Lake Prioritization for Protecting Swimmable Use

Part of a series on Minnesota Lake Water Quality Assessment

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Executive Summary

The quality of many of Minnesota's lakes is impaired as a result of cultural eutrophication. Reading from Minnesota's 1994 305 (b) Report to Congress *".....of lakes less than 5,000 acres (99 percent of Minnesota's lakes) only 51 percent fully support swimmable uses......Nutrients are the primary pollutants that degrade lake water quality below use thresholds and phosphorus (P) is the most significant of these."*

In a world with unlimited dollars for monitoring lakes and restoring lakes with impaired water quality there would be little need to prioritize activities. However, since there is a limited amount of dollars for these activities at the national, state, and local levels, there is a need to prioritize those dollars and energies that are spent on these activities -- especially in a state like Minnesota with such a large water-resource base. Further, given the expense of restoration activities, typically measured in the hundreds of thousands of dollars per lake, it is wise to protect lake condition whenever possible. Thus, we are proposing a prioritization system that can be applied at a state, basin (watershed), or county level to assist in determining which lakes might be prioritized over others for *monitoring*, *protection*, and/or *restoration*.

A decision tree approach was used as a means for conducting the prioritization. In the prioritization scheme the *primary* emphasis is placed on protecting those lakes which currently have good water quality and monitoring those with inadequate data. A *secondary* emphasis is on the prioritization of lakes for purposes of restoration. MPCA's ecoregion-based P criteria, in conjunction with Carlson's TSI, served as a primary basis for developing the prioritization. In the overall scheme, lake size was used in the prioritization and, in particular, lakes of 100 acres or more would be of a higher priority for protection, restoration, and/or more extensive monitoring. Other considerations which could be used for further prioritization if data are available (e.g., in a local water plan or watershed district plan) could include: mean depth, watershed size, public access, land use in the shoreline and immediate watershed, and--perhaps most importantly--*proposed* changes in land use in the watershed.

Once lakes are prioritized there must be some likely outcomes or actions to be instituted. A brief discussion of some options is provided. Opportunities to implement these options may vary between basins, watersheds, or counties, depending on available resources.

- **Monitoring** - Under this category the following options were offered: Citizen Lake Monitoring Program (CLMP), Lake Assessment Program (LAP) level, tributary monitoring and Clean Water Partnership Program (CWP) level (diagnostic-feasibility). Within each of these categories there may be some subcategories or enhancements which might be conducted as well.

- **Protection** - Projects instituted as part of a *protection* project are not that much different than those that might be addressed in the course of a restoration. The main difference might be the associated costs of doing a few projects to *protect* current in-lake conditions rather than numerous projects across a large watershed in an attempt to *improve* in-lake conditions. In small watersheds, identifying effective protection projects may be rather straightforward, while in large or complex watersheds, with a wide mixture of land uses, it may be necessary to monitor major tributaries to identify subwatersheds which yield the highest P loading. Those subwatersheds

yielding the highest P loads should be the focus of further investigation and targeted for protective Best Management Practices (BMPs). (In almost every case, though, it will be essential to develop a lake management plan before implementing extensive watershed projects.) Examples of potential projects and related considerations are presented.

For the MPCA this scheme has been applied in a basin context as a part of the *basin information documents*. However, the scheme can be applied at a county or watershed district level as well (see Appendix). County or watershed authorities employing this scheme could use this prioritization as a starting point or a framework for developing their priorities for advanced monitoring and protection. Additional factors can and should be included if information is available. In addition to the considerations used in this scheme, county and watershed authorities should consider input from citizen advisory committees, county coalitions of lake associations (COLAs), and others interested and involved in the monitoring and protection of water resources in their county or watershed. This should allow for broader acceptance of the priorities that are established.

Lake Prioritization for Protecting Swimmable Use

INTRODUCTION

The quality of many of Minnesota's lakes is impaired as a result of cultural eutrophication. Reading from Minnesota's 1994 305(b) Report to Congress *".....of lakes less than 5,000 acres (99 percent of Minnesota's lakes) only 51 percent fully support swimmable uses......Nutrients are the primary pollutants that degrade lake water quality below use thresholds and phosphorus (P) is the most significant of these."*

In a world with unlimited dollars for monitoring lakes and restoring lakes with impaired water quality there would be little need to prioritize activities. Likewise, if all lakes were of good quality or able to attain oligotrophic conditions there would also be little need to prioritize. However, since there is a limited amount of dollars (for these activities) at the national, state, and local levels, there is a need to prioritize those dollars and energies that are spent on these activities -- especially in a state like Minnesota with such a large water-resource base. Ideally, a ranking or prioritization system that leads to a candidate pool of high-priority waters can simplify the task of selecting watersheds for focused management action (USEPA, 1993). Further, given the expense of restoration activities, typically measured in the hundreds of thousands of dollars per lake, it is wise to protect lake condition whenever possible. Thus, we are proposing a prioritization system that can be applied at a state, basin (watershed), or county level to assist in determining which lakes might be prioritized over others for *monitoring*, *protection*, and/or *restoration*.

In order to meet the goals of the Clean Water Act (CWA), the MPCA focuses on whether lakes meet *swimmable* or *fishable* uses. As schemes are developed to prioritize lakes for monitoring, protection, and/or restoration, both aspects of use-support should be considered. Initially, though, they will be addressed separately. The primary reason that lakes in Minnesota are not suitable for swimming is the accelerated aging (cultural eutrophication) which occurs as a result of excess nutrient and sediment loading to the lakes because of human activities in the watersheds.

The use of prioritization/classification systems to focus protection activities has been an important issue in other states as well, e.g., Vermont and Maine (USEPA, 1993). In Minnesota, the need to promote lake protection has been identified in several different forums. For example, the Freshwater Forum convened lay and professional lake "experts" to discuss the status of lake management in Minnesota in 1991. Recommendations in the final report of the forum pointed to the need for a lake classification system and need to promote *lake sustainability*. The working definition of sustainability in this case was "the ability of the lake to assimilate cultural activities while maintaining the preferred condition of the lake.... The preferred condition of a lake is based on its geomorphic and biologic characteristics and relates to past and current uses in and around the lake (Freshwater Forum, 1992)." The MPCA's Water Quality Division (WQD), recognizing P as the primary pollutant causing lake and river eutrophication, assembled an in-house task force to develop an overall strategy for addressing P in MPCA's point and nonpoint source activities. One of the recommendations from that effort was to "broadly promote lake protection initiatives." Further, it was noted that the in-lake P criteria should be used as a basis for prioritizing monitoring and assessment activities and identifying lakes in need of protection (MPCA, 1997). The proposed prioritization scheme in this report will focus on prioritizing lake management activities with respect to the attainment of swimmable use--with an emphasis on protecting lakes which currently have good water quality and support swimmable use.

BACKGROUND

A *proactive* prioritization system is helpful to target prevention and protection efforts at the most vulnerable lake drainage areas (USEPA, 1993). For example, Maine's "Lake Vulnerability Index" uses the hydrologic characteristics of a lake and the rate of watershed development to predict increases in mean lake P over time. The index is used to evaluate the relative vulnerability of a large number of lakes having limited data. Vermont has developed a lake index to identify lakes needing special protection. The Vermont index takes into account the presence of unique features; e.g., whether the lake is threatened by rapid development or whether the lake is vulnerable to impact by having a P concentration in transition between mesotrophic and eutrophic (Garrison, 1995).

P is the primary pollutant associated with accelerated aging or eutrophication of Minnesota's surface waters. It is often the least available nutrient—the "limiting nutrient"— controlling the extent of plant growth in lakes. Rapid and excessive growth of aquatic plants and algae can change the character of a lake and impair its recreational uses. Total phosphorus (TP) is frequently a key parameter in determining the degree of eutrophication in a particular lake. TP concentration also figures prominently in lake protection/classification systems in Vermont, Maine, and other states (USEPA, 1993; Garrison, 1995). In this document P and TP will be used interchangeably.

The prioritization scheme that follows is based on a lake's summer-mean TP concentration as compared to ecoregion-based P criteria (Heiskary and Wilson, 1988). In this scheme lakes are ranked by P concentration relative to other lakes in the same ecoregion. In the absence of P data, other TSI measures--Secchi transparency and chlorophyll a--are used to rank the lakes. Additional considerations in this scheme are the quality (age) of the data used to make the assessment of the surface area of the lake. Each of these features will be discussed further. Two potential uses of the prioritization scheme are for state agency administration and local water plan guidance. Examples of both are included in the appendices.

Ecoregions

Since lake morphometry (size and depth) and watershed characteristics vary between lakes and regions in the state we cannot expect the same level of water quality for all lakes (or regions). Nor is it reasonable to expect that we can "restore" or "rehabilitate" all lakes which have degraded water quality. The *ecoregion framework* can serve as a basis for evaluating lake condition and setting preliminary water quality goals. Ecoregions, areas where the land use and water resources are similar, have been mapped by the USEPA for the lower 48 states based on overlaying maps of land form, soil type, land use, and potential natural vegetation (Omernik, 1987). Minnesota is characterized by seven ecoregions, four of which contain 98 percent of Minnesota's lakes (Figure 1). These four are the Northern Lakes and Forests, North Central Hardwood Forests, Western Corn Belt Plains and Northern Glaciated Plains. The major drainage basins may include one or more of these ecoregions. For example, the Lake Superior basin drains a portion of the Northern Lakes and Forests while the Red

River basin drains portions of five ecoregions. Lake condition may vary substantially across a basin because of these underlying patterns in land use, soil type, land form, and potential natural vegetation.

Lake conditions and lake-basin characteristics vary between regions—from the small, deep lakes of the Northern Lakes and Forests to the large, shallow lakes of the Western Corn Belt Plains and Northern Glaciated Plains. Results of lake observer surveys indicate that the perceptions of what constitutes high transparency or severe algal blooms also varies by region. In general, lake users in northern Minnesota are less tolerant of reduced transparency and blooms than are those in southern Minnesota. Several reference lakes (least impacted lakes in the ecoregion) were selected in each ecoregion and monitored over two to three summers. Data from these lakes along with user perception information derived from the CLMP, an extensive review of the literature, and a review by an expert panel led to the development of P criteria for the "most sensitive uses" within each ecoregion (Table 1). The uses addressed include drinking water, cold water fisheries and primary contact recreation. Since their establishment in 1988, the P criteria have served as a basis for prioritizing and selecting nonpoint source (NPS) projects and setting water quality goals.

Minnesota's P criteria provide a sound basis for determining a lake's ability to support swimmable uses. For the purposes of Minnesota's 305(b) reports to Congress we have used the P criteria in conjunction with Carlson's TSI (Carlson, 1977) as a means to classify lakes relative to support of swimmable use. The following categories of swimmable use support and working definitions are as follows: *full-support* - few algal blooms and adequately high transparency exist throughout summer to support swimming; *support-threatened* - swimmable use is still fully supported, but lake is near the P limit for its ecoregion and small increases in in-lake P could result in increased algal blooms and perceptible decreases in transparency; *partial-support* - algal blooms and low transparency may limit swimming for a significant portion of the summer; and *non-support* - severe and frequent algal blooms and low transparency will limit swimming for most of the summer. By using Carlson's TSI we are able to estimate use support based on chlorophyll-a and Secchi transparency in addition to P. The relationships between TP, chlorophyll-a and Secchi transparency have been well established for Minnesota lakes based on data from the ecoregion reference lakes (Figures 3a and 3b) and other sources. Use-support thresholds for each ecoregion are defined in Figure 2.

