)
5. Fresh (Wet) Meadows, Sedge Meadows, Calcareous Fens, Open Bogs, Coniferous Bogs, Hardwood Swamps, Coniferous Swamps, Shrub-Carrs and Alder Thickets (Peat/Muck Soils)
6. Shallow Marshes
7. Deep Marshes

This scheme may provide a useful guide for combining wetland types for the purpose of developing target hydrographs. Even if not directly applicable, the number of distinct target hydrographs needed for the variety of wetland types in the state is likely to be similar to that above.

The relationship of appropriation permits to the Public Waters Inventory and Wetland Conservation Act requirements needs to be clarified. If a wetland that is not a public water (as identified on the DNR Public Waters Inventory) would be affected by an appropriation and the wetland is wholly owned by the

permit applicant, the applicant could apply for an appropriation amount that exceeds the normally applicable diversion limit if he or she first obtained approval of a wetland replacement plan from the local government unit under the provisions of the Minnesota Wetland Conservation Act (see Minn. Rules Chapter 8420). Note that approval of a wetland replacement plan requires the applicant to demonstrate that there are no feasible alternatives to draining the wetland, in light of the project purpose. (Permanent, total drainage of public waters, including public waters wetlands, is prohibited.)

Groundwater Modeling

The relationship of groundwater to surface water bodies, and the impacts on those water bodies, are often complex. This relationship can be further complicated if there are multiple water supply wells. Groundwater modeling is a method that can be used to assess cumulative impacts to surface water bodies from multiple pumping wells.

Determining the relative impacts on a water body attributable to each individual groundwater user is complex. For example, pumping groundwater from a well directly adjacent to a stream will have a greater impact on the stream than pumping from a well located farther away. While the well near the stream might rapidly affect the stream, the one farther away might have a delayed and smaller impact to the stream. Another challenge is how to determine and account for cumulative impacts of pumping from multiple wells.

In determining a diversion limit, it is essential to account for the cumulative impacts of groundwater removal from all wells within the aquifer system. Diversion limits must also consider how directly the aquifers being used are connected to surface water features. While water table aquifers have the most direct connection to streams, lakes, and wetlands, buried aquifers may also be closely connected to water table aquifers. Figure 15 shows the complex relationships among water table aquifers and confined aquifers in an environment with multiple wells and one surface water feature.

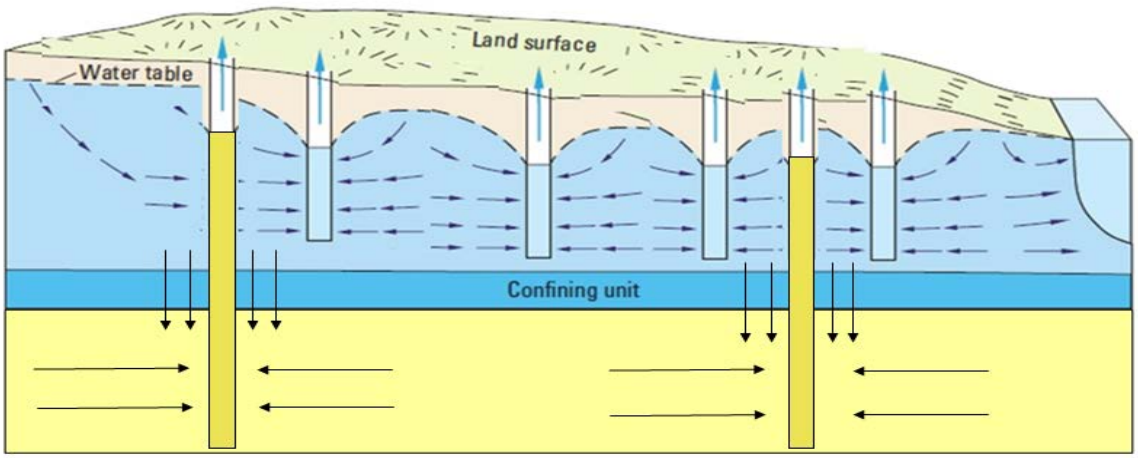

Figure 15. Diagram showing complex groundwater flows within and between aquifers and a surface water body. Source: USGS.

The DNR currently uses simple analysis techniques to evaluate potential impacts to surface water bodies from proposed groundwater use and to investigate well interference complaints. These methods are

valid for their current application and would continue to be used, often in conjunction with aquifer testing, for evaluating impacts from individual appropriation permits on nearby features. These simple methods may not be applicable to complex settings or larger areas with multiple wells. However, simple analysis methods would be useful for initial screening of potential impacts in more complex settings, and could help identify where more complex models will be needed. Complex models, such as a three-dimensional MODFLOW model, are better suited to predict aquifer conditions and run "what if" scenarios. "What if" scenarios can be used to simulate different amounts of pumping in different locations and aquifer formations and to predict the effect on streamflow and lake or wetland levels.

The following types of information and inputs are necessary to develop detailed groundwater models:

- Thresholds defining negative impacts to streams, lakes, and wetlands due to water appropriations
- Geologic and aquifer framework (location, orientation, and connectivity of aquifers)
- Groundwater recharge calculations for the modeled area
- Groundwater pumping history
- Climatology (precipitation and evapotranspiration)
- Soils and land cover
- Groundwater levels/elevations from monitoring wells
- Stream gaging and lake level monitoring data
- Hydrogeologic properties from aquifer tests

Current efforts: The DNR is currently developing a hydrological model focused on groundwater-surface-water interactions for the Little Rock Creek area in Morrison and Benton counties. The U.S. Geological Survey and Metropolitan Council are developing a hydrological model focused on groundwater-lake interactions for lakes within the North and East Metro Groundwater Management Area, which the DNR will apply to evaluations in that GWMA. A hydrological model is also planned for the proposed Bonanza Valley Groundwater Management Area. The DNR will continue to develop hydrological models for other areas of intensive groundwater use where negative impacts are a concern.

The Relevance of Recharge and Reuse

Stakeholders who assisted the DNR with this project frequently raised the topic of recharge and its effect on the availability of groundwater. In particular, they asked whether increasing infiltration of stormwater through green infrastructure could increase the amount of groundwater available for use. There is also widespread interest in using stormwater for irrigation as a way to offset the need for groundwater.

Land uses that reduce or increase the amount of recharge should be considered in the water budget model for a given surface water system. The map of potential recharge on page 11 is based on a model that estimates the extent to which groundwater can be naturally recharged by precipitation. That model takes land use into account. This includes factors such as land cover and the relative amount of impervious surface, which can impede recharge. The potential recharge model does not factor in the impacts of agricultural drainage, an area where additional research is needed.

Increasing infiltration of groundwater through biofiltration and similar green infrastructure techniques would eventually be reflected in an increased supply of groundwater in water table aquifers, potentially offsetting declines caused by groundwater withdrawals.

