APPROACHES TO SETTING NUTRIENT TARGETS IN THE RED RIVER OF THE NORTH

Topical Report RSI-2328

prepared for

International Joint Commission
1250 23rd St. NW, Room 100
Washington, DC 20440

March 2013

RESPEC
CONSULTING & SERVICES

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by

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EXECUTIVE SUMMARY

The International Joint Commission, through its International Red River Board (IRRB), has developed a proposed approach for a basinwide nutrient management strategy for the international Red River Watershed. One component of the nutrient management strategy involves developing nitrogen and phosphorus targets along the Red River including sites at the outlet of the Red River into Lake Winnipeg, the international boundary at Emerson, and subwatershed discharge points in the watershed. These nutrient objectives will be coordinated with developing nutrient objectives for Lake Winnipeg. As a first step in developing the nutrient targets, the IRRB contracted RESPEC to conduct a literature review of the available scientific methods for setting nitrogen and phosphorus water-quality targets. Based on the findings of the literature review, RESPEC was asked to provide recommendations on the method(s) most appropriate for the Red River. This report includes the findings of the literature review and the recommended scientific approaches for developing nitrogen and phosphorus targets in the Red River.

Multiple technical approaches were reviewed. One category of approaches uses the reference condition and includes techniques such as using data from reference sites, modeling the reference condition, estimating the reference condition from all sites within a class, and paleolimnological techniques to reconstruct the reference condition through historical data. The second category of approaches involves stressor-response relationships. With this approach, conceptual models are developed, exploratory data analysis is used to understand the system and suggest statistical approaches for modeling, and then stressor-response relationships are modeled. Other approaches include considering downstream water resources, maintaining existing water-quality conditions, and using literature values.

Two integrated approaches to developing nutrient targets to address the goals of restoring and protecting the Red River and Lake Winnipeg are recommended. A stressor-response modeling approach for the Red River should be completed in parallel to considering the downstream nutrient targets for Lake Winnipeg. These two approaches may yield different candidate nutrient targets, and these targets should be integrated to ensure compatibility. A comprehensive, long-term monitoring plan should also be developed and implemented, which will allow evaluation of goal attainment. The targets themselves should be evaluated periodically to ensure they remain appropriate to the overall goals of the Red River and are feasible.

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1.0 INTRODUCTION

1.1 BACKGROUND

The International Red River Board (IRRB) was established by the International Joint Commission (IJC) in 2001 “to assist the Commission in preventing and resolving transboundary disputes regarding the waters and aquatic ecosystem of the Red River and its tributaries and aquifers.”[1] The IRRB focuses on factors that affect water quality, water quantity, and aquatic integrity using the best available science and knowledge of the aquatic ecosystem.

The IRRB’s Water Quality Committee, which was established in 2011, is coordinating the development and implementation of a nutrient management strategy for the Red River Watershed [International Red River Board, 2011]. The mission statement established for this strategy is “To develop a collaborative, science and watershed-based approach to managing nutrients in the Red River and its watershed with the goal of restoring and protecting aquatic ecosystem health and water uses in the Red River Watershed and Lake Winnipeg” [International Red River Board, 2011].

One component of the nutrient management strategy involves developing nitrogen and phosphorus targets along the Red River including sites at the outlet of the Red River into Lake Winnipeg, the international boundary at Emerson, and subwatershed discharge points in the watershed. These nutrient objectives will be coordinated with developing nutrient objectives for Lake Winnipeg. As a first step in developing the nutrient targets, the IRRB contracted RESPEC to conduct a literature review of the available scientific methods for setting nitrogen and phosphorus water-quality targets. Based on the findings of the literature review, RESPEC was asked to provide recommendations on the method(s) most appropriate for the Red River. This report includes the findings of the literature review and the recommended scientific approaches for developing nitrogen and phosphorus targets in the Red River.

This report focuses on the available methods for setting water-quality targets for protecting and/or restoring aquatic ecosystems. Targets set for aquatic ecosystem health are assumed to be, at a minimum, as protective as those targets established for other uses.

1.2 WHY SET NUTRIENT TARGETS?

Nutrient targets are developed to establish a defined level of protection from elevated nutrient inputs into waterbodies. Excessive nutrients can harm aquatic systems, which can lead to degraded aquatic ecosystems and interference with human uses such as aquatic recreation, drinking water, fish consumption, and aesthetics. Nutrient targets can be set by local,

[1] From directive assigned to the IRRB from the IJC on February 7, 2001.

state/provincial, or federal governments, or by citizen groups organized for the purpose of protecting local water resources. Targets can be regulatory, which requires permit conditions enforced by the government. Targets can also be nonregulatory and serve as goals for water managers.

Nutrient targets can be both narrative and numeric. Narrative targets prohibit unacceptable conditions, such as nuisance algae blooms, and can include water-quality protection endpoints, such as the protection of biological integrity. Numeric targets establish a concentration or loading goal for a particular pollutant.

Multiple nutrient targets can be set for the same parameter for different goals of waterbodies. For example, a nitrogen target to protect a waterbody that is used as a drinking water source would typically be more stringent than a nitrogen target to protect a waterbody that is used for recreation but not for drinking water. However, a nitrogen target that is based on protecting aquatic life might be more stringent than the goals set for either of the human uses.