Figure 1. Minnesota's Seven Ecoregions

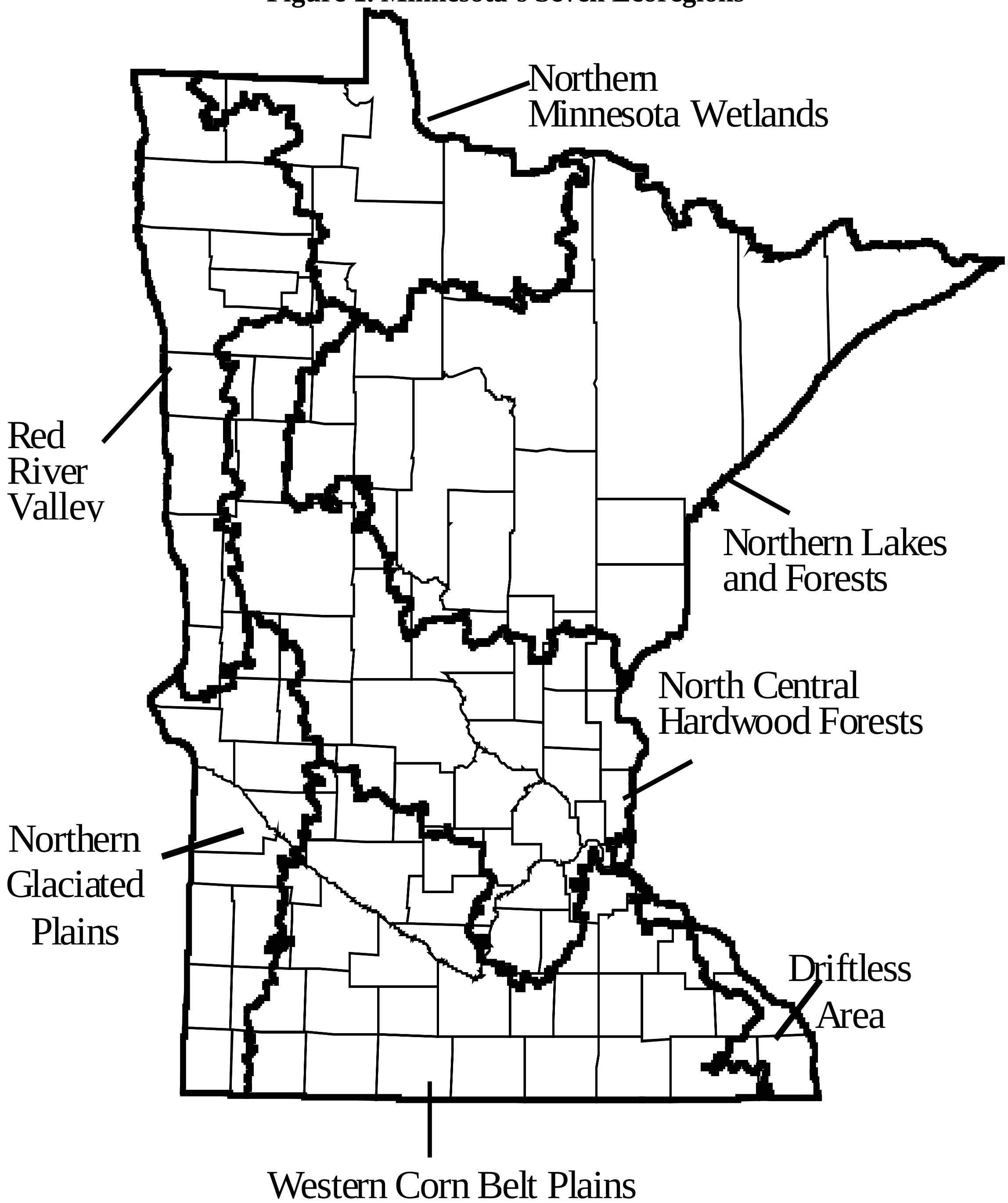


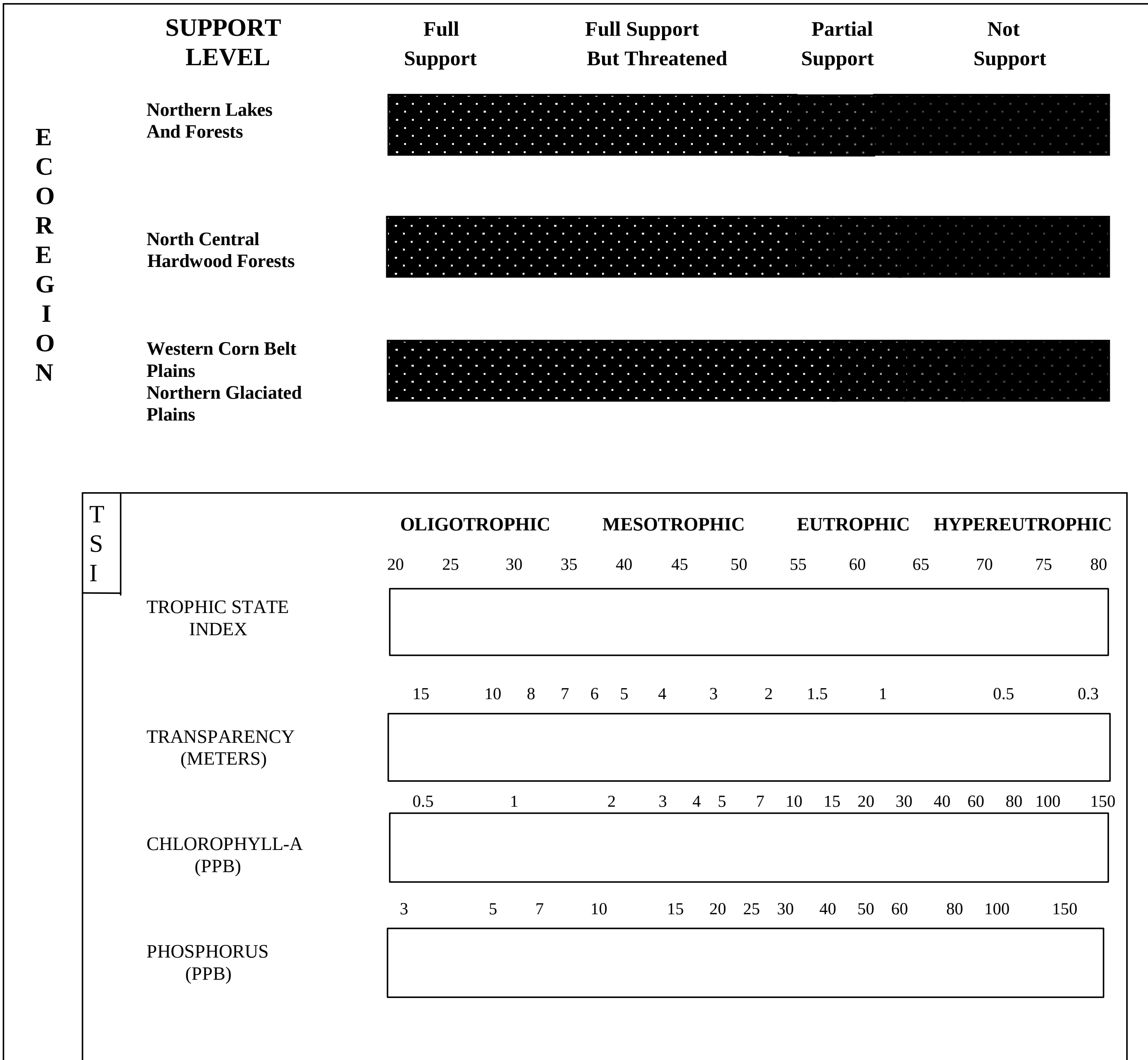
Table 1. Minnesota Lake Phosphorus Criteria (Heiskary and Wilson, 1988).

Ecoregion	Most Sensitive Use	P Criteria
Northern Lakes and Forests	drinking water supply cold water fishery primary contact recreation and aesthetics	**< 15 μg/L** **< 15 μg/L** **< 30 μg/L**
North Central Hardwood Forests	drinking water supply primary contact recreation and aesthetics	**< 30 μg/L** **< 40 μg/L**
Western Corn Belt Plains	drinking water supply primary contact recreation (full support) (partial support)	**< 40 μg/L** **< 40 μg/L** **< 90 μg/L**
Northern Glaciated Plains	primary contact recreation and aesthetics (partial support)	**< 90 μg/L**

The Northern Lakes and Forests and North Central Hardwood Forests ecoregion's P criteria levels, 30 micrograms per liter and 40 micrograms per liter, respectively, serve as the upper thresholds for *support-threatened* swimmable use. Those concentrations correspond to Carlson's TSI values of 53 and 57, respectively. *Full-support* of swimmable use is set at slightly lower concentrations, 25 micrograms per liter and 30 micrograms per liter, respectively, which ensure that conditions associated with "impaired swimming" would occur less than ten percent of the summer. P concentrations above criteria levels would result in greater frequencies of nuisance algal blooms and increased frequencies of "impaired swimming." The upper threshold for *partial-support* of swimmable use was set at 60 and 63 Carlson TSI units, respectively, for these two regions. As P concentrations increase from about 30 micrograms per liter to 60 micrograms per liter, summer mean chlorophyll-a concentrations increase from about 10 micrograms per liter to 30 micrograms per liter (Figures 2 and 3a) and Secchi transparency decreases from about 1.7 m to 0.8 m (Figures 2 and 3b). Over this range, the frequency of nuisance algal blooms (greater than 20 micrograms per liter of chlorophyll-a) increases from about five percent of the summer to about 70 percent of the summer (Figure 4). The increased frequency of nuisance algal blooms and reduced Secchi transparency results in a high percentage of the summer (26-50 percent) perceived as "impaired swimming" (Heiskary and Wilson, 1990).

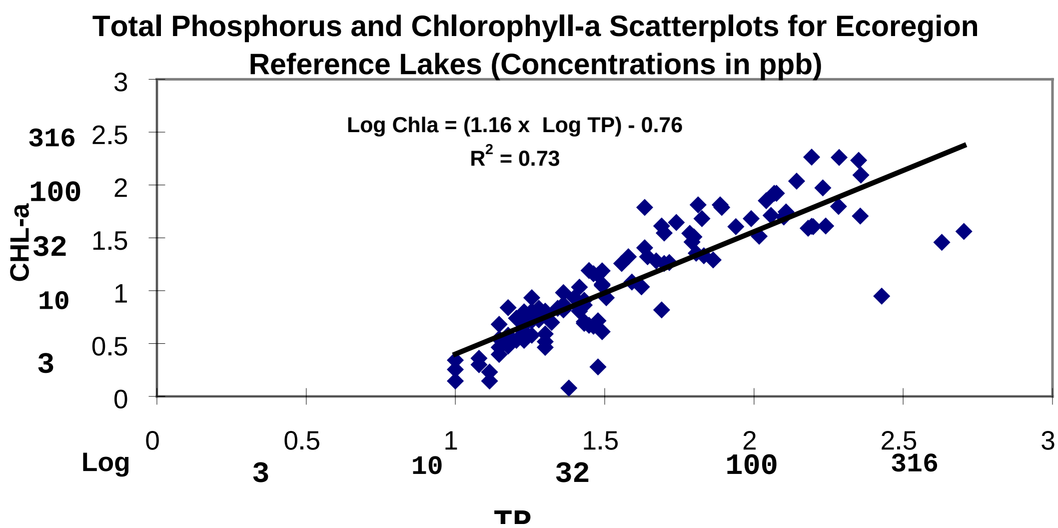
P concentrations above 50 micrograms per liter (Northern Lakes and Forests) and 60 micrograms per liter (North Central Hardwood Forests) were associated with *non-support* of swimmable use. At P concentrations above 60 micrograms per liter, severe nuisance algal blooms (greater than 30 micrograms per liter of chlorophyll-a) may occur over 40 percent of the summer. This will result in a high frequency (greater than 50 percent of summer) of impaired swimming and greater than 25 percent as "no swimming."

Figure 2. MPCA's Swimmable Use Support Classification Relative to Carlson's Trophic State Index by ecoregion.



Carlson's TSI box from: Moore, L. and Thorton, K. [Ed.] 1988. Lake and Reservoir Restoration Guidance Manual. USEPA. EPA 440/5-88-00.

Figure 3a.



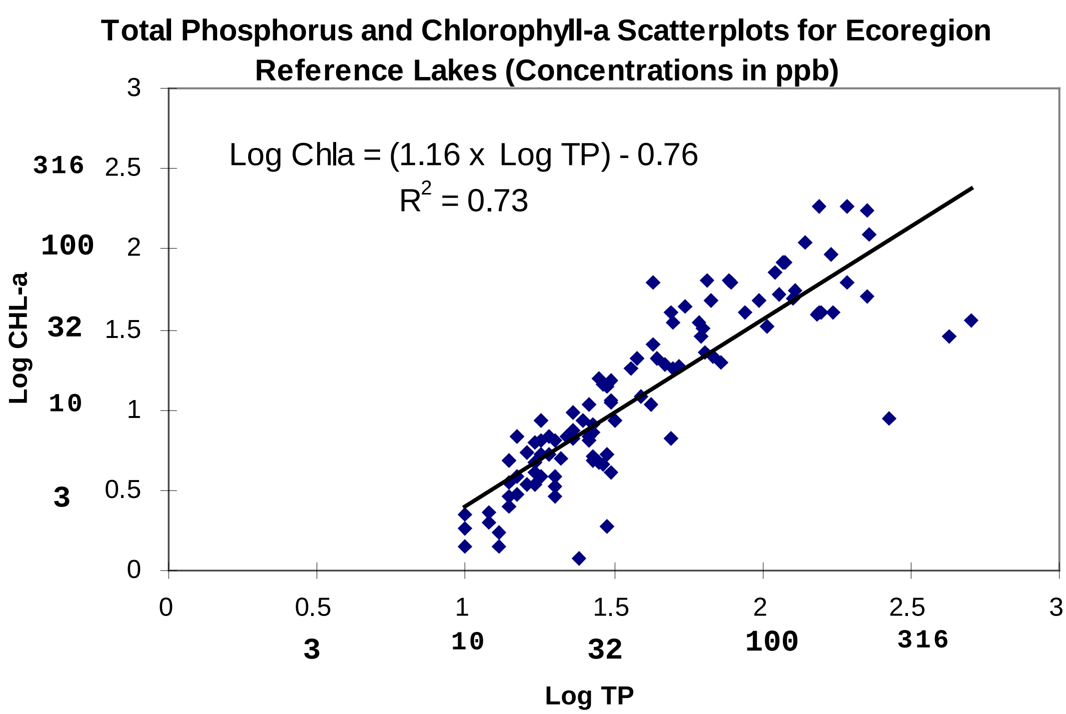


Figure 3b.