A recent change to statute exempts projects that use stormwater from water use permit fees "unless the commissioner determines that the proposed use adversely affects surface water or groundwater."[4] Infiltration of stormwater can introduce contaminants into groundwater, so projects must be designed and reviewed carefully.

[4] §103G.271, subd. 6 (g)

V. Applying the Threshold Approach to Water Use Permitting

A question that came up frequently in our discussions with stakeholders is how DNR would apply thresholds and diversion limits to existing and future appropriation permits. Many stakeholders are concerned about the implications for agriculture, for water-intensive industries and, generally, for economic development. Others are concerned with the effectiveness of the approach in protecting natural resources.

It is important to recognize that in permitting decisions, the DNR must comply with existing statutes and rules, which already direct the DNR to set protected flows for streams and protection elevations for lakes, and to avoid or mitigate any loss of wetlands. Water allocation priorities are also clearly established in statute, while water appropriation rules already include a detailed process for resolution of water use conflicts (Minn. Rules 6115.0740). A water use conflict occurs "where the available supply of waters of the state in a given area is limited to the extent that there are competing demands among existing and proposed users which exceed the reasonably available waters." If a conflict exists, water users have the opportunity to develop a plan for "proportionate distribution of the limited water available among all users in the same priority class."

Based on the recommendations in this report and our existing groundwater management responsibilities, the DNR would set thresholds for specific surface water resources and conduct groundwater modeling in those (limited) areas where surface water features are considered to be at risk due to intensive use of groundwater, or combined surface and groundwater use.

The essential elements of this approach are already being piloted in the three Groundwater Management Areas (GWMAs) that are currently completing their planning phases. A GWMA is a geographic area within which groundwater users share a common and connected groundwater resource that is experiencing increasing use. Users include both those who are required to have appropriation permits and those who do not require permits (i.e., those using less than 10,000 gallons/day or 1 million gallons/year). In each GWMA, the DNR intends to review all appropriation permits over the next five years to ensure that groundwater use is sustainable. The DNR will be collecting additional information and doing additional analysis to inform those permit reviews. If the analysis indicates that current use is not sustainable, the DNR will revise appropriation permits following procedures outlined in rule and statute. In each GWMA, the DNR will consult with a stakeholder advisory group, before it implements or modifies the plans being developed.

Relationship to Permitting

The legislation that directed this report (see inside cover page) does not require or suggest that the report deal with the process or details of groundwater permitting, other than the identification of definitions and thresholds for negative impacts to surface waters. However, identifying definitions and thresholds inevitably, and understandably, raises questions about how the thresholds will be applied in the context of permitting.

A sequence of steps would lead from an established threshold to the individual permitting decision. In areas where detailed groundwater modeling is undertaken, these steps are as follows:

1. The sustainable diversion limit would be defined in terms of a protected flow or elevation for one or more water features.
2. A groundwater model would be used to determine whether existing and/or proposed cumulative groundwater withdrawals in the area (drawing from combination of sources, including streamflow and aquifers) are likely to exceed the sustainable diversion limit.
3. If sustainable diversion limits are exceeded, or likely to be exceeded, then the DNR would establish a planning process involving stakeholders and permittees to evaluate water use priorities and determine options to adjust appropriations and stay below the diversion limit.
4. Individual appropriation permits would be assessed in relation to the cumulative limit. If necessary, appropriation permits would be adjusted at specified intervals so that the cumulative withdrawal limit is not exceeded.

In locations where multiple surface water features could potentially be affected, the most conservative threshold would typically be used, although the location and resource values of a particular surface water feature might be the determining factor.

In areas where detailed groundwater modeling is not available, simpler modeling techniques would be used to determine if individual or multiple water appropriations will negatively impact surface water features. Aquifer tests can be used to evaluate the impact of individual wells.

The DNR strives to ensure that permitting decisions are quantifiable, technically and scientifically sound, and as timely as is compatible with sound decision making. As new information becomes available through groundwater and surface water monitoring, the DNR's intent would be to periodically evaluate diversion limits and adjust water appropriation permits accordingly.

Water users, whether they are public suppliers, agricultural irrigators, industry, businesses or golf courses, need reliability and predictability. Establishing negative impact thresholds and sustainable diversion limits should ultimately improve the predictability and consistency of water appropriation decisions. It should also reduce the need to modify permits during drought and thus allow water users to rely on a fixed quantity in most years, although extreme drought conditions extending over multiple years might still call for emergency water use restrictions.

Establishing negative impact thresholds and sustainable diversion limits is the first step in the process of allocating water resources among individual appropriators. Further discussion is needed as to how best to engage current and prospective water users in allocation decisions once we have determined the amount of available water in a given hydrologic area.

Minnesota's water appropriation statutes were formulated in an era when groundwater resources were viewed as essentially unlimited. Allocating water resources in an environment where those resources may in fact be limited calls for additional research and discussion. Our statutes and rules may need to be revised to provide better guidance. The DNR is currently researching potential models of water allocation systems used in other states and regions as part of this larger discussion.

Local Government Role and Responsibilities

Local governments, through their land use decisions, also play a significant role in determining the number and nature of residential, commercial, and industrial water users. Demand for agricultural irrigation is less affected by, though not disconnected from, local land use decisions. Water users

coming into an existing "neighborhood" of appropriators have the same rights to appropriate water as existing users—i.e., 10,000 gallons/day or 1 million gallons/per year, and are subject to state permitting thereafter. Under Minnesota's riparian water law system, there is no "first in time, first in right" determination and a new permit applicant has no greater or lesser priority than an existing permit holder under state statute, assuming both wish to use water for the same purpose. In planning for future development, local governments should carefully consider the sustainability of their water supplies and the extent to which new water-intensive uses should be encouraged or allowed under zoning and other local regulatory controls. A planning process that considers the needs of all existing water users, future needs, and opportunities for water conservation can help to sustainably manage existing and proposed uses.

Managing Water Allocation in a Complex Environment

Figure 16 depicts some of the issues involved in managing water allocations within a hypothetical hydrologic area. It shows a number of wells in proximity to the various types of surface water bodies discussed in this report. Note that the area is not a watershed, as typically defined by surface features, but rather is defined based on groundwater use and relationships among aquifers and surface water bodies. A sketch like this one has proved helpful to stakeholders in illustrating the DNR's approach to applying protected flows and protection elevations to allocation management issues within a given area.