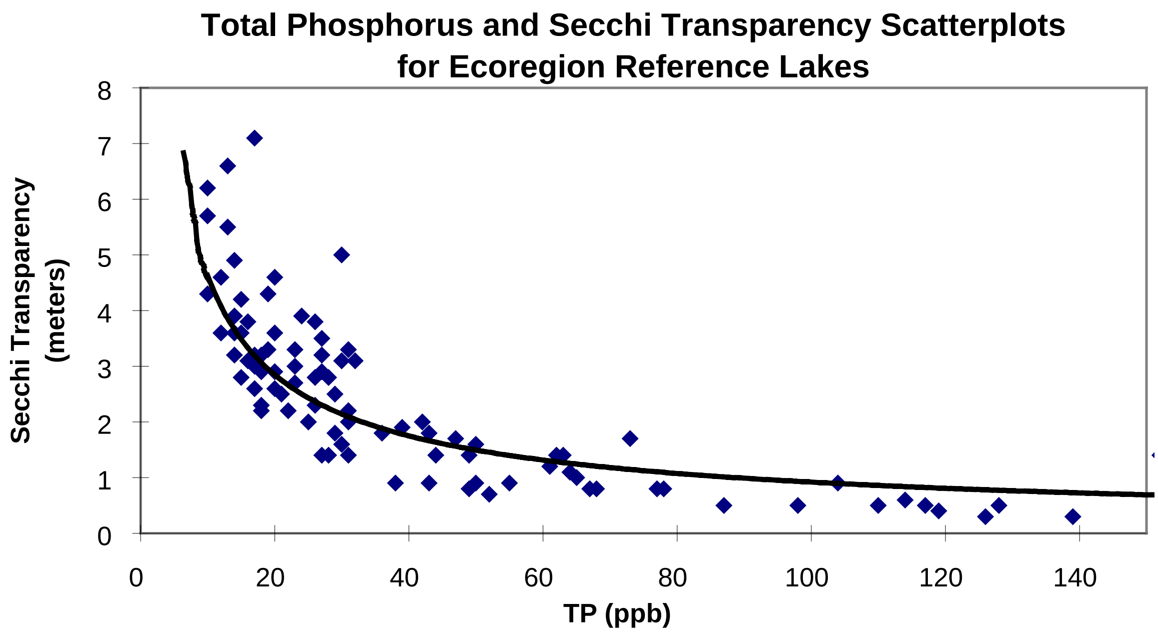
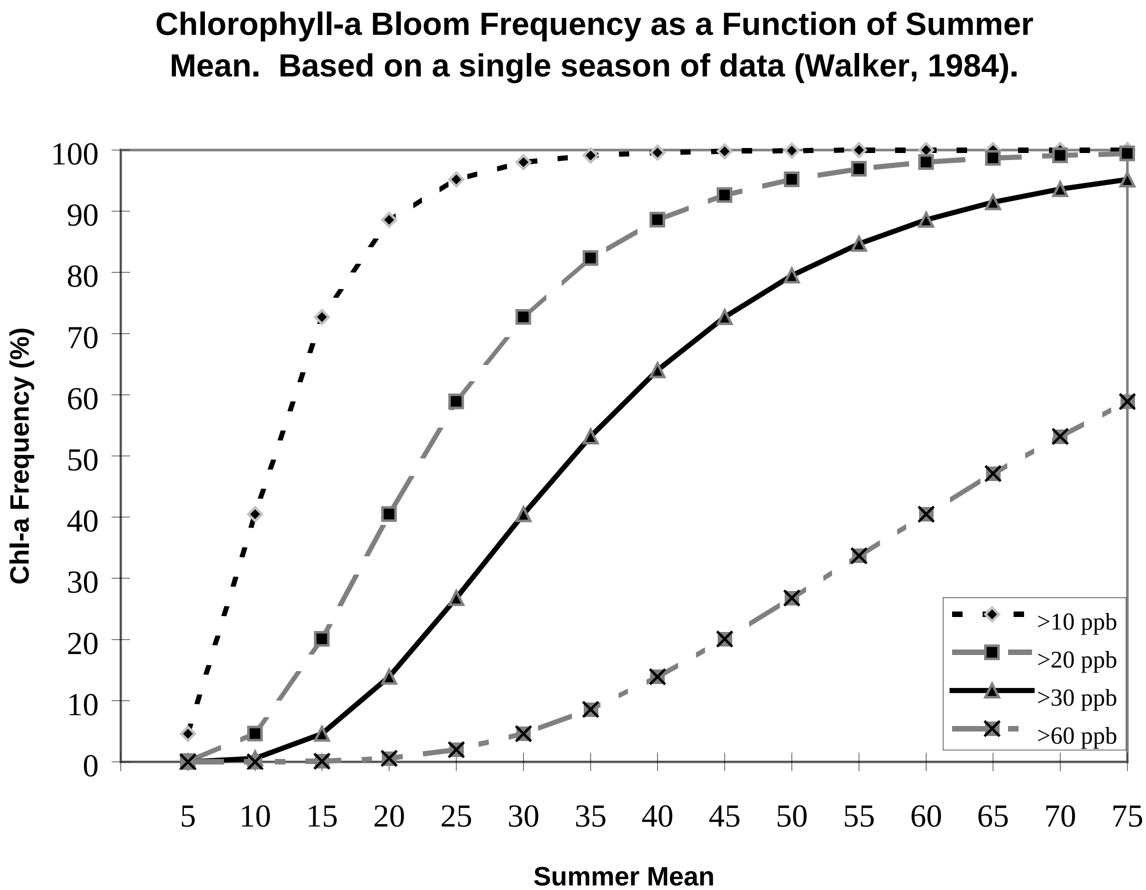

Total Phosphorus and Secchi Transparency Scatterplots
for Ecoregion Reference Lakes
Secchi Transparency
(meters)
TP (ppb)
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140

Figure 4. Chlorophyll-a Interval Frequency as a Function of Summer-Mean Chlorophyll-a.



For the Western Corn Belt Plains and Northern Glaciated Plains the upper TP thresholds for *full-support* and *support-threatened* are 40 micrograms per liter and 70 micrograms per liter, respectively, which correspond to Carlson's TSI units of 57 and 65. At a TP concentration of 70 micrograms per liter, summer-mean chlorophyll-a concentrations average 30-35 micrograms per liter and Secchi transparency is about 0.7 meter. Nuisance algal blooms (greater than 30 micrograms per liter of chlorophyll-a for these regions) would occur for approximately 40 to 50 percent of the summer (Figure 4). Few lakes in these two ecoregions have TP concentrations of 40 micrograms per liter or less. *Partial-support*, which corresponds to an upper TP threshold of 90 micrograms per liter or less (Carlson's TSI = 69), is a more reasonable goal for the majority of the lakes in these two ecoregions. TP concentrations greater than 90 micrograms per liter are considered *not supporting* of swimmable use. At TP concentrations greater than 90 micrograms per liter, Secchi transparency averages 0.5 meter or less and nuisance algal blooms may occur 75 percent of the summer or more.

Lake Size

Minnesota has about 11,842 lakes greater than 10 acres in size. They are distributed as follows based on surface area (MDNR, 1968).

Size	Total Percent	Total Number
10-100 acres	70%	8,289
100-5,000 acres	29%	3,491
>5,000 acres	<1%	62

The MDNR Fisheries Section estimates that there are about 5,500 lakes in the state that can potentially be managed for a fishery. Of this number, they have “managed” or have information on about 4,000. They note that many of those that are not managed are very small lakes in either the Superior (includes BWCAW) or Chippewa National Forests. Thus, many of these lakes are protected from human disturbance by virtue of their location and possible access limitations.

The above table suggests that the majority of Minnesota’s lakes are less than 100 acres in size. A prioritization scheme that factors in lake size could substantially reduce the number of lakes that need to be a “high” priority. The following observations provide a rationale for using lake size as part of a prioritization scheme.

- In the early 1980s a lake classification scheme was developed for use in the Clean Lakes Program (CLP) for Minnesota (MPCA, 1982). In that system, lakes with surface areas greater than 150 acres were given 10 priority points while those less than 150 acres received none. The rationale for that decision was as follows: large lakes can accommodate more and more varied recreational uses than small lakes, lake size has been used by the MDNR to prioritize lakes for public access development, and other states have included lake size in their prioritization schemes.

- Public interest as reflected by participation in the CLMP and requests for participation in the LAP are skewed toward lakes greater than 100 acres. In the case of CLMP, of the 500 lakes in the program in 1993, 89 percent are greater than 100 acres in size. Of the approximately 150 requests for participation in the LAP, over 95 percent were for lakes of greater than 100 acres.

- MDNR’s Division of Waters and the University of (U of M) have focused on lakes larger than 100 acres when conducting shoreland surveys. For example, in a 1970 University lakeshore study, lakes greater than 150 acres were included.

- Hank Todd (1990), former director of the Minnesota State Tourism Department, used lake surface area as a basis for estimating the economic impact of lakes on the local economy. For example, he estimated that lakes generate 16.5 jobs per thousand lake acres and consumer purchases at $ 509 per acre. Dziuk (1992) used these and other figures to estimate the economic impact of all lakes in the Big Sandy Lake area watershed. From their work it is evident that large lakes may make a larger economic contribution to local communities than small lakes.

Based on this information, it seems reasonable to use lake surface area as one variable in a prioritization scheme. Further, it may be appropriate to focus efforts on lakes of 100 acres or greater, especially in those counties, ecoregions, or basins with a large number of lake resources. For example, about 31 of 87 Minnesota counties have 100 lakes (excluding dry basins) or more. In these counties a threshold of 100 acres might be appropriate, while in counties or regions with few lakes a smaller lake surface area threshold might be appropriate.

PRIORITIZATION SCHEME

A decision tree approach was used as a means for conducting the prioritization (Figure 5). Following is a description of a scheme for prioritizing management (monitoring, protection and restoration) of lakes for achieving (protecting) swimmable use. In this scheme an emphasis is placed on protecting lakes currently in good condition; i.e., those characterized as *full- support* or *support-threatened* based on their trophic status (details on these categories were previously presented). This strategy assumes that protecting resources currently in good condition is a better investment and a higher priority than restoring resources which are highly impacted and which may or may not respond to reductions in nutrient loading. This scheme is not intended to be all-encompassing and will focus on data which is readily available for lakes based on our annual assessment of lake data in STORET, USEPA's water quality data base. The factors we have chosen to include are summer-mean P concentration, location of the lake (in terms of ecoregion and basin), and quality (age) of data. In the absence of P data we base use-support on Secchi or chlorophyll-a measures.

As a part of the MPCA's basin planning process, the prioritization was conducted by ecoregion within each basin (major watershed). If a basin or county is characterized by more than one ecoregion, lakes in the basin (county) would be sorted by ecoregion and then prioritized (Appendix). Some subsequent prioritization may be needed following this step. General concepts in the prioritization scheme follow:

- Lakes with P data are separated from those without (step 1.1, Figure 5). Those without P data are placed in the *monitor* category. Baseline data is needed to accurately prioritize the lake in terms of protection or restoration and to avoid making judgments based on insufficient data (USEPA, 1993). For lakes in the *monitor* category, use-support is determined based on Secchi or chlorophyll-a data as in Figure 1 and then further prioritized as in Figure 5 (2.1-2.6). This reasoning is consistent with other state prioritization/ranking schemes which establish minimum data requirements.

Lakes with P data are divided into categories of *protection* and *restoration* based on P criteria for use support (step 1.2, Figure 5). Lakes slated for *protection* include *full-support* or *support-threatened*, and those slated for *restoration* include *partial-support* and *non-support of swimmable uses.*

Figure 5. Lake Prioritization—Swimmable Use Support

By ecoregion (all assessed lakes within a given basin, county, etc.)

(1.1) Lakes with Phosphorus (P) data

(1.2) **Protect** *Full Support (FS) or Support-Threatened (ST)* — **Restore** *Partial Support (PS) or Non Support NS)*

(1.3) ---- **FS** ---- | ------- **ST** ------ | --------- **PS** ------ | ------ **NS** -----

(1.4) current | old | old | current | current | old | old | current

(1.5) **Protect** [2] | **Monitor**[1] | **Protect** [1] | **Restore** [1] | **Monitor**[2] | **Restore** [2]

(1.6) **sort by size** (largest to smallest) largest lakes in highest priority in each category

(2.1) Lakes without P data (classify based on Secchi TSI) - need monitoring prior to developing protection programs

(2.2) **Protect** *Full Support (FS) or Support-Threatened (ST)* — **Restore** *Partial Support (PS) or Non Support NS)*

(2.3) ------**FS**------- | ------ **ST** ------- | ------ **PS** ---- | ------- **NS** ------

(2.4) current | old | old | current | current | old | old | current

(2.5) **Monitor**[3] | **Monitor**[1] | **Monitor**[2] | **Monitor**[2] | **Monitor**[1] | **Monitor**[3]

(2.6) **sort by size** (from largest to smallest) largest lakes highest priority in each category

Support Categories by ecoregion based on TP

ecoregion	full-support (FS)	support-threatened (ST)	partial-support (PS)	non-support (NS)
NLF	<25 ug/L	25 - 30 ug/L	30 - 50 ug/L	> 50 ug/l
NCHF	< 30 ug/L	30 - 40 ug/L	40 - 60 ug/L	> 60 ug/L
WCBP/NGP	< 40 ug/L	40 - 70 ug/L	70 - 90 ug/L	> 90 ug/L

Notes: Old = data > 10 years old, current = data <10 years old
Protect/Restore/Monitor - within category priority - 1= highest , 2 = secondary , etc.

- The *quality* of the data used to determine use support is assessed (1.4, Figure 5). Lakes with *old* data (> 10 years old, also referred to as "evaluated") are slated for monitoring (i.e., determining whether the lake has been classified correctly). Lakes with *current* data (< 10 years old, also referred to as "monitored") are further prioritized. For lakes with either current or old data, the lakes *nearest* the P criteria level for primary contact recreation (on the verge of either supporting or not supporting use) are given the highest priority for monitoring or other actions. Lakes which *fully support* use may need less attention than those on the verge of not supporting swimmable use (threatened). In the case of restoration, lakes which *partially support* swimmable use may be better candidates for restoration than those which do not currently support swimmable use (may be extremely shallow, very large watersheds, etc.).

- *Lake size* is used to further prioritize, with the emphasis on lakes greater than 100 acres in size (1.6, Figure 5). This will emphasize those lakes most likely viewed as a priority by the public, local units of government, and other state agencies.

Other considerations which might be applied at a local level for further prioritization if data are available (e.g., in a local water plan or watershed district plan) include:

- *Lake depth* - Lake depth is an important parameter to consider for further prioritization. Based on linear regressions of ecoregion reference lake data, mean depth is the single most important predictor of in-lake P (Heiskary and Wilson, 1988) and is a primary variable in most lake-eutrophication models. In general, deeper lakes, which stratify, tend to have lower P concentrations as compared to shallow lakes in the same region (Table 2). As a very general rule-of-thumb, lakes with maximum depths greater than about 30-35 feet will tend to stratify during the summer, while lakes with maximum depths of 20 feet or less most often remain well mixed (Heiskary and Wilson, 1990). A minimum of one summer's worth of monitoring dissolved oxygen (DO) and temperature profiles is needed to accurately characterize a lake's mixing status. From a restoration perspective, deeper lakes should be prioritized higher than shallow lakes since they are more likely to respond favorably to reductions in nutrient loading, whereas shallow lakes may suffer from excess internal loading of P even after external P loads have been reduced. From a protection perspective, though, good-quality shallow lakes might be considered a higher priority than deep lakes since small increases in P loading to a shallow lake may lead to rapid eutrophication, which may be difficult to reverse.

- *Watershed Size* - Give lower priority to lakes with large watershed size as compared to lake surface area (e.g., as per ranking criteria for CWP funding). Lakes with very large watershed-to-lake ratios (e.g., 100:1 or greater) often have very high NPS loads (MPCA, 1982), and it may be difficult to address enough sources of nutrients in their watersheds to exhibit visible improvement in lake quality.

- *Modeling* - Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow of water that enters the lake. The "Minnesota Lake Eutrophication Analysis Procedures" (MINLEAP) was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake condition with minimal input data and is described in greater detail in Wilson and Walker (1989). This model provides a quick estimate of how a lake's observed water quality compares to that predicted for the lake based on its size, watershed area, and ecoregion. It also provides an estimate of the expected variability in summer-mean P, which may further aid prioritization.

A regression model developed by Vighi and Chiaudani (1985), which is based on the morphoedaphic index commonly used in fishery science, is another useful tool and is included in the MINLEAP program. Their regression equation predicts TP based on lake morphometry (mean depth) and alkalinity or conductivity and is intended to provide an estimate of background TP concentration for a lake. This equation can be quite useful for lakes which were thought to be naturally oligotrophic or mesotrophic (the model development data set did not include shallow lakes in agricultural settings which may have tended to be more eutrophic naturally). When combined with the MINLEAP predictions this can provide a good basis for estimating a lake's change from background condition and setting in-lake water quality goals.

- *Public access* - It has long been a precedent to give higher priority to lakes with public access (e.g., MPCA, 1982 and Section 314 CLP guidance). Those with public access will provide more opportunity for use and recreation to the public than lakes without public access.

- *Land use in immediate watershed or shoreland area* - Land use characteristics in the immediate watershed and shoreland area may be an important consideration for prioritization at the local level. Some characteristics which could be considered include: percent of lakeshore under public ownership (the higher the percentage the lower the priority), percentage of undeveloped land in wetlands, percentage of undeveloped lands with steep slopes, percentage of undeveloped lakeshore in private holdings of 600-foot or more blocks, and the amount of undeveloped land with good road access.

- *Change in land use in watershed* - A primary recommendation from the 1995 National Nutrient Assessment Workshop (USEPA, 1996) noted that "states should include land use as a separate early warning indicator (i.e., if development is proposed in a watershed, an EIS should be done to assess the potential impact of such development on the surrounding watershed). Thus, any lake which has significant changes in land use proposed should be a high priority for monitoring and protection-related activities. P export as a function of land use (Figure 6) is well documented (e.g., Walker, 1985 and Reckhow and Simpson, 1980). For example, changing from forested to urban land use results in higher P export because of reduced infiltration, increased runoff, and land use practices in the urban landscape (e.g., lawn fertilization). Protection-related activities may include installation of properly designed sedimentation basins in areas where urban or residential development is taking place. In instances of significant changes in agricultural or silvicultural activities, BMPs which minimize erosion from the sites and encourage buffers from watercourses are desirable. In instances where feedlots are a concern, BMPs are associated with animal waste handling and land application (ensuring that adequate areas for land application are available), fencing of animals away from watercourses, and other measures to minimize the likelihood of these nutrient-rich wastes from entering surface or groundwater. From a monitoring standpoint a minimum of one summer's worth of data is needed to establish some baseline data for the lake and allow for modeling estimates to be made.

- *Public water supply* - Because of their inherent importance to a community and public health implications associated with degraded water quality (i.e., eutrophication), lakes or reservoirs which serve as public water supplies should be a high priority for protection. This is a common feature in many state ranking systems (U.S. EPA, 1993). Some information on eutrophication-related impacts in public water supply may be found in Heiskary and Wilson (1988).

- *Economic contribution* - Certain lakes because of their size, depth, fishery and aesthetic values, or other characteristics may have a significant impact on a local or county economy. This might be reflected by high resort usage, an abundance of public accesses (e.g., beaches, parks or boat landings), and/or a high tax base. As a result, these lakes may be deemed a high priority for monitoring or protection. As noted previously Todd (1990) and Dziuk (1992) related economic benefit to lake surface area. A brief overview of their work and a potential method for estimating economic impact is provided in Heiskary et al., 1994.

Table 2. Distribution of TP (μg/L) Concentrations
by Mixing Status and Ecoregion (Heiskary and Wilson, 1988).
D = Dimictic, **I** = Intermittent, **P** = Polymictic

	Northern Lakes and Forests			**North Central Hardwood Forests**			**Western Corn Belt Plains**		
Mixing Status:	**D**	**I**	**P**	**D**	**I**	**P**	**D**	**I**	**P**
Percentile value for [TP]	ppb								
90 %	**37**	**53**	**57**	**104**	**263**	**344**	**--**	**--**	**284**
75 %	**29**	**35**	**39**	**58**	**100**	**161**	**101**	**195**	**211**
50 %	**20**	**26**	**29**	**39**	**62**	**89**	**69**	**135**	**141**
25 %	**13**	**19**	**19**	**25**	**38**	**50**	**39**	**58**	**97**
10 %	**9**	**13**	**12**	**19**	**21**	**32**	**25**	**--**	**69**
# of obs.	257	87	199	152	71	145	4	3	38

ACTIONS OR OUTCOMES FROM PRIORITIZATION

Once lakes are prioritized there must be some likely outcomes or actions to be taken on these lakes. This discussion will focus on monitoring and protection-related activities rather than restoration. Guidance on restoration may be obtained from Moore and Thornton (1988) or Cooke et al. (1986). A brief discussion of some options follows. Opportunities to implement these options may vary between basins, watersheds, or counties, depending on available resources.

1. **Monitoring** - Under this category four options will be noted as follows: CLMP, LAP level, tributary, and CWP level (diagnostic-feasibility). Within each of these categories there may be some subcategories or enhancements which might be conducted as well. An overview of the three follows:

- *CLMP* - This level of monitoring is appropriate for all lakes. Increasingly this is the data we rely on for detecting temporal trends in eutrophication, since we seldom have sufficient data on TP or chlorophyll-a to detect trends. CLMP monitoring would be the first choice for any lake which does not have *current* data. The CLMP data will provide an improved basis for correctly classifying the lake and placing it in the prioritization system. Also, it begins to provide baseline information on year-to-year variability, which is important in more advanced monitoring programs. Another advantage of the CLMP is that it comes at no cost to a local unit of government in terms of money or data management. Data are updated annually and are available on request for use in local water planning or other activities. Some counties (typically local water planners working in conjunction with COLAs) have taken this a step farther with their trophic status monitoring programs. In these programs TP, chlorophyll-a, and Secchi are monitored for one or more years. This provides additional data and provides an improved basis for prioritizing the lakes for future actions. Other volunteer monitoring programs, such as the Metropolitan Council's Citizen-Assisted Monitoring Program (Anhorn, 1997), also afford an opportunity for lake associations and interested citizens to gather additional data on their lakes. Whenever possible, data from these efforts are placed in STORET as well and thus can be combined with other sources of data to allow for trend assessment.

- LAP - This level of monitoring is the next step up. It considers not only the water quality of the lake but also watershed, fishery, and other pertinent characteristics. This type of monitoring is often most efficient and effective when done as a collaboration between a lake association, local unit of government, and state resource managers. It may be conducted by consultants as well if resources permit. The data collected is likely the minimum needed prior to implementing meaningful *protection* projects in the watershed. This level of monitoring does not usually provide enough information, though, to diagnose all significant sources and develop feasible alternatives for addressing large-scale pollution problems in severely impacted lakes. Additional details on this and different levels of monitoring (Appendix, Table 1) are provided in the Lake and Watershed Data Collection Manual (Heiskary et al., 1994).

Figure 6. P Export Coefficients. Estimated ranges by land use based on (1) general literature estimates and (2) Yellow Medicine River Watershed data from the Lake Shaokotan CWP Project (Schuler, 1992).

- *Tributary monitoring* - If in-lake conditions have been adequately characterized (e.g., through a LAP study or multiple years of a county water plan or related monitoring), it should be beneficial to monitor significant inflows to priority lakes. This monitoring would involve paired measures of flow and TP. Ideally, continuous flows or daily-stage flow measures might be taken as well as the grab samples and discreet flow measures. Locating the sample site near a bridge or culvert should facilitate more frequent measures and thus improve the accuracy of the loading estimates. The purpose of this monitoring is to calculate flow-weighted mean TP concentrations for major tributaries (subwatersheds) to the lake and provide a basis for identifying which subwatersheds contribute the highest P loading. These loading estimates will also be valuable for modeling and goal-setting purposes. In turn, these subwatersheds could be investigated in more detail for potential BMP implementation. Wilson and Schuler (1991) provide a good overview of stream sampling considerations.

- *CWP or CLP* - These types of studies, also referred to as "diagnostic-feasibility" studies, provide the level of resolution needed to accurately characterize in-lake conditions, determine accurate water and nutrient budgets, and determine appropriate sites for implementing BMPs and other pollution control measures. The monitoring portion of these studies is conducted for a minimum of one water-year. Often two or more years are desirable, depending on flow conditions and the complexity of the system. Actual implementation may take place over the course of several more years -- again dependent on the scope of the problems identified. The studies in their initial phase, "Phase I" as they are commonly referred to, may cost anywhere from tens of thousands of dollars to over $100,000. Costs are typically shared between the state and local unit of government. In the case of CLP projects, cost-share dollars were available from the federal government as well -- however, this program is not funded at the present time. Given the high cost of this type of project and limited cost-share dollars available, it is very important to prioritize how and where these projects are undertaken (thus the CWP project ranking scheme). These high project costs speak to the need to protect resources so that they do not become degraded to the point where these extensive projects are needed to restore or rehabilitate the systems.

2. **Protection** - The projects instituted as part of a protection project are not that much different than those that might be addressed in the course of a watershed-wide restoration. The main difference is the associated costs of doing a few projects to *protect* current in-lake conditions rather than numerous projects across a large watershed in an attempt to *improve* in-lake conditions. "Lakeshed" projects as proposed by BWSR (Krystosek, personnel communication) would likely fit in this category. Additionally, in the case of a restoration, there is a need to be assured that projects are targeted at those sites deemed most critical, that some measure of the "success" of the implementation might be made, and that ultimate load reduction dictated by the Phase I study be met. In the course of restoration projects, more cost-share or loan dollars may be available to offset project costs. In the case of true "protection-oriented" projects there is still the need to target those projects and watersheds where the most benefit might be obtained, but there is less of an onus (or in many instances the ability) to actually measure the impact of the particular BMP instituted or the effect of an education program. Rather, the intent is to take reasonable steps to minimize or reduce nutrient and sediment inputs into waters of currently good water quality. In small watersheds this may be rather straightforward, while in large or complex watersheds, with a wide mixture of land uses, it may be necessary to monitor the major tributaries in order to identify

those subwatersheds which yield the highest P loading. Those subwatersheds with the highest P loading should be the focus of further investigation and implementation of protective BMPs as needed to reduce P loading. Wilson and Schuler (1991) provide useful guidance for *tributary monitoring*. This tributary monitoring should probably be employed prior to instituting a series of expensive BMPs in a large/complex watershed where there is some uncertainty as to where the most significant sources of P loading may arise. Some possible protection-oriented projects follow:

- *Lake Plan* - In most instances, developing a *lake management plan* will precede any meaningful protection efforts. The plan will guide your efforts and gain the buy-in of local government officials and state agencies. In this planning process, information on the lake and its watershed is assembled, goals for the lake and its watershed developed, and management options discussed. It may also serve as a basis for seeking funding to carry out your proposed projects. The manual "Developing a Lake Management Plan" (ILCC, 1996) should be a helpful resource in this regard.