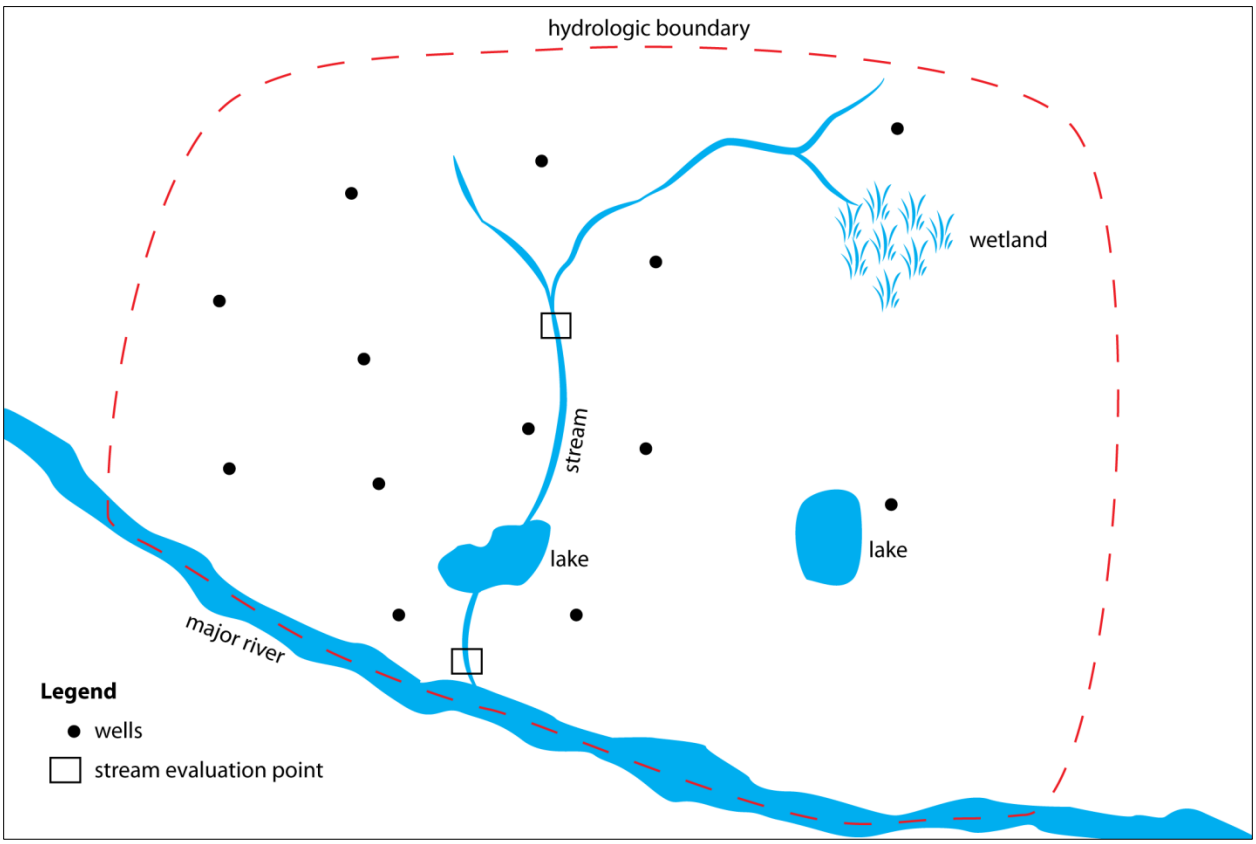

Figure 16. Example of hydrologic area with surface water features potentially affected by groundwater appropriations.

Typically:

- Effects on streamflow from the wells close to the stream will be greater than effects from the wells further away.
- Effects on streamflow in the upper reaches of the stream will usually be proportionally greater than effects in the lower reaches, since the base flow in the upper reaches is lower.
- The diversion limit for the lake connected to the stream would generally be that of the stream.
- The diversion limit for the isolated lake would be based on its water level records, key resources, and riparian uses, all of which contribute to a water budget that is used to establish a protection elevation.
- The water regime for the wetland may also affect the flow of the tributary stream.
- The wells in the illustration may serve multiple use categories, such as irrigation, municipal, golf course, and industrial users. Each falls into a different 'priority' class according to statute (§ 103G.261). If the amount of water available for use is less than the amount of water requested for appropriations, these priorities would need to be reflected in the final allocation plan.

VI. Statutes and Rules: Potential Changes Needed

After careful consideration of the existing water appropriation statutes, the DNR recommends a number of changes that we believe will clarify the relationship between surface water and groundwater resources and, most importantly, appropriately reflect their interconnected nature. While statute and rule already provide the DNR with the authority to set protection elevations and protected flows, and to determine when a groundwater appropriation will have a negative impact on surface water resources, the following revisions to statute would better reflect our proposed approach to establishing negative impact thresholds and sustainable diversion limits. Although some stakeholders have advocated for a numerical limit to water diversions that can be applied statewide, we believe that this is not a practical, feasible, or protective approach, given Minnesota's diversity of climatic conditions, land use patterns, and water resources, all of which point to a need for more resource-specific limits.

Definitions: We recommend incorporating the following definitions into Chapter 103G. These concepts are presented in greater detail in Section III of this report.

- Negative impact to surface waters – in relation to water appropriations, a change in hydrology sufficient to cause ecosystem harm or alter riparian uses long-term.
- Ecosystem harm – in relation to water appropriations, to change the biological community and ecology in a manner that results in a less desirable and degraded condition.
- Sustainable diversion limit – in relation to water appropriations, a maximum amount of water that can be removed directly or indirectly from a surface water body in a defined geographic area on an annual basis without causing a negative impact to the surface water body.

Integration of Groundwater and Surface Water Provisions: There is a circular relationship between two sections of statute that deal with surface water and groundwater. Currently, Section 103G.285 establishes limits for withdrawals from surface water bodies (watercourses and basins), while Section 103G.287 establishes standards for groundwater appropriations. However, "groundwater appropriations that will have negative impacts to surface waters are subject to applicable provisions in section 103G.285" – in other words, to the surface water provisions.

The circularity of the relationship between these sections has been challenging to understand and apply in practice. It is difficult to identify a negative impact on a surface water body without examining all the water appropriations – from groundwater and surface water – that combine to affect that surface water body. If the analysis indicates that a negative impact is likely, it is difficult to set limits on groundwater use based on the standards in 103G.285, which is geared toward surface water withdrawals (i.e., a pipe withdrawing water from a stream or lake).

Therefore, the DNR recommends combining many of the standards in these two sections into a single "Water Appropriations" section that would recognize the hydrologically connected and interdependent nature of surface and groundwater resources. The timeline for preparation of this report did not allow the DNR to prepare detailed statutory language reflecting our recommended approach. We are currently consulting with other state agencies and stakeholders and do plan to develop draft language. At a conceptual level, elements of our proposal include:

- Incorporating the provisions for "protection of water supplies" currently in 103G.287, subd. 3 and the "sustainability standard" in 103G.287, subd. 5 into the combined Water Appropriations section. These broad standards should be applicable to all water supplies and appropriations, not just groundwater resources.
- Using the term "protected flows" (already defined in Minn. Rules) to replace "specified low flows" for watercourses. "Low flows" are often interpreted as a single point at which surface water appropriations are cut off, while "protected flows" are intended to maintain the seasonal variability in flow that is needed for a healthy stream ecosystem. As discussed in Section III, imposing a single cut-off point does not preserve this variability. Criteria for determination of protected flows would to be articulated. These would include considerations such as temperature and vegetation.
- Using and clarifying the term "protection elevation," replacing the "one-half acre foot" standard for surface water withdrawals from lakes and other basins. The one-half acre foot standard has been difficult to apply to groundwater withdrawals and has tended to encourage use of groundwater as a substitute for surface water. Existing criteria for determining the protection elevation (elevation of habitat-related aquatic vegetation, existing riparian uses, the volume of the basin and the slope of the littoral zone) could be expanded to provide additional guidance.
- Surface water appropriations from trout streams would remain limited to temporary appropriations. Groundwater appropriations affecting trout streams would be subject to the same standards as other watercourses, in terms of setting protected flows. Including factors such as temperature and vegetation in this process should ensure that the unique values of trout streams are protected.
- In locations where protected flows and/or protection elevations need to be established, a public process that involves water users, including irrigators, public water suppliers, recreationalists, and others, could be established, to better understand the multiple resource values and trade-offs that must be considered in setting these limits.

Next Steps: The DNR is working with stakeholders, including permittees, local and regional agencies, legislators, and state water management agencies, to develop and refine potential statutory language. Additional changes to state rules would likely be needed to align with the new statutory language and provide more detailed discussion of the process for setting thresholds and sustainable diversion limits.

The approaches outlined in this report for establishing protected flows, protection elevations, and sustainable diversion limits for streams, lakes, and wetlands have not yet been applied in Minnesota. The DNR intends to continue implementing and evaluating these approaches in various settings where surface water resources appear vulnerable to groundwater appropriations. The results of these evaluations may also be valuable in updating and clarifying state rules on water appropriation management.

VII. Conclusions

The following key points summarize the findings and recommendations in this report:

Minnesota is in the "urgency room," not the "emergency room," in terms of water use management. Minnesota has plentiful water supplies. Even so, there are several places around the state where demand for groundwater may be greater than supply. These places tend to be in the drier southwestern areas of the state, in the heavily irrigated central sands, and in the Twin Cities Metropolitan Area (see map on page 10).

The state's water management policies, statutes, and rules are strong and conceptually sound. It is the policy of the state that we try to maintain the natural pattern of fluctuating hydrographs (e.g., spring high flows, late summer low flows) in our surface and groundwater systems. Statutes and rules allow the DNR to preserve those natural patterns by establishing protected flows for streams and protection elevations for basins. In addition, the state has established "no net loss" policies, statutes, and rules for wetland management and a protective statute for calcareous fens.

The state's water management statutes could be improved. It would increase statutory clarity to define "negative impacts," "ecosystem harm," and "sustainable diversion limits." Another clarifying step would be to combine the statutes on surface water and groundwater appropriations, to emphasize the hydrologic connections between surface water and groundwater.

There is a strong scientific basis for maintaining the natural dynamic patterns of surface water bodies by establishing protected flows for individual streams, protection elevations for individual basins, and target hydrographs for wetlands. Science indicates that our streams, basins, and wetlands are vulnerable to undesirable ecosystem change during conditions of low flow, low elevation, or deviation from the target hydrograph, respectively. These conditions will be made worse during regular, periodically occurring severe drought.

- Protected flows in streams should be based on 10-15% of median low flows. Generally, the median low flow occurs in August (see pages 16-19).
- There are two types of basins that require different approaches to setting protective elevations. One is a basin with a stream that regularly flows out of it. This type of basin can be managed using a protected flow for the outflowing stream. The other is a basin with infrequent surface water outflow. This type of basin will need a protection elevation that reflects its regularly occurring, natural lake level patterns, resource values and riparian uses (see pages 20-24).
- Wetland hydrographs can be characterized and used to set targets for low water levels through development of target hydrographs (see pages 24-26).

Over the next five years, the DNR intends to set protected flows, protection elevations, and target hydrographs for water bodies in places where demand for water may be exceeding sustainable supplies. The DNR is currently establishing three groundwater management areas in parts of the state experiencing high demand for groundwater (see page 33). The DNR will set protected flows, protection elevations, and target hydrographs for some surface waters within these groundwater management areas, and potentially in other areas of the state, as described above, in order to manage water appropriations. The changes to statute recommended in this report would help support that work.

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Glossary of Terms

7Q10 – the seven-day, ten-year summer low flow, typically used in water quality assessments.

Aquifer – any water-bearing bed or stratum of earth or rock capable of yielding groundwater in sufficient quantities that can be extracted (Minn. Rules, part 6115.0630, subp. 2).

Appropriating – withdrawal, removal, or transfer of water from its source regardless of how the water is used (Minn. Stat., sec. 103G.001, subd. 4).

Base Flow: Sustained, gradually varying or steady flow in a stream provided by groundwater discharge, the near surface soil profile, bank storage and wetland and lake storage

Basin – a depression capable of containing water which may be filled or partly filled with waters of the state. It may be a natural, altered, or artificial depression (Minn. Rules, part 6115.0630, subp. 5).

Cfs – cubic feet per second, used to measure streamflow.

Confined (artesian) aquifer – a water body or aquifer overlain by a layer of material of less permeability than the aquifer. The water is under sufficient pressure so that when it is penetrated by a well, the water will rise above the top of the aquifer. A flowing artesian condition exists when the water flow is at or above the land surface (Minn. Rules, part 6115.0630, subp. 4).

Drought – as defined in the U.S. Drought Monitor. Severe drought has a range of -3.0 to -3.9 and extreme drought has a range of -4.0 to -4.9 on the Palmer Drought Severity Index.

Normal (climate) – the average of a climate variable such as precipitation or temperature over a standard 30-year period (e.g., 1981–2010).

Protected flow – the amount of water required in the watercourse to accommodate instream needs such as water-based recreation, navigation, aesthetics, fish and wildlife habitat, water quality, and needs by downstream higher priority users located in reasonable proximity to the site of appropriation (Minn. Rules, part 6115.0630, subp. 12).

Protection elevation – the water level of the basin necessary to maintain fish and wildlife habitat, existing uses of the surface of the basin by the public and riparian landowners, and other values which must be preserved in the public interest (Minn. Rules, part 6115.0630, subp. 13).

Q90 – the stream discharge that statistically was exceeded 90% of the time during the period of record analyzed.

Recharge – the natural or manmade infiltration of surface water into the groundwater system.

Riparian – relating to or located on the bank of a natural watercourse or water basin.

Water table -- Water beneath the land surface occurs in two principal zones: the unsaturated zone and the saturated zone. **The upper surface of the saturated zone is referred to as the water table.** Below the water table, the water pressure is great enough to allow water to enter wells, thus permitting groundwater to be withdrawn for use. The depth to the water table is highly variable, ranging from zero when it is at land surface, such as at a lake or wetland, to hundreds or even thousands of feet deep. **In Minnesota, the water table is generally close to the land surface**, typically within a few tens of feet in much of the state.

Water-table aquifer or unconfined aquifer – an aquifer where groundwater is under atmospheric pressure (Minn. Rules, part 6115.0630, subp. 17), allowing the water level to easily rise and fall.