- *Economics* - A good starting point may be to establish the economic benefits of your lake to the local community (township, city or county). This will help build a case for the protection projects you propose. By establishing the *economic significance* of the lake in relationship to water quality, the need to protect or improve water quality will become readily evident and will begin to justify the expenditure of funds for this purpose. For example, economic analyses in Maine and other locales associate the effects of water quality on lakeshore property prices (Michael et al., 1996). Resource materials such as this or those previously noted (Dziuk, 1992a; Todd, 1990; and Heiskary et al., 1994) may be useful in this regard. Likewise, information from the Minnesota Department of Tourism as presented by Steve Markuson, Director, at the 1996 NALMS conference may be helpful as well. For example, Markuson (1996) noted a significant correlation (r=0.65) between county lake area and county domestic-travel gross receipts, and that overall Minnesota's lake-area gross receipts value is $ 1.8 billion annually.

- *Education* - Education will be an important component of any protection or restoration strategy. Education should target all age levels and not simply be limited to adults. Involving youth in these efforts targets the future beneficiaries of these efforts as well as future resource managers. Educational programs should deal with both the nature of specific threats to lake impairment and practical means for preventing damaging thresholds of pollutant loadings from being exceeded. Dziuk (1992b) posed several questions for lake associations to consider regarding the education of their members and lake users. Answers to these questions might be used to help design an effective education program.

- *Urban/residential watersheds* - P exports from urban watersheds rival that of agricultural watersheds (Figure 6). Dealing with storm water from existing and future developments (residential, commercial and industrial) is the number one water pollution concern in urban (or soon to become urban) watersheds. The best time to address storm water impacts, and protect a lake or stream, is when a parcel of land is under development. During development it is relatively easy to include properly sized sedimentation basins and reduce the amount of impervious surfaces. Sedimentation basins should be designed to address water quality as well as hydrologic concerns. Schueler et al. (1996) and MPCA (1995) present several practical and diverse urban BMPs that could be considered. There are various models (e.g., Walker, 1987; Pitt, 1994; Schueler et al., 1996) available to assist with BMP design. Many watershed districts, watershed management organizations, and others charged with minimizing storm water impacts should be familiar with such design criteria. Alternatives to addressing storm water during development are retrofitting systems or adding sedimentation basins, both of which can be very expensive. Other protective measures to consider include street sweeping, leaf litter control, stenciling of storm water drains (to discourage the introduction of pollutants), encouraging homeowners to use P-free fertilizers, and other educational opportunities intended to encourage BMPs throughout the watershed. An "Urban BMPs" manual, available through the MPCA, has additional ideas.

- *Agricultural watersheds* - P export from agricultural watersheds is often high relative to other land uses (Figure 6). There are many opportunities to institute protection activities in the agricultural landscape--though some of these may be limited by the availability of cost-share dollars. Projects of most significance from a water quality protection standpoint are those which minimize the amount of nutrients and sediments which move from the land to watercourses and ultimately to lakes in the watershed. Targeting lands adjacent to tributaries, ditches, or on the lakeshore may make the most sense where water flows are directly connected to the lake. Potential activities or projects include fencing livestock out of watercourses; ensuring that all livestock containment facilities in direct contact with a watercourse have adequate containment of wastes and adequate land to apply wastes; observing a setback when land-applying manure adjacent to streams, ditches and lakeshore areas; considering installation of vegetative buffer areas adjacent to watercourses (e.g., CRP Riparian Buffer Strips); using BMPs on highly erodible lands; considering retirement (e.g., CRP or RIM) of highly erodible lands adjacent to or near watercourses; and considering restoring wetlands whenever possible. Figure 6 depicts the differences in P loading rates from a southwestern Minnesota watershed and the dramatic differences between CRP-dominated subwatersheds versus those which are predominantly cultivated or containing feedlots. De Laney (1995) provides a good overview of options for agricultural watersheds with a focus on the water quality benefits associated with constructed wetlands in agricultural landscapes. Technical and financial assistance for these projects may be available through the Natural Resource Conservation Service (NRCS), SWCD offices, Fish and Wildlife Service (FWS) (wetland restoration), or watershed districts. Other potential sources include BWSR challenge grants, MPCA and MDA State Revolving Fund (SRF) loans, and MDNR.

- *Forested watersheds* - In predominantly forested watersheds, P export is typically low (Figure 6) and in-lake TP concentrations are typically low (Table 2, Figure 3). Because of retention by soils and vegetation, minimal amounts of P move from the landscape to lakes and streams and that which does make its way there is more commonly in a soluble form rather than soil-bound (Verry and Timmons, 1982). However, lakes in the forested regions are very sensitive to additional inputs of P (Figure 3). Thus, any activities which encourage more runoff to the lakes, such as near-shore development, road building, or silvicultural activities, should be monitored closely to ensure that runoff is minimized and BMPs are used. A forestry BMP manual is available through the MPCA, MDNR and others to provide ideas on appropriate protection measures. Appropriate setbacks during construction should be observed and, whenever possible, natural vegetation in the riparian area should be preserved.

- *Shoreland areas* - Projects in the shoreland or riparian areas of lakes are an important part of an overall protection effort. Second- and third-tier developments should be considered for inclusion in these efforts as well. These projects often have a strong emphasis on education since there are limited enforceable regulations. As a part of education efforts, an emphasis should be placed on maintaining vegetative buffers between lawns and the lake, maintaining natural vegetation whenever possible in the riparian area, minimizing the use of fertilizers or, if necessary, using P-free fertilizers, discouraging burning of leaves on the lakeshore or otherwise placing other organic materials in lakes, and minimizing the disturbance (removal) of aquatic plants in the near-shore area. These plants provide important habitats for aquatic life and serve to protect shorelines from wind and wave erosion. There are a variety of manuals and handbooks which provide ideas on protection of enhancement of near-shore areas. With respect to first-, second-, and even third-tier development, special efforts should be made to minimize the amount of impervious areas and efficiently handle runoff from existing impervious areas via properly designed sedimentation basins, grassed waterways, and other means prior to the runoff water reaching the lake or inflowing stream.

In addition to these projects there are some “regulatory” considerations in the shoreland areas which can help to protect lake water quality. Some counties are beginning to use land-zoning authority to exclude intensive land uses such as livestock feedlots from locating within a lakeshore zone. Other measures include observing proper setbacks when developing lakeshore property, minimizing erosion during construction, and requiring on-site systems to be in compliance with state and local codes. Increased attention has been placed on on-site individual sewage treatment systems (ISTS) in recent years, and there is a great deal of interest on behalf of lake associations and others to bring systems in the shoreland areas up to code. Technical and possibly financial assistance on ISTS issues may be obtained from Minnesota Extension, the MPCA, and county Planning and Zoning. The SRF may be one potential source of low-cost loans to help upgrade systems.

CONCLUSION

Preserving the quality of Minnesota’s lakes is essential to the state and local economies. However, there is a limited amount of dollars available at the national, state, and local levels for monitoring or restoring lake water quality. Further, given the expense of restoration activities, typically measured in the hundreds of thousands of dollars per lake, it is wise to protect lake condition whenever possible. This proposed prioritization system can be applied at a state, basin (watershed), or county level to assist in determining which lakes might be prioritized over others for *monitoring*, *protection*, and/or *restoration*.

Primary emphasis is placed on protecting those lakes which currently have good water quality and monitoring those with inadequate data. A *secondary* emphasis is on the prioritization of lakes for purposes of restoration. MPCA’s ecoregion-based P criteria, in conjunction with Carlson’s TSI, served as a primary basis for developing the prioritization. Lake size was also used in the prioritization. Lakes of 100 acres or more would be at a higher priority for protection, restoration, and/or more extensive monitoring. Several other options which might be considered in a prioritization scheme (e.g., in a local water plan) were offered as well.

For the MPCA, this scheme has been applied in a basin context as a part of the basin information documents. This scheme might also be applicable at a county or watershed district level as well (see Appendix). County or watershed authorities employing this scheme could consider it as a starting point or a framework for developing their priorities for advanced monitoring and protection. In addition to the considerations used in this scheme, county and watershed authorities should consider input from citizen advisory committees, county COLAs, and others interested and involved in the monitoring and protection of water resources in their county or watershed. Such input should allow for broader acceptance of the priorities that are established.

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Appendix

Table 1. Levels of lake and watershed assessment

Figure 1. Minnesota's major drainage basins and ecoregions

Example Prioritizations

a. Douglas County

b. Itasca County

c. Minnesota River Basin

d. Red River Basin

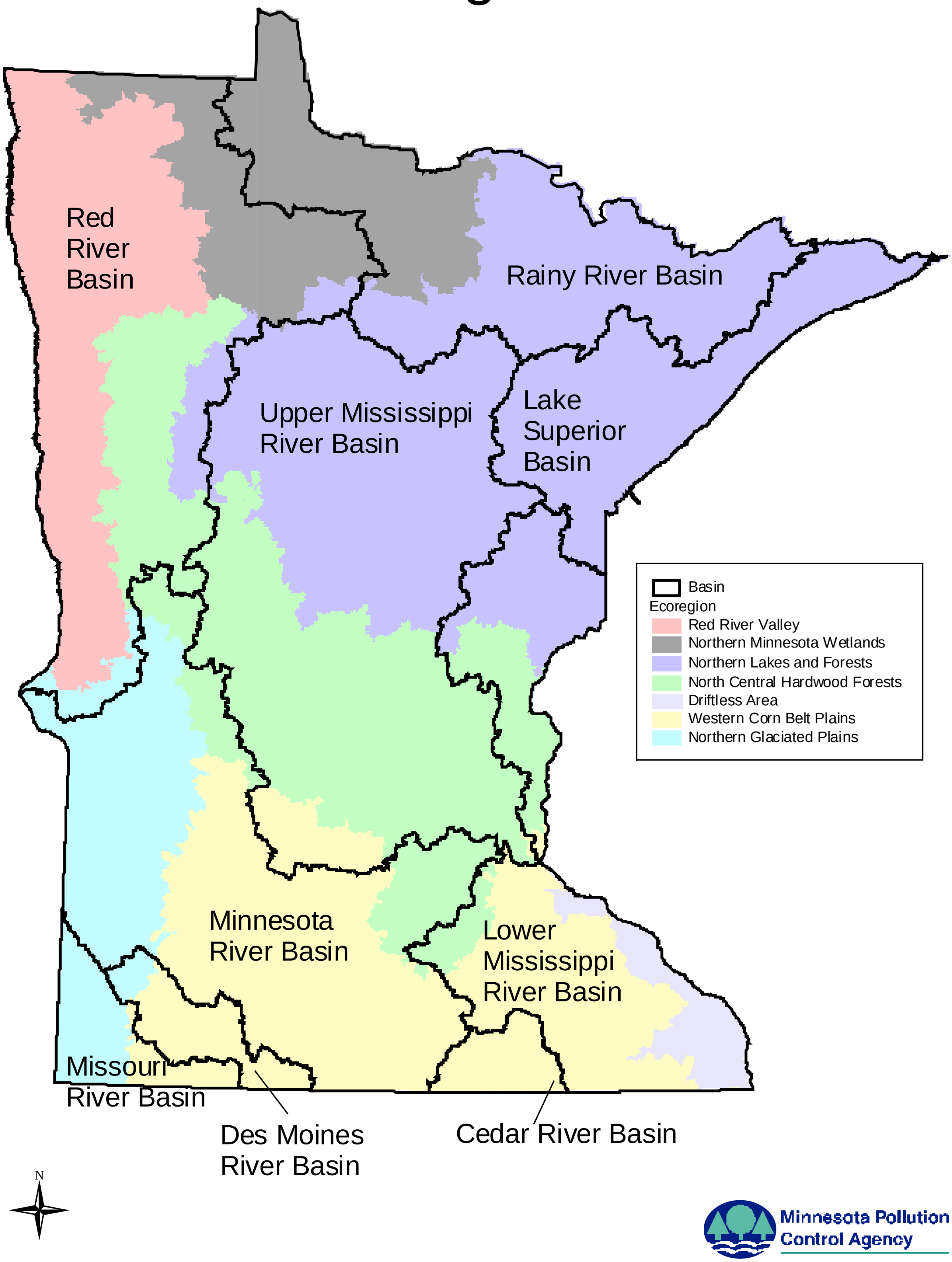
e. Lake Superior Basin

(Lake list for each example prioritization available on request)

Table 1. Levels of Lake and Watershed Assessment

Level	- Characteristics -				
	Water Quality	**Basin**	**Watershed**	**Biological**	**Socioeconomic**
Basic	• Monitor 1 x/ month from June-Sept. chemistry, D.O., chlorophyll • Do Secchi weekly from June-Sept. • Use MINLEAP model	• Determine surface area, mean depth, volume, and shoreline length • Monitor lake level	• Delineate watershed boundary & determine area • Determine which "ecoregion" lake is in • Define lake type (e.g., seepage, drainage) •	• Obtain current fisheries data from DNR • Review historical macrophyte data	• Determine uses of lake • Identify perceived lake problems, sources • Document problems
Intermediate	• Increase sample frequency to 6-10 samples from May-Oct. • Increase # of sites • Establish rain gauges • Evaluate water quality trends • Use Reckhow and Simpson model •	• Determine geologic origin and setting of lake • Calculate percent of littoral area	• Determine land use composition • Locate all tributaries • Determine # of shoreland residences • Conduct septic survey • Determine soil types	• Conduct macrophyte survey • Identify algae • Analyze current and historical fish survey and stocking data	• Compile lake history • Document surface use conflict • Compile real estate values • Identify likely range of lake water quality goals
Advanced	• Monitor lake 8-10 times from May-Oct. • Conduct limited tributary monitoring • Gauge stream flow • Estimate ground water influx-flow direction • Estimate nutrient loads • Use BATHTUB model	• Determine volumes for individual basins • Calculate fetch length by basin	• Conduct detailed land use • Delineate subwater-sheds • Locate all culverts and inlets • Locate any point sources, feedlots, etc. • Inspect septic systems	• Analyze fishery & stocking data for trends • Review Aquatic Plant Management permit history for lake • Review Fisheries Management Plan	• Review permit history for shoreland alterations • Determine economic significance of lake • Set goals

Minnesota Ecoregions and Basins



a) Douglas County Lakes Prioritization

In a county with about 375 lakes greater than 10 acres in size it may be desirable to prioritize lakes for purposes of water quality monitoring, protection and, where needed, restoration. In an effort to assist local water planning efforts, the lakes in Douglas County were prioritized according to MPCA's proposed prioritization scheme. The primary emphasis in the scheme is placed on protecting those lakes which currently have good water quality. The proposed prioritization could be considered as a starting point or framework for developing priorities for advanced monitoring and implementation of protection projects. In addition to the considerations used in this scheme, other factors might be considered (as noted in the prioritization document); and input from citizen advisory committees, county COLAs, and others interested and involved in the monitoring and protection of water resources in the county could be considered as well.

The prioritization was conducted based on existing lake water quality data for the county which was available through STORET, USEPA's national water quality data bank. MPCA, Citizens Lake-Monitoring Program (CLMP), watershed district, MDNR, consultant, etc. data are stored in this system. The most recent assessment of all Minnesota lake water quality data in the system (MPCA, 1996) is the basis for this prioritization and includes data from 1970 through 1995. The prioritization scheme, definitions, and background information are supplied in the prioritization document. Following are some notes which correspond to the attached prioritization for Douglas County. For any lakes which are not noted in this priority scheme, an initial step would be to enroll the lake in the CLMP and MDNR's Lake Level program. These two programs provide an initial basis for tracking trends in water quality and quantity for lakes, and ideally these programs should precede other more intensive monitoring efforts whenever possible.

Douglas County Prioritization Notes:

The following prioritization was based on water quality data for 39 lakes in the county. While it is likely there may be more lakes with data, this evaluation represents all Douglas County lakes in STORET as of 1995. If additional data is available, it could be incorporated into this prioritization. The prioritization was conducted by ecoregion within the county. Douglas County is characterized by two ecoregions: North Central Hardwoods Forests (NCHF) ecoregion to the north and east and the Northern Glaciated Plains (NGP) to the southwest. Most of the lakes are located in the NCHF ecoregion (Table 1).

Sources of data

The MPCA and Alexandria Lakes Area Sanitary District (ALASD) have collected data on several lakes in the county. Completed Lake Assessment Program (LAP) studies were conducted on Miltona, Le Homme Dieu, Latoka, Andrew, Lobster, and Red Rock Lakes. These studies provide good baseline data and an initial basis for implementing protection efforts. Ecoregion-referenced (e.g., Irene and Chippewa), regional (e.g., Mill), and point-source impacted lake studies (e.g., Whiskey) contribute data as well. Recent Clean Water Partnership studies on Agnes, Winona, and Henry provide data as well. Numerous lakes are monitored through the CLMP--with lakes like Ida and Miltona having some of the best CLMP data bases in the state.

Protection

Of the 39 lakes (basins), ten *fully support* swimmable use based on current phosphorus (P) data. All of these lakes would appear to be good candidates for protection considering their currently low P concentrations, large surface area, and extensive shoreland development. Six other lakes were support-threatened. Of these, five had current data. Of the five with current data: Irene, Geneva, Lobster (west basin), and Victoria might be the highest priorities for protection considering that their current P concentrations are near the ecoregion P criteria level, that they are relatively large lakes, that they have high shoreline development, and that there is strong citizen interest in water quality based on years of CLMP participation. The other two lakes in this category, Turtle and Herberger Lakes, may benefit from enrollment in the CLMP if residents or users of the lake are interested in gathering information on these lakes.

Restoration

All the lakes in the "restoration" category were considered *non-supportive* of swimmable uses. Based on lake surface area and current P data, Mill and Smith Lakes may be good candidates for further work. Of the four lakes with old data, further monitoring could be done if there were a strong local interest in the form of an active lake association. However, based on their high P concentrations, small surface areas, and little (or no) participation in the CLMP, none present themselves as high priorities.

Lakes without P data

There are several good candidates for further monitoring; e.g., LAP, COLA TSI monitoring, etc. Aaron and Stowe Lakes could be good candidates for baseline monitoring since their Secchi TSI values suggest *support-threatened* conditions as compared to *full support* for the other lakes in this category. They are also relatively large lakes. There seems to be some local interest in the water quality of Aaron and Moses Lakes based on a LAP application which was submitted by a sportsman's club interested in these lakes. Of the nine fully-supporting lakes, Lake Ida would be the highest priority for advanced monitoring based on its surface area and its very long record in the CLMP. Lakes Mary and Oscar would likely be priority lakes as well. Lake Mary, while one of the largest lakes in the county, has very limited participation in the CLMP. It could be a priority, as well, if CLMP monitoring continues.

Northern Glaciated Plains ecoregion

Only one lake from this portion of the county had data in STORET-- Red Rock Lake. A LAP study was conducted on Red Rock, and some follow-up work is or was in process there. This may be an example of a lake where more advanced monitoring (e.g., tributary monitoring) may be needed to better document sources and the magnitude of P loading to the lake and help direct restoration efforts.

b) Itasca County Lakes Prioritization

In a county with about 945 lakes greater than 10 acres in size (MDNR, 1968), it may be desirable to prioritize lakes for purposes of water quality monitoring, protection and, where needed, restoration. This would seem to be a daunting task given the large number of lakes. However, if we consider the size distribution of the lakes, it may be less of a problem--especially if we focus on the larger lakes. Of the 945 lakes, 709 are less than 100 acres in size, 41 are greater than 500 acres, and the remainder are between 100-500 acres in size (MDNR, 1968). Itasca County has a wide variety of lake basins. Many lakes were formed in ice block deposits in glacial till and outwash. In addition to these natural lakes, the county has three large reservoirs--Pokegama and Blandin on the Mississippi River and Prairie on the Prairie River.

In an effort to assist local water planning efforts, the lakes in Itasca County were prioritized according to MPCA's prioritization scheme for swimmable use support. The prioritization was conducted based on existing lake water quality data for the county which was available through STORET, USEPA's national water quality data bank. MPCA, Citizens Lake-Monitoring Program (CLMP), watershed district, MDNR, consultant, etc. data are stored in this system. The most recent assessment of all Minnesota lake water quality data in the system (MPCA, 1996) is the basis for this prioritization and includes data from 1970 through 1995. The prioritization scheme, definitions, and background information are supplied in the prioritization document. Following are some notes which correspond to the attached prioritization for Itasca County. For any lakes which are not noted in this priority scheme, an initial step would be to enroll the lake in the CLMP and MDNR's Lake Level program. These two programs provide an initial basis for tracking trends in water quality and quantity for lakes, and ideally these programs should precede other more intensive monitoring efforts whenever possible.

Itasca County Prioritization Notes:

The following prioritization was based on trophic status data for 150 lakes in the county. Of this number, 32 lakes are greater than 500 acres, 74 lakes are between 100-500 acres, and 44 lakes are less than 100 acres. Thus a high percentage (78 percent) of the lakes greater than 500 acres are represented, as well as 38 percent of the lakes between 100 - 500 acres. While it is likely that there may be more lakes with data, this evaluation represents all Itasca County lakes in STORET as of 1995. If additional data is available, it could be incorporated into this prioritization. The prioritization was conducted by ecoregion within the county. Itasca County is located in the Northern Lakes and Forests ecoregion.

In addition to the following notes there are likely other relevant considerations which could be used to further prioritize efforts. Much of the land use in Itasca County is characterized by forested or marsh land uses. With the exception of lakes near Grand Rapids or other cities, the biggest threat to cultural eutrophication likely arises from development in the nearshore area, road building, and silviculture activities. Also, many of the lakes are protected, in part, by being located in the Chippewa National Forest. Thus, barring any major disturbance or land use changes in their watersheds, these lakes could be a slightly lower priority for advanced monitoring. Perhaps the single most important criteria for prioritizing a lake, beyond those noted here, would be whether any major change in land use in the watershed of the lake is anticipated (e.g., extensive shoreland or residential development); in these cases it is essential to have adequate baseline data in order to develop an appropriate lake-protection strategy.

Sources of data

The MPCA has collected data on several lakes in the county. Completed Lake Assessment Program (LAP) studies were conducted on Wabana, Swan, and Trout Lakes. These studies provide good baseline data and an initial basis for implementing protection efforts. Ecoregion-referenced (e.g., Big Island and Burnt Shanty) and acid rain referenced lake monitoring (e.g., Bass and Black Island) contribute data as well. A Clean Lakes Program study on Trout Lake at Coleraine provides detailed data as well. Numerous lakes are monitored through the CLMP--with lakes like Deer, Pokegama, and Siseebakwet having some of the best CLMP data bases in the state. Of the 150 lakes, 84 have at least one phosphorus measurement and were prioritized based on phosphorus. The remainder had only Secchi data and, thus, the Secchi TSI and use-support classification were used.

Protection

Of the 150 lakes, 39 *fully support* swimmable use based on their phosphorus (P) concentration. Of these, 11 were based on current data. Of those with old data--the lakes greater than 100 acres in size could be considered priorities for further monitoring; and of these--Hart, Thistledew, and Coon may be among the highest priority based on size. Fifteen other lakes were *support-threatened*. Of these lakes, only Stingy and Crum were based on current data. Of the lakes with old data, Squaw Lake may be the highest priority for further monitoring given its size and shallowness. All lakes in the "protection" category should be good candidates for protective efforts in their watersheds. Special attention should be placed on some of the shallower lakes such as Buck and Burnt Shanty, which may because of their shallowness be more susceptible to cultural eutrophication impacts as compared to the deeper lakes.

Restoration

Thirty lakes were considered *partial-support* or *non-support*. Of the *partial-support* lakes, only Trout and Prairie were based on current data. Efforts have been underway on Trout to improve its quality. Prairie Lake is one of three reservoirs in Itasca; as such it likely has a very large watershed, which is common for reservoirs. It is also quite shallow and is very dark in color as a result of extensive wetlands in its watershed. No chlorophyll-a data were available to assess how responsive Prairie Lake might be to excess phosphorus loading, as some darker lakes generate less chlorophyll-a per unit of TP than do clear lakes. Further monitoring might be merited for Prairie Lake as well as some of the larger *partial-support* lakes with old data such as Big Club, Cut Foot Sioux, and Dora.

All of the lakes classified as *non-support* of swimmable use had old data. Based on lake surface area--Bowstring, Round, and Little Winnibigoshish may be the highest priorities for baseline monitoring.

Lakes without P data

The remainder of the lakes (66) were assessed based on Secchi data. Of the lakes in the protection category, those classified as *support-threatened* (5 lakes) as compared to *fully support* may be the highest priority for baseline trophic status monitoring or LAP studies. Of these, Split Hand, Crooked, and Lawrence might be the highest priorities. Of the *fully-support* lakes there are several good candidates for baseline monitoring, with the large lakes like Pokegama, Sand and Deer likely being high priorities. Some of the lakes with very long CLMP records might be good candidates as well (e.g., Turtle and Siseebakwet). Three lakes were considered *partial-support* based on Secchi. Of these, Dixon may be the highest priority for baseline monitoring based on its size. All lakes which were classified based on old data should be enrolled in the CLMP if there is interest in the water quality from lake users or residents or if there is a need to begin to establish a current baseline for the lake--e.g., in anticipation of development in the watershed.

c) Minnesota River Basin Lakes Prioritization

The Minnesota River drains three separate ecoregions. The NGP is located in the western portion of the basin and accounts for about 32 percent of basin by area. It is a relatively lake-poor region. The NCHF is located in the northwestern and eastern portions of the basin and accounts for 16 percent of the basin. Major tributaries which drain from this ecoregion are the Chippewa River and Pomme de Terre River. A majority of the basin's lakes are in this ecoregion. The WCBP accounts for 52 percent of the basin and is drained by several major tributaries which flow north and east to the Minnesota River, including the Blue Earth, Cottonwood, and Redwood Rivers.