Well interference – A situation where an appropriation reduces water levels beyond the reach of public water supply and private domestic wells constructed according to Minn. Rules, part 4725 (Minn. Stat., sec. 103G.287, subd. 5; Minn. Rules, part 6115.0730).

Appendix A: Stakeholder and Public Input

The Thresholds Project has benefited from substantial involvement by stakeholders and other interested parties. Key meetings and presentations are listed below and discussions are summarized.

Selected Project Meetings and Presentations		
Date	**Meeting Description**	**Meeting Purpose**
7/22/2015	Streams Advisory Work Group Meeting 1	Introduce project; review scientific literature and options
8/6/2015	Wetlands Advisory Work Group Meeting 1	Introduce project; discuss classification schema for wetlands (types, hydrogeologic settings, etc.). Under what circumstances are wetlands vulnerable to groundwater withdrawals; can negative impacts can be identified and measured?
8/13/2015	Streams Advisory Work Group Meeting 2	Further discussion of options; group recommendations for thresholds and management prescriptions; review material for presentation to stakeholders
8/26/2015	Stakeholder Advisory Group Meeting 1	• Orient stakeholders to the project and the people • Develop a shared understanding of the charge from the legislature • Hear stakeholder perspectives and questions about the project and preferences for future meetings and engagement opportunities
9/3/2015	Lakes Advisory Work Group Meeting 1	Discussion of how to characterize and set thresholds – Part 1
9/17/2015	Lakes Advisory Work Group Meeting 2	Discussion of how to characterize and set thresholds – Part 2
Various	Lakes Advisory Focus Group Discussions	Shallow Lake Impact Evaluation Criteria/Process – 10/29/2015 Recreational Uses Impact Evaluation Criteria/Process – 11/6/2015 Fish Habitat Impact Evaluation Criteria/Process – 11/13/2015
9/23/2015	Wetlands Advisory Work Group Meeting 2	Discuss and refine “target hydrograph” approach, hydrologic groupings of wetland types, treatment of degraded wetlands
9/30/2015	Stakeholder Advisory Group Meeting 2	• Discuss hydrology and ecology of MN lakes, streams and wetlands • Background on the statutes and rules for water appropriations related to these features • Discuss possible approaches to further defining or clarifying statutes and rules • Hear stakeholder perspectives about the types of information available and possible approaches
10/14/2015	Water Resources Conference	Introduction to project, discussion of DNR’s approach to groundwater management
10/20/2015	Metro District, MN Association of Watershed Districts	Introduction to project and issues; discussed possible approaches to thresholds for negative impacts
10/21/2015	Stakeholder Advisory Group Meeting 3	• Continue discussion on hydrology and ecology of MN lakes, streams and wetlands, groundwater recharge, and the permit process • Discuss underlying principles and possible approaches to establishing thresholds for negative impacts to streams, lakes, and wetlands

Selected Project Meetings and Presentations		
11/4/2015	Legislative Water Commission	Update on status of project and preliminary findings; discussed possible approaches to thresholds for negative impacts
11/12/2015	Stakeholder Advisory Group Meeting 4	• Review partial draft report • Discuss impressions and concerns re proposed definitions and thresholds
11/16/2105	Clean Water Council	Update on status of project and preliminary findings
12/10/2015	Stakeholder Advisory Group Meeting 5	• Review Final Stakeholder Review Draft of report • Discuss next steps and ongoing outreach

Website: A page for the project was established on the DNR website under "Groundwater Management." Presentations, meeting summaries, and drafts of this report have been posted in accessible format. An email address was established for comments and questions on the report.

E-mail bulletins: The DNR established a mailing list through the GovDelivery service that is used to send most state agency newsletters. As of December 2015, the list had about 400 subscribers and eight bulletins had been sent providing details on upcoming meetings, summaries of meeting discussions, and links to the project webpage.

Highlights of Stakeholder Meetings

Meeting 1: Invited stakeholders and other participants were asked about their initial thoughts on the project. Participants shared their specific concerns and those of their interest groups on topics such as well-drilling, watershed protection, golf-course management, and water conservation.
Attendees discussed the project's scope, timeframe, and stakeholder engagement process. Additional participants were suggested, and a fifth meeting was added to the schedule based on suggestions. Participants were interested in exploring:

- Adaptation to increasing demand
- The interconnectedness of water appropriation statutes/rules with other statutes/rules, federal regulations
- How DNR makes permitting decisions
- Climate change considerations
- Mitigation actions that can reduce negative impacts, such as stormwater reuse

Meeting 2: The meeting was focused around four presentations: 1) Climatology/Hydrology; 2) Streams; 3) Lakes; and 4) Wetlands. Participants had many questions about technical and policy aspects of each presentation. General discussion followed the presentations. Topics discussed included:

- Implementation of stream thresholds – how these could be managed equitably across an aquifer and how often thresholds would be re-evaluated
- For wetlands, relevance of current conditions vs. past status
- Impacts of stormwater (MS4) requirements for cities on total runoff and recharge
- Impacts of new water users coming in to an area
- Nitrate contamination of groundwater
- Effects of other water diversions such as sump pumps and tiling systems
- Priorities in statute for water use (i.e., "essential" and "non-essential" uses)
- The DNR's organizational and staff capacity to implement these approaches

- Relationship to other planning processes such as One Watershed One Plan, community Water Supply Plans, etc.

Meeting 3: This meeting included three presentations: 1) Potential Groundwater Recharge (USGS model); 2) Water Appropriations; and 3) Hydrogeology and Groundwater Modeling. Potential approaches to setting thresholds were presented.

Discussion focused on recharge issues, including including effects of pattern tiling, land use data, lakes and wetlands, and potential uses of the recharge model. Questions were raised about how much water is authorized in appropriation permits compared to how much is actually pumped statewide, and on estimates for the amount of pumping from domestic wells.

Small group discussions focused on several key questions/concerns: the way streams, lakes, and/or wetlands are impacted by groundwater appropriations, the approaches presented by the DNR to developing thresholds, and the DNR's approach to making permitting decisions.