For the Minnesota River basin, 176 lakes (112,066 acres) were assessed. Of the 140 lakes, 80 percent, representing 93,304 acres (83%), were monitored. The high percentage of monitored data reflects monitoring conducted by the MPCA as well as monitoring conducted by citizens in the CLMP or in conjunction with local water plans.

The majority of assessed lakes were located in the NCHF (110 lakes, 63 percent), followed by the WCBP (42 lakes, 24 percent) and the NGP (24 lakes, 13 percent). However, the NGP lakes were rather large, accounting for 78 percent of total acres.

Since the Minnesota River drains multiple ecoregions, swimmable use was determined based on ecoregion criteria and is summarized for the basin as follows. Only 67 lakes (38 percent), accounting for 36,622 acres (33 percent), fully support swimmable use. In contrast, 71 lakes (40 percent) accounting for 52,994 acres (47 percent), are non-supporting. The remainder of the lakes (22 percent) partially support swimmable use. In order to place this in perspective for the basin, an analysis by ecoregion was conducted.

Of the 110 assessed lakes in NCHF, 48 lakes (44 percent) fully support swimmable uses, while 35 lakes (31 percent) do not support swimmable uses (Figure). The remainder (25 percent) partially support. In terms of trophic status, the majority (59 lakes, 53 percent) are eutrophic or hypereutrophic (28 lakes, 25 percent). However, a small portion are mesotrophic (19 lakes, 17 percent) or oligotrophic (4 lakes). In the NGP, only five lakes (21 percent) were fully supporting and four (six percent) partially supporting; the remaining (63 percent) were non-supporting. Trophic status is predominantly hypereutrophic (19 lakes, 79 percent) along with four eutrophic and one mesotrophic lakes. The sole mesotrophic lake, Elk Lake in Grant County, is somewhat deeper (maximum depth of 29 feet) than the norm (maximum depths of 7-14 feet) and most likely has a small watershed.

In the WCBP, 19 lakes (45 percent) fully support swimmable use, while seven (17 percent) are partially supporting. Those which support swimmable use are often deeper than the norm for the ecoregion. The majority of the lakes (20, 67 percent) are hypereutrophic, and the remainder are eutrophic. The remaining 21 lakes (50 percent) do not support swimmable use.

Minnesota River Basin Lake Prioritization and Related Activities

All lakes in the basin for which data was available in STORET were prioritized as per the previous discussion. The intention is to identify lakes which should be slated for protection versus restoration and those in need of additional data collection prior to instituting extensive lake or watershed management. In cases where data is available but not in the STORET data base, it could be considered in the same fashion as the proposed prioritization and the lake could be prioritized accordingly. A few notes follow which describe activities which have been taken on lakes in this listing as well as identifying lakes which should be good candidates for protection, restoration, or further monitoring. The discussion is organized by ecoregion.

Northern Glaciated Plains

Only Elk and Barrett Lakes in Grant County were in the protection category. Both were previously monitored by the MPCA. Barrett is located on the upper reaches of the Pomme de Terre River and receives drainage from the NCHF ecoregion to the north. Elk Lake would be a high priority for protection.

The MPCA has monitored several of the lakes classified as non-supporting of swimmable use. LAP studies were conducted on Lac Qui Parle, Hendricks, Perkins and Red Rock. Perkins Lake is also located by the Pomme de Terre River, downstream from Barrett Lake. CWP or CLP projects were conducted on Big Stone and Shaokotan. The majority of the other lakes with current data have been monitored by the MPCA in the course of our ecoregion-reference lake monitoring and other studies in this region. The state of South Dakota conducted some CLP work on the Hendricks Lake watershed, but the outcome is unknown. Lake Benton is likely a high priority for further investigation and a possible CWP project based on interest from the local community and the size of the lake. CLMP monitoring should be encouraged for any of the lakes on the list which have lakeshore residents concerned about the quality of the lakes.

Western Corn Belt Plains Ecoregion

The MPCA has monitored the majority of the lakes listed for the WCBP ecoregion. Good data bases are available for five of six lakes slated for protection: LAP studies were conducted on Ballantyne, St. James and Fish; St. Olaf is an ecoregion-reference lake; and Wellner Hagman is a relatively new reservoir and has been monitored over two summers. Lily Lake would be a high priority for monitoring if it has not been recently monitored, e.g., in conjunction with work on Lake Crystal.

Of the six lakes which partially support swimmable use, LAP studies have been done on Bass, Lura and Long, while Madison was sampled in the course of our regional-reference lake monitoring. South Silver and Swan Lakes would be priorities for monitoring and may be sampled in 1998 based on regional staff recommendations.

Of the lakes which do not support swimmable use, LAP studies have been done on Hanska, Fox, Duck, and Sleepy Eye. Sleepy Eye's fishery was recently rehabilitated by the MDNR. MPCA staff have worked with DNR to track progress on this project. Further work is being done on Hanska as well, and there may be some local follow-up on Fox Lake also. CWP projects have been or are being conducted on Duck, Mountain and Redwood Lakes. For those lakes with old data--Freeborn, High Island, Eagle, Silver and Washington might be good candidates for future monitoring; however, given their extreme shallowness, they may not be particularly good candidates for restoration. CLMP monitoring should be encouraged on the lakes which do not have current data and where there is some citizen interest in the water quality.

North Central Hardwood Forests

As noted previously, this portion of the Minnesota River basin has the highest density of lakes; and because of their morphometry and watershed characteristics, they tend to have better water quality than lakes in the NGP and WCBP portions of the basin. The MPCA has monitored several lakes in this portion of the basin through the LAP and reference lake monitoring efforts. This combined with local water plan TSI monitoring efforts (e.g., Pope County) provide good data for assessing lake condition.

Of the lakes slated for protection--Minnewaska, Linka, and Games Lakes were sampled through the LAP, while Chippewa, Maple, Florida, George, Scandinavian, and Reeds were sampled as a part of the MPCA's regional reference and trend monitoring efforts. Florida Lake has been deemed a priority for a LAP study in the Kandiyohi Local Water Plan, and a study may be conducted in 1997. Additional data should be collected on Signalness Lake (also referred to as Mountain Lake) at some point in the future since it currently has very good water quality for this ecoregion but is relatively shallow. Most, if not all, of its watershed is located in a state park, which should provide some protection from future degradation. Reeds Lake in Waseca County is a very good candidate for protection considering its good quality relative to other lakes in this lake-poor county. Since it is relatively shallow it is especially important to minimize nutrient loading, which could rapidly degrade the lake. Turtle Lake in Douglas could be a good candidate for further monitoring since its P data base consists of one measurement and its mean TSI value of 61 is indicative of only partial support. Likewise, it is a very shallow lake and, thus, very susceptible to further eutrophication.

Several LAP studies have been done on lakes classified as partially supporting swimmable use, including: Pelican (Grant and Pope Counties), Waconia, Norway, and Eagle. The LAP studies on Norway and Waconia have prompted further follow-up at the local level. Eagle Lake has had extensive studies conducted on it dating back to the 1970s when the lakeshore was sewered.

However, despite this measure, the water quality of the lake has not improved; in fact, the CLMP record suggests a non-significant decline in transparency over time. Upstream NPSs and urban stormwater are likely sources of excess nutrients. Pelican Lake in Pope County is getting further investigation as a part of a county-sponsored study of its main tributary, “Trappers Run.” This tributary drains to Lake Minnewaska -- a lake which should be a very high priority for protection given its currently good water quality and large size. High nutrient concentrations in Trappers Run lead to the impaired water quality in Pelican Lake, which in turn can lead to excess P loading to Minnewaska.

Several of the lakes characterized as non-supporting of swimmable use have been sampled by the MPCA. Emily and Gilchrist Lakes in Pope County were sampled through the LAP. Some follow-up watershed investigation is underway in the Lake Emily watershed as a result of the LAP. This investigation is focusing on the nutrient-rich drainage from the Little Chippewa River which was diverted into Lake Emily several decades ago as a part of a county ditch project. The lake association, DNR, and county will be looking at the possibility and consequences of routing this drainage back into its natural channel and hence to the Chippewa River. Other lakes which have been studied more extensively include Crystal, Lower Prior and Alimagnet Lakes through the CLP or CWP programs. Some recent investigations of point-source impacts have provided data on Winkler and Miller Lakes in Carver County and Whiskey Lake in Douglas County. In each case, present or former point-source discharges have impaired the quality of these lakes. In the case of Winkler and Miller Lakes, which are a part of the Carver Creek watershed, substantial reductions in in-lake P have resulted from recent improvements in the upstream wastewater discharge. These lakes will continue to be monitored in the future. Two other lakes upstream of Winkler and Miller--Rice and Hydes Lakes--should be considered for monitoring as well. Both have high P concentrations but are upstream of the discharge affecting Winkler and Miller Lakes.

Of the lakes which fully support or are support-threatened based on Secchi data there are several good candidates for more intensive monitoring. Based on surface area, Ten Mile and Eagle in Otter Tail and Andrew and Long in Kandiyohi would likely be good candidates for additional monitoring. Long Lake in Kandiyohi and Aaron Lake in Douglas County have submitted LAP applications for consideration in 1997. Henderson Lake in Kandiyohi County had a LAP study conducted in 1996 at the request of the association and local water planner. There are numerous lakes in Dakota (e.g., lakes in Eagan) and Hennepin Counties (e.g., Bush and Bryant) which undoubtedly have data; but it is not in STORET, so it cannot be considered here. In the case of the lakes in Eagan, the city has undertaken an active surface water management program which has its own priorities for monitoring, protection and restoration. For all lakes classified as having old data, participation in the CLMP would be the alternative of first choice to begin to establish a current data base.

d) Red River Basin Lakes Prioritization

The Red River basin is a fairly complex basin, draining portions of five different ecoregions (Table 1). The Red River Valley (RRV) ecoregion comprises the largest portion of the basin (51 percent). However, the Northern Minnesota Wetlands (NMW) ecoregion (21 percent) and North Central Hardwoods Forests (NCHF) ecoregion (19 percent) comprise significant portions as well.

Of the 142 assessed lakes, 7 lakes are >5,000 acres (55,814 acres, 38 percent). Six of the seven are in the NCHF ecoregion, with Otter Tail Lake, at 14,753 acres, being the largest of the assessed lakes in the Red River basin. Lake Traverse, at 11,528 acres, is the second largest and is located in the NGP ecoregion and outlets to the Red River via the Bois de Sioux River.

There are significant differences in land form and glacial geology between these regions and, subsequently, distinct differences in terms of number and morphometry of lakes between ecoregions (portions of the basin). A total of 142 lakes, representing 148,401 acres, were assessed in the Red River basin. Of these, 114 lakes (80 percent) representing 125, 135 acres (84 percent) were monitored. As with the Minnesota River basin, the high percentage of monitored lakes can be attributed not only to MPCA monitoring efforts but also to strong participation in the CLMP and active monitoring programs conducted by counties through local water planning.

A vast majority of the assessed lakes, 118 lakes (83 percent) representing 130,632 acres (88 percent), fully support swimmable use. Only 12 lakes (9 percent), representing 13,207 acres (9 percent), do not support swimmable use. The remainder partially support.

The NCHF portion of the basin contains the majority of the assessed lakes (117 lakes, 82 percent) and acres (126,222 acres, 85 percent). Many of the lakes in this portion of the basin drain to the Red River via the Otter Tail, Buffalo, and Wild Rice Rivers. The majority (101 lakes, 86 percent) of the lakes in the region fully support swimmable use. The remainder partially support swimmable use (81 lakes). The remainder (8 lakes) do not support swimmable use. Four of these lakes receive (past or present) wastewater effluent (St. Clair, Stinking, Orwell, and Unnamed). The other four lakes were rather small and shallow.

The NLF portion of the basin had 16 (11 percent) assessed lakes, representing 7,407 acres (5 percent) of the total for the Red River basin. The primary tributaries to the Red River basin from this region are the Clearwater and Wild Rice Rivers. Of these 16 lakes, 15 fully support swimmable use and one partially supports. Trophic status is either oligotrophic (6 lakes) or mesotrophic (10 lakes).

The RRV portion of the basin is the largest in terms of area but has the fewest lakes of any region in the basin. This is a direct result of glacial activity in this portion of the state. The P criteria for the NCHF ecoregion were used to assess use-support in this region since there are too few lakes to develop a good set of reference lakes. Of the five lakes (2,369 acres) assessed--one fully supports, three partially support and one does not support swimmable use. Four lakes are eutrophic, and one is hypereutrophic.

Red River Basin Lake Prioritization and Related Activities

All lakes in the basin for which data was available in STORET were prioritized as per the previous discussion. The intention is to identify lakes which should be slated for protection versus restoration and those in need of additional data collection prior to instituting extensive lake or watershed management. In cases where data is available but not in the STORET data base, it could be considered in the same fashion as the proposed prioritization and the lake could be prioritized accordingly. A few notes follow which describe measures which have been taken on lakes in this listing as well as identify lakes which should be good candidates for protection, restoration, or further monitoring.

Northern Glaciated Plains

Only one lake in this portion of the basin had current phosphorus data--Traverse Lake. Traverse Lake lies along the Minnesota-South Dakota border and forms the headwaters of the Bois de Sioux River. Current data indicate non-support of swimmable use, and a CWP project is currently underway on the lake. Three other lakes have old data including two “Unnamed” lakes near Donnelly and East Toqua near Graceville. The two unnamed lakes are rather small and would not be considered priorities. East Toqua is rather large but shallow. CLMP monitoring would be useful here to provide baseline data. Trophic status monitoring may be appropriate if the lake were deemed a priority in the local water plan.

Northern Lakes and Forests

Of the 16 lakes assessed in this portion of the basin, only six had P data. Of these, only--three Long Lost, Walker Brook, and Julia--were based on current data, while Green Water, Medicine, and Sandy were based on old data. Long Lost was sampled through the LAP in 1995 and would be a high priority for protection. Green Water, Medicine , and Sandy would be good candidates for further monitoring and protection as well.

All ten of the lakes without P data fully support swimmable use. Of these, the four largest--Blackduck, Pine, Clearwater, and White Fish--would be the highest priorities for further monitoring. Clearwater Lake was included in the LAP in 1996. Blackduck Lake was featured in a MPCA Water Quality Trend Assessment Report (Heiskary and Klang, 1993). Blackduck exhibited a significant increase in transparency based on 12 years of data. The improvement in transparency was felt to be a result of improved wastewater treatment by the city of Blackduck. Given the low trophic state based on Secchi, it is likely that these ten lakes will be good candidates for protection.

Northern Minnesota Wetlands

Only one lake was assessed in this region--Bartlett Lake at Northome. Bartlett Lake was non-supportive of swimmable use based on old data. This lake previously received wastewater effluent from the city of Northhome. Available records suggest that the effluent was diverted from the lake in the 1980s. A National Eutrophication Survey report was done on this lake in the 1970s. This lake could be a candidate for further monitoring if it were deemed a priority in the local water plan.

Red River Valley

Three of four assessed lakes in this region of the basin had P data. Of these, Maple Lake partially supports, while Lightning and Mustinka River flowage did not support swimmable use. Maple Lake has had a history of lake level problems, and various solutions have been proposed to alleviate the lack of water or improve water flow-through characteristics. It has good water quality based on available data and would be a good candidate for protection.

Lake Bronson was assessed based on Secchi. This lake would be an excellent candidate for further assessment since it is the primary feature in the state park in which it is located. This likewise may make it a good candidate for protection.

North Central Hardwood Forests

A good data base is available for assessing lake condition in this region based on MPCA's LAP and regional reference lake sampling, local water plan COLA monitoring, and lake association participation in the CLMP. Several of the lakes with P data and fully supporting of swimmable use have been monitored through the LAP: Dead, Big Pine, Clitheral, East Battle, Marion, Stuart, Sand Hill, Middle Cormorant, and Turtle. Turtle Lake, in Becker County, is an example of a lake exhibiting an improvement in trophic status over time and has a very good data base. It was speculated that improvements in on-site systems around the lake were one of the factors contributing to the improvement in the condition of the lake. Several other fully-supporting lakes were sampled as a part of the MPCA's ecoregion-reference lake sampling,.including: Big Cormorant, Detroit, Elbow, Long, Jewett, Twin, Pickerel, and Heilberger. Several others were sampled in conjunction with routine monitoring of lakes in the area. Four lakes were assessed based on old data. Of these lakes, West Battle and Lizzie would be priorities for further monitoring based on their size. Detroit Lake has been studied through the CLP as well.

Of the lakes classified as support-threatened based on P data, four had LAP studies: Height of Land, Floyd, Wall, and Little Toad. The Pelican River Watershed District continues to work in the watershed of Floyd Lake, and there continues to be concerns regarding the degree of development in its immediate watershed and the status of on-site systems. At Height of Land Lake there were concerns as to the impact of water level controls upstream on the national wildlife refuge. Work has been undertaken in the watershed of Wall Lake to reduce nutrient loading. A reevaluation of Wall Lake was conducted by the MPCA in 1995 at the request of the association. Data from the 1995 study was compared to data from 1981 and 1987 and 11 years of Secchi data. Based on this assessment, it appeared that P concentrations were slightly lower in 1995. Secchi transparency data revealed a significant improvement over time. Investigations in the watershed of Little Toad Lake continue as lakeshore residents continue to be concerned about the possibility of feedlot runoff reaching the lake. The MPCA may cooperate with the association on a sampling effort there in 1997. All lakes listed as support-threatened would be good candidates for protection.

Of those listed as partially-supporting, Lake Sallie has been assessed through the CLP and an extensive data base is available through the Pelican Lake Watershed District. This lake has exhibited significant shifts in its fishery over time, and these shifts have been linked to changes in the lake's water quality over the same period.

Of the non-supporting lakes, St. Clair has also been assessed through the CLP. Its high P concentration can be traced to the Detroit Lakes municipal wastewater discharge which enters the lake. The two lakes in Polk County--Turtle and Whitefish--could be priorities for further work since there are relatively few lakes in this county.

There were numerous lakes classified as fully supporting based on Secchi. Of these, nine are greater than 1,000 acres in size and could be considered priorities for baseline trophic status monitoring: Otter Tail, Lida, Pelican, Melissa, Blanche, Long, Little McDonald, Rose, and Rock Lakes. Of these, only Pelican Lake has a current application submitted for the LAP. Of the lakes with surface areas less than 1,000 acres, only Lake Six has a current application for the LAP. Given the large number of fully-supporting lakes with only Secchi data, it may be difficult to acquire baseline trophic status data on many of them over a short period of time. One additional strategy might involve the assessment of long-term Secchi records for these lakes. Any lakes exhibiting a significant decline in transparency over time should be a high priority for baseline monitoring. This strategy combined with priorities in the local water plan and interest on behalf of the lake associations may help identify priorities for additional monitoring. Until such monitoring is conducted, though, it would be wise to consider protective strategies for these lakes and thus be wary of land use or other changes which might impact their water quality.

For any of the remaining lakes on the list, monitoring Secchi through the CLMP is recommended as the best way to establish baseline data. No LAP or related studies should be conducted without this baseline. Of the support-threatened, partial-support, and non-support lakes--Cross Lake in Polk County might be the best candidate for some additional monitoring since there has been participation in the CLMP and because of the paucity of lakes in the county.

e) Lake Superior Basin Lake Prioritization

The Lake Superior basin is 6,141 square miles in area and drains one ecoregion--Northern Lakes and Forests (NLF). Thus, NLF in-lake P criteria serve as the basis for defining swimmable use support (Figure 2). There are a total of 208 lakes (80,059 acres) assessed in the current report. Of these, two lakes (Island Reservoir and Whiteface Reservoir, totaling 11,220 acres) are > 5,000 acres in size. Of the total lakes assessed, 98 lakes (47 percent) are based on monitored (1985 or newer) data. In terms of acres, 55,665 acres (70 percent) are based on monitored data. This is a marked contrast to the other basins (Table 2), where the monitored lakes (acres) exceed evaluated ones. This discrepancy for the Lake Superior basin can be attributed to reduced MPCA monitoring efforts in this basin in recent years, low participation in CLMP, and a large percentage of the lakes being located in the BWCAW. Much of the evaluated data was acquired during acid-rain surveys (including a fly survey of BWCAW) in the early 1980s.

The majority of the lakes (160 lakes or 77 percent) and acres (60,881 acres or 76 percent) fully support swimmable uses. A very small percentage of the lakes (12 lakes or 6 percent) do not support swimmable uses. These lakes tend to be quite shallow with maximum depths ranging from 9 to 31 feet and are frequently highly colored (which will reduce transparency). Four of these lakes receive (past or present) WWTF discharges. However, all wastewater dischargers in this basin would have to comply with the 1 mg of P/L effluent rule which is specific to the Lake Superior basin, unless a variance had been granted.

The vast majority of the lakes are in oligotrophic (21 percent) or mesotrophic condition (45 percent; Figure ?). Four lakes would be characterized as hypereutrophic-- Headquarters, Longyear, Elbow and Mashkenode. These four lakes are very shallow, and two--Elbow and Mashkenode--received wastewater effluent. The remainder of the assessed lakes are eutrophic.

Lake Superior Basin Lake Prioritization and Related Activities

All lakes in the basin for which data was available in STORET were prioritized as per the previous discussion. The intention is to identify lakes which should be slated for protection versus restoration and those in need of additional data collection prior to instituting extensive lake or watershed management. In cases where data is available but not in the STORET data base, it could be considered in the same fashion as the proposed prioritization and the lake could be prioritized accordingly. A few notes follow which describe measures which have been taken on lakes in this listing as well as identify lakes which should be good candidates for protection, restoration, or further monitoring.

Northern Lakes and Forests ecoregion

A majority of the lakes deemed *fully-supporting* or *support-threatened* had assessments based on old data. Much of this P data was acquired in the course of large-scale acid rain investigations in the early 1980s. Of those characterized as fully-supporting, Caribou and West Bearskin in Cook County and Pike in St. Louis County were monitored through the LAP. Leora, Dodo and Rose Lakes were sampled by the North St. Louis SWCD. The original LAP study on Caribou Lake was conducted in 1987 at the request of the lake association. Results from that study suggested some improvement in transparency over time. It was speculated that cessation of logging in the upper watershed may have led to lower nutrient loading to the lake. A follow-up investigation was requested in 1995 (?) as residents felt that the water quality of the lake was declining as a result of increased development around the lake and problems associated with on-site systems. Data from that investigation suggested that there may have been a slight decline in water quality. Continued CLMP monitoring will be useful to help track changes in the condition of this as well as other lakes.

Among the *support-threatened* lakes, Maple Leaf was assessed through a cooperative LAP study which the MPCA did in conjunction with the North St. Louis SWCD. This is a fairly developed lake, and the residents were concerned about the potential for water quality degradation. Winkle and Basset Lakes were sampled by the SWCD as well. Embarrass Lake was sampled by the MPCA to assess possible effects of upstream wastewater.

Given the large number of *fully-supporting* and *support-threatened* lakes in this basin with only old data available to characterize condition, it would seem to be a difficult task to prioritize lakes for more advanced monitoring. In addition to sorting the lakes by size, as is the case in the table, it might also be pertinent to ask which lakes may be susceptible to impacts from development or other activities in the watershed. With that as an additional basis it would seem to be reasonable to prioritize the lakes in the "corridor" between Lake Superior and the BWCAW and along the Gunflint Trail north of Grand Marais as being of higher priority for monitoring, since lakes in the BWCAW are well protected from the impacts of development. Given this additional criteria, lakes such as Devils Track, Two Island, East Bearskin, Elbow, Northern Light and Clara would seem to be priorities.

Very few of the *partial-support* lakes had current data. Of the six lakes, two lakes were studied through the LAP. Long and Horseshoe Lakes were assessed because local residents were concerned about the potential for excess nutrients arising from the upper watershed, runoff from adjacent roads, and poorly maintained on-site systems. For those lakes with old data, CLMP may be a viable alternative for providing some current information. However for some of the highly colored lakes which are common in this region, Secchi alone may not give an accurate reflection of lake trophic status and there may be a need to collect TP and chlorophyll-a data as well if a problem is suspected. The extent of development around a lake and lake size might also be valid criteria when deciding which lakes should have more intensive monitoring. Thus, some of the larger lakes like Seven Beaver, Whitewater, Crescent and Dumbell could be good candidates.

Only three of the *non-supporting* lakes have current data. Wild Rice (and Fish Lake) and Elbow Lakes in St. Louis County were studied as a part of the LAP in 1990 and 1987, respectively. The study of Elbow Lake was conducted to assess the impacts of upstream wastewater treatment plant effluent on the lake. Of the non-support lakes with old data, Hay Lake in Carlton County might be a priority for additional monitoring since there are only 74 lakes greater than 10 acres in Carlton County.

Of the lakes which *fully support* or *partially support*, there are several good candidates for baseline trophic status or LAP-level monitoring. Again, those lakes most likely to be subjected to development or other disturbances in the watershed should be high priorities. For example, LAP applications have been submitted for Clearwater, Pike, Hungry Jack, and Deer Yard Lakes in Cook County. These lakes are likely high priority in the local plan and are in or near the “corridor” along the North Shore or north of Grand Marais. Other lakes that might be priorities for baseline monitoring could include Island Lake Reservoir, Caribou, and Lax Lakes in St. Louis County and Big and Chub Lakes in Carlton County. For those lakes currently in the CLMP but lacking other water quality data, it will be essential to continue Secchi disk monitoring so that any trends in water quality might be detected. Should a statistically-significant trend in transparency be identified for any of these lakes, trophic status or LAP-level monitoring should be undertaken to provide some baseline data and to begin to assess potential causes of the trend. For those lakes without current data, it is important to get enrolled in the CLMP since this will provide a good starting point for characterizing current conditions.