Responses were focused around several themes:

- The challenges of factoring in seasonal impacts, climate changes, and particularly sensitive systems such as cold water streams
- Questions regarding the availability of sufficient data, the feasibility of applying the threshold approach, the DNR's capacity to monitor conditions
- Questions about where thresholds would need to be established, given Minnesota's diversity of hydrologic and climatological conditions
- Concerns about the implications for existing permit-holders under drought conditions or if negative impact thresholds are crossed
- Concerns about the differences between natural fluctuations and human-induced impacts and the degree to which ecosystems can rebound from periods of water scarcity

Meeting 4: This meeting was focused on a review of a partial draft of this report that included draft definitions and methods for establishing thresholds for streams, lakes and wetlands. Small group discussions focused on ideas for improving the working draft, definitions, approaches and rationale for thresholds. Among the issues discussed were:

- Additional concerns regarding availability of data and the DNR's capacity to implement the suggested approaches
- Extensively altered systems (i.e., many wetlands) and how these might be managed
- How to quantify negative impacts and suggestions for more or less restrictive language
- Differences between actual water use and permitted use, and whether the amount of water being permitted is sustainable
- Suggestions for greater emphasis on groundwater recharge

Meeting 5 and additional comments on draft report: This meeting was devoted to a review of the draft report, focusing on proposed definitions, proposed statutory changes, and approaches to establishing thresholds and sustainable diversion limits. Among discussion topics were:

- Preference for a public process that could evaluate socioeconomic impacts of various appropriation scenarios
- Pros and cons of 15% and 10% thresholds for streams and for a single recommendation vs. a range of options

- Discussion of terminology such as “desirable” and “degraded,” and whether these are overly subjective or vague; who makes these determinations
- Potential effects of limiting appropriations on businesses, local governments
- Concerns regarding applicability of proposed thresholds to cold water (trout) streams

On the process as a whole, comments included appreciation for the inclusive nature of the process and the value of conversations among participants. There was some frustration with the tight schedule and not enough opportunities to discuss the recommendations in detail.

Summary of Stakeholder Comments

Stakeholder comments, when reviewed, express three basic themes. We have tried to address each of these in this report, as follows.

1) Questioning the availability and quality of the data needed to establish negative impact thresholds and sustainable diversion limits, as well as the DNR’s staffing capacity to conduct the needed research.

> Response: We believe the recommendations in this report can be implemented in those locations where groundwater use may be putting surface water resources at risk. The DNR is already working with water users, local governments and other stakeholders to manage water use in the three Groundwater Management Areas and other local areas such as the Little Rock Creek watershed.

2) Concern regarding the potential impacts of setting thresholds on individual permit holders, including agricultural irrigators, businesses and municipal users and, by extension, regional economies.

> Response: As noted in section V, the DNR intends to set thresholds for specific surface water resources and conduct groundwater modeling in those parts of the state where surface water features are considered to be at risk due to intensive use of groundwater, or combined surface and groundwater use. We agree that an inclusive public process can assist in establishing thresholds and acceptable diversion limits. Permit-holders in these areas should not anticipate sudden “cut-offs” of their appropriations, but should expect gradual adjustments at defined intervals, as monitoring and modeling yield more information.

3) Concern over aspects of water management not directly addressed in this report, including issues such as water quality and water allocation priorities.

> Response: We anticipate that many of these issues will continue to be discussed in the context of potential statutory changes, through the efforts of other state water management agencies, and under the auspices of other multi-disciplinary bodies such as the Clean Water Council and the Environmental Quality Board. The DNR is currently researching potential models of water allocation systems in other states and regions to add to this discussion.

Appendix B: Example of Setting Protection Elevations for a Lake

This appendix illustrates a hypothetical example that illustrates some of the issues involved in setting thresholds and establishing sustainable diversion limits for a lake with multiple riparian uses. A hypothetical example is used because a full analysis of an actual surface water body is beyond the scope of this report.

The hypothetical lake is a deep lake with extensive shallow areas. It frequently has periods when its water level is below the runout elevation and there is no surface outflow (see Figure B1 below). It is used extensively for boating and also has a strong fishery supported by a diverse aquatic plant community.

The process to set diversion limits involves four steps, as described in pages 20 through 24 of this report. Figure B1 shows the lake level measurement records that are available for the lake. The first step is the development and calibration of a water budget model assuming no appropriations affecting the lake. The water budget model uses precipitation and temperature patterns and inflow and outflow estimates to simulate lake level changes. Fig B2 shows the lake level predictions from the water budget model. The water budget model allows us to test how lake levels would respond to various amounts of appropriation activity.

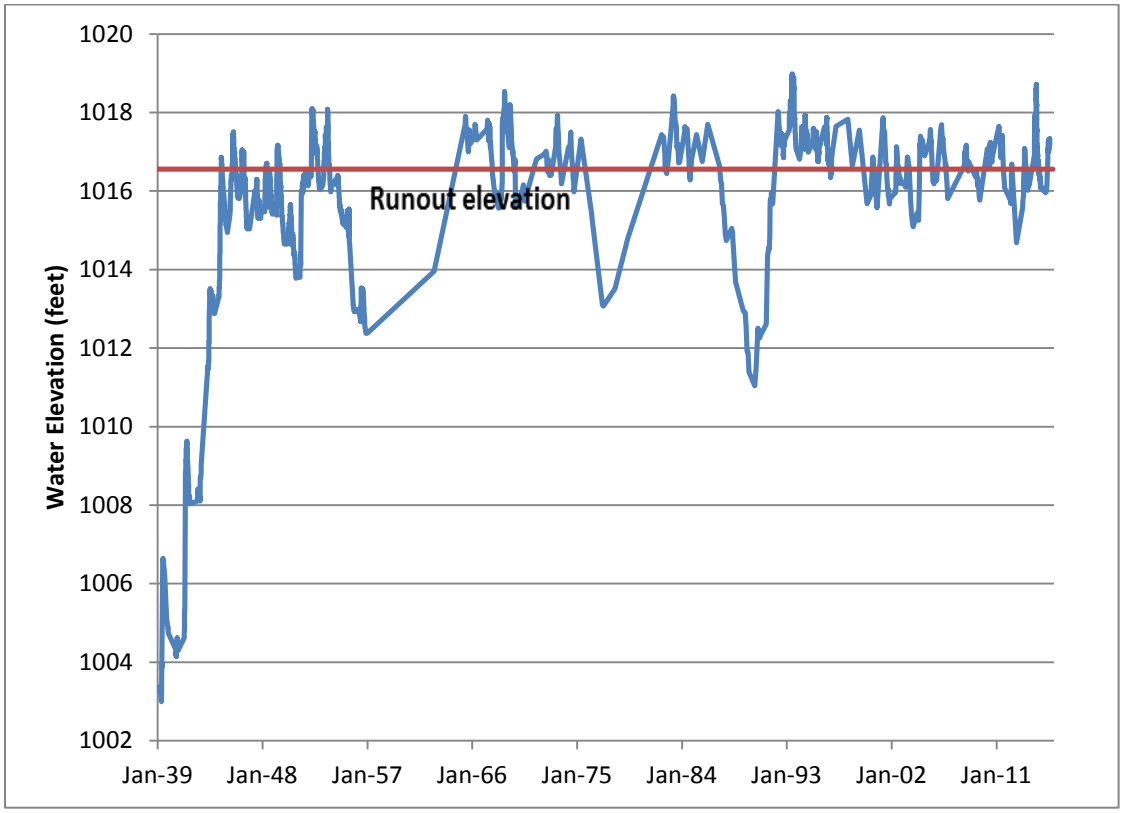

Figure B1. Lake level records for period of record

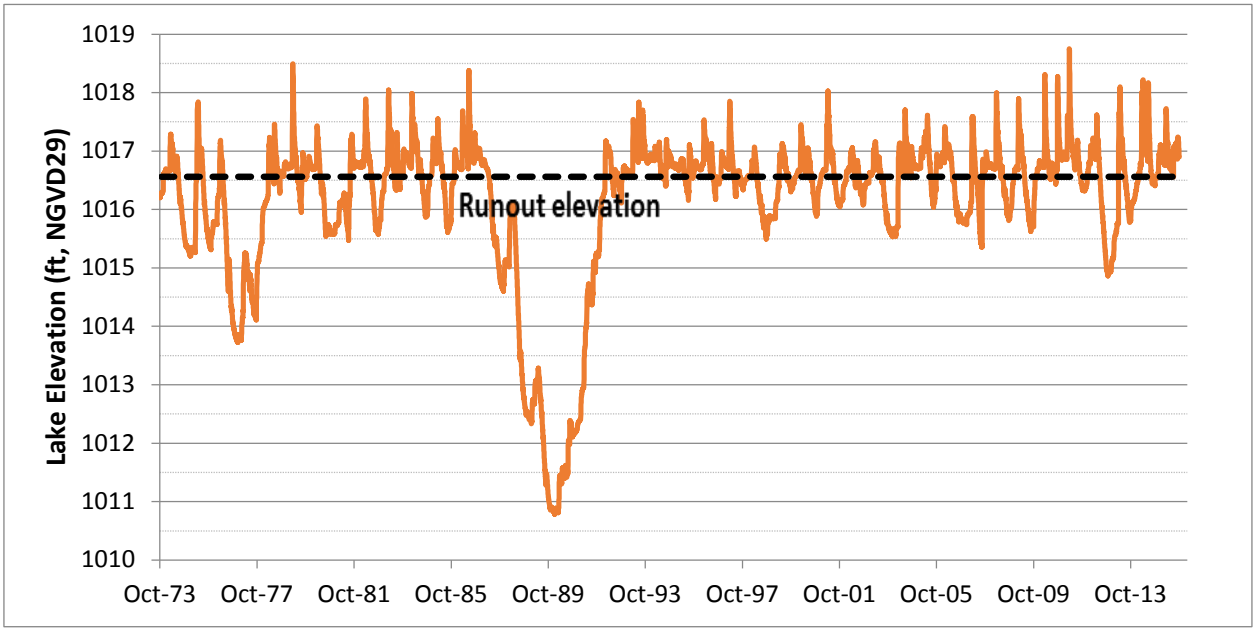

Figure B2. Water budget model for lake

The second step in the process is to convert the water budget results into a water level exceedance curve (Figure B3). The curve represents how often the lake level has been at or above a specific elevation.

The third step in the process is to identify lake levels that limit or impact specific uses. In this example we are going to identify thresholds to maintain recreational use and protect aquatic plant habitat.

The DNR typically designs a public access so that it is usable down to the ordinary low water level. In this example, at elevations below 1,015.5 feet the public access is no longer usable. As shown in Fig. B2, the public access will become unusable for short periods of time in some years but can be unusable all year when the lake is at exceptionally low levels.

The lake has two large basin connected by a shallow channel. Boating through the channel between the two basins becomes infeasible when lake levels drop below an elevation of 1,013 feet.

The critical water level necessary to sustain the lake's aquatic plant community was identified at 1,014.3 feet. If water levels drop below 1,014.3 feet for extended periods, impacts to the aquatic plant habitat are expected to occur. Figure B3 shows a lake level exceedance curve with the three different lake levels.

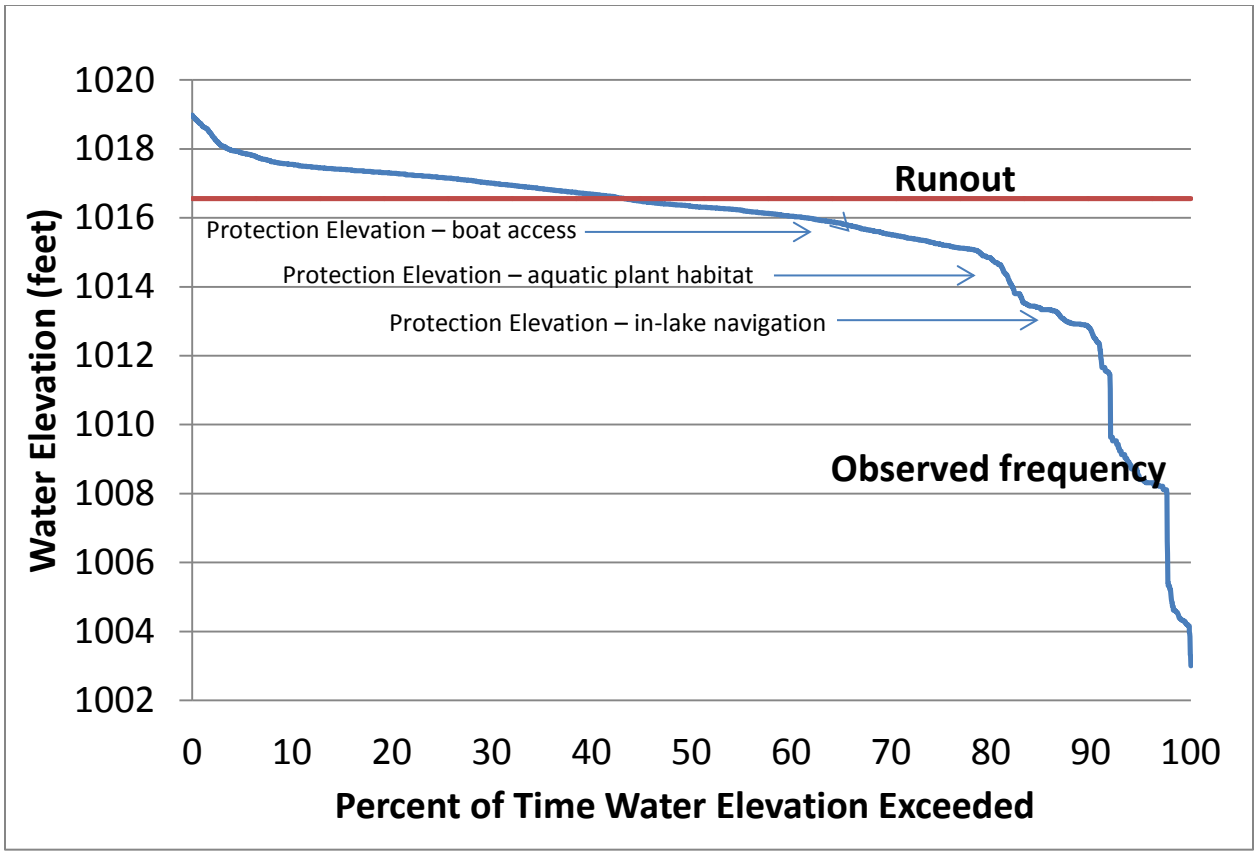

Figure B3. Exceedance curve with protection elevations

The fourth step of the process is to simulate the impact of appropriation loss. There are currently no surface or groundwater appropriations from the lake. For this example, two levels of appropriation loss were evaluated: a volume equivalent to two inches and a volume equivalent to four inches from the lake's surface area. The two scenarios shown in the chart below used the water budget model to simulate how this appropriation activity would have impacted the lake's water level during the during the critical May – September portion of the year. Figure B4 indicates how these levels of appropriation would affect the frequency of lake levels falling below the protection elevation for the three identified functions of the lake: boat access, aquatic plant habitat, and in-lake navigation.

The three scenarios are:

1. No appropriation
2. Level 1: 2 inches removed annually
3. Level 2: 4 inches removed annually

Finally, in the fifth step of the process, the DNR would gather public input to help determine how much change in water levels and water level frequencies could be allowed before a negative impact threshold was crossed. In this example, boat access elevation might be judged to be the most sensitive. Under Scenario 2, boat access would be limited an average of four additional days per boating season, while Scenario 3 would affect access an additional 19 days. When setting the negative impacts threshold, the input from one or more of the resource assessments could be used. In this case, the predicted impact of Scenario 3 on both access and aquatic plant habitat might be deemed unacceptable.

Additional scenarios would need to be evaluated if there are other important natural resource features or ecological endpoints that need to be considered. For example, for a shallow lake that provides significant waterfowl habitat, more drawdown might be desirable to improve the habitat. For a wild rice lake, a higher protection elevation may be desirable. Public input should also be considered in understanding the uses and resources of the lake when establishing a protection elevation.

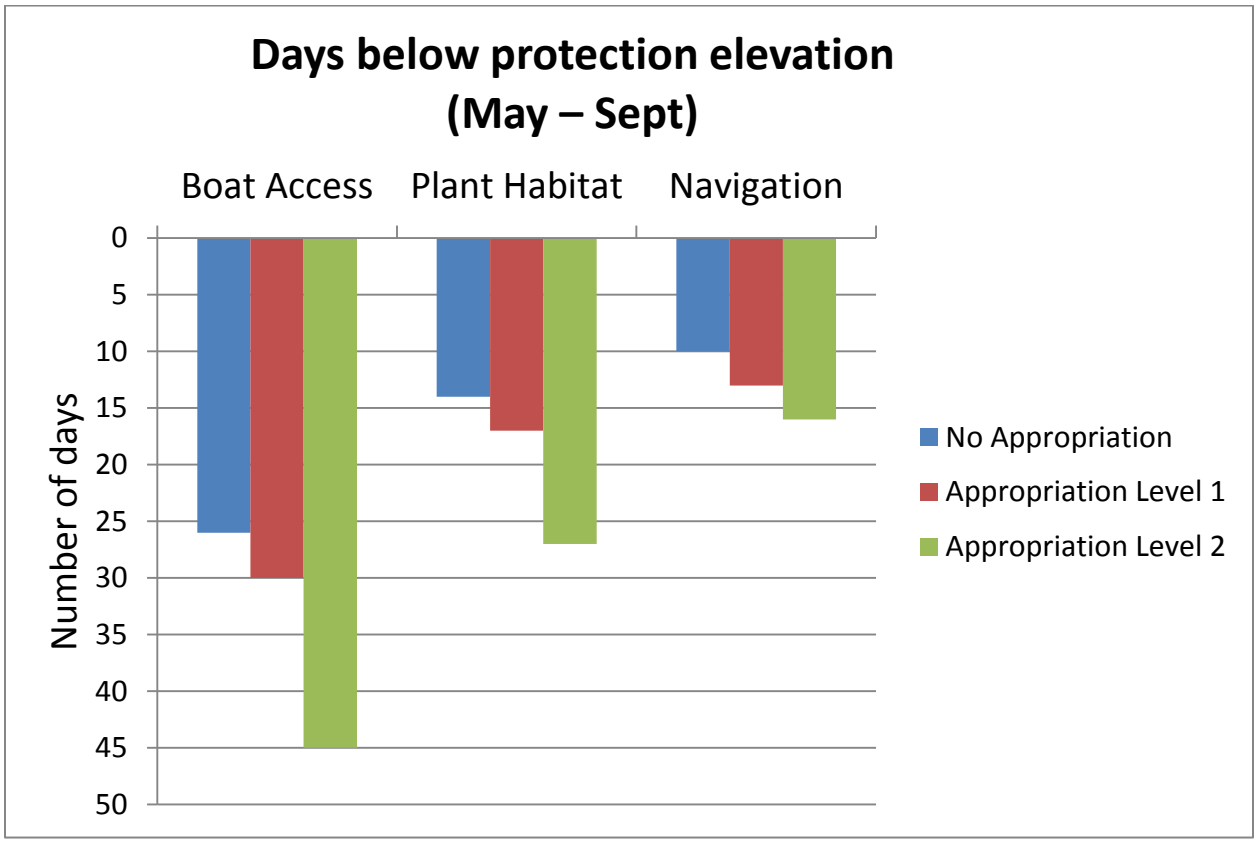

Figure B4. Three appropriation scenarios for lake levels

Appendix C: Examples of Percent of Flow Approach Used for Water Management

The table below illustrates examples of water management approaches used in other jurisdictions that restrict both groundwater and surface water allocation. Table adapted from Richter et al., 2011, with updates. Presence in the table does not imply applicability to Minnesota.

Location	Ecological Goal	Cumulative allowable depletion	Considerations	Decision process
Florida (SWFWMD)	Avoid significant ecological harm (maximum 15% habitat loss)	8-19% of daily flows	Seasonally variable extraction limit; 'hands-off' flow (no withdrawals below)	Scientific peer review of site-specific studies
Michigan	Maintain baseline or existing condition	6-15% of August median flow	Single extraction limit for all flow levels	Stakeholders with scientific support
Maine	Protect class AA: 'outstanding natural resources'	10% of daily flow	Single extraction limit for all flow levels above a 'hands-off' flow level	Expert derived
Massachusetts	Sustainable management of water resources that balance human and ecological needs	Basin safe yield: 55% of annualized Q90 For sub-basins, maximum level of August median streamflow alteration ranges from 3-10% for Categories 1 and 2 for each season.	Seasonal extraction limit based on category	Expert, scientific support
Rhode Island	Maintain habitat conditions essential to a healthy aquatic ecosystem	6 Bioperiods and 5 classes Summer Period Class 1-3 streams can deplete 10, 20, and 30% of the 7Q10, respectively	Allocation limited by cumulative streamflow depletion Identify allowable depletion limit even during dry conditions	Scientific support, stakeholders, public process
European Union	Maintain good ecological condition	7.5-20% of daily flow 20-35% of daily flow	Lower flow; warmer months; 'hands-off' flow Higher flow; cooler months	Expert derived

Appendix D: Project Participants and Advisors

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