1.3 RED RIVER WATERSHED

The Red River Watershed (Figure 1-1) is located in Manitoba, Saskatchewan, Minnesota, North Dakota, and South Dakota, and it flows north 885 kilometers (550 miles) into Lake Winnipeg. While the Assiniboine River is a tributary to the Red River and, therefore, part of its watershed, discussion of the Red River Watershed often refers to the Red River drainage area that does not include the Assiniboine River (Figure 1-2). The Winnipeg River and the Saskatchewan River (Figure 1-1) are the other major rivers that drain to Lake Winnipeg. The Red River is a turbid and nutrient-rich system; the Red River (including the Assiniboine River Watershed) represents approximately 46 percent of the total nitrogen load to Lake Winnipeg and 73 percent of the total phosphorus load [Bourne et al., 2002], whereas it only represents 13 percent of the water inflow to the lake [Environment Canada and Manitoba Water Stewardship, 2011]. The Assiniboine River only represents approximately 15 percent of the total nitrogen and total phosphorus load in the Red River at its outlet to Lake Winnipeg [Bourne et al., 2002].

Trends of increasing nitrogen and phosphorus at locations along the Red River were seen from 1978 through 1999 [Jones and Armstrong, 2001]. Even though nutrient concentrations in the river are adequate enough to support algal growth, excessive algal growth in the river is not commonly seen [Goodman, 1997]. The high turbidity in the downstream portions of the river restricts light availability for algal growth. Turbidity in the upstream portions of the river (upstream of Fargo/Moorhead) is not as high, and chlorophyll concentrations in those segments are within the range of what is expected given the nutrient concentrations and relationships between nutrients and chlorophyll in other river systems in the region [Heiskary and Markus, 2003]; this suggests that algae in the southern segments are limited by nutrients as opposed to by light.

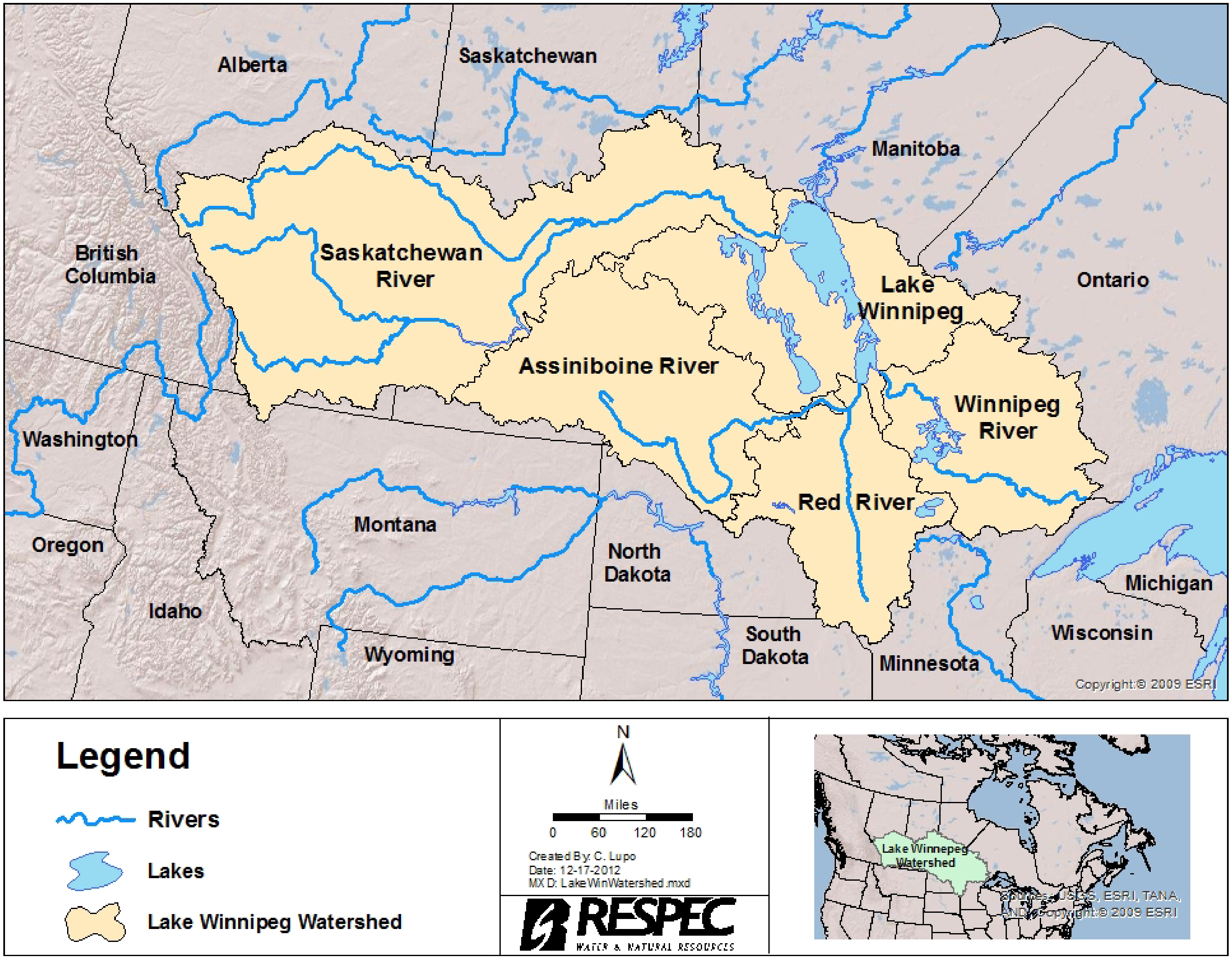

Figure 1-1. Lake Winnipeg Watershed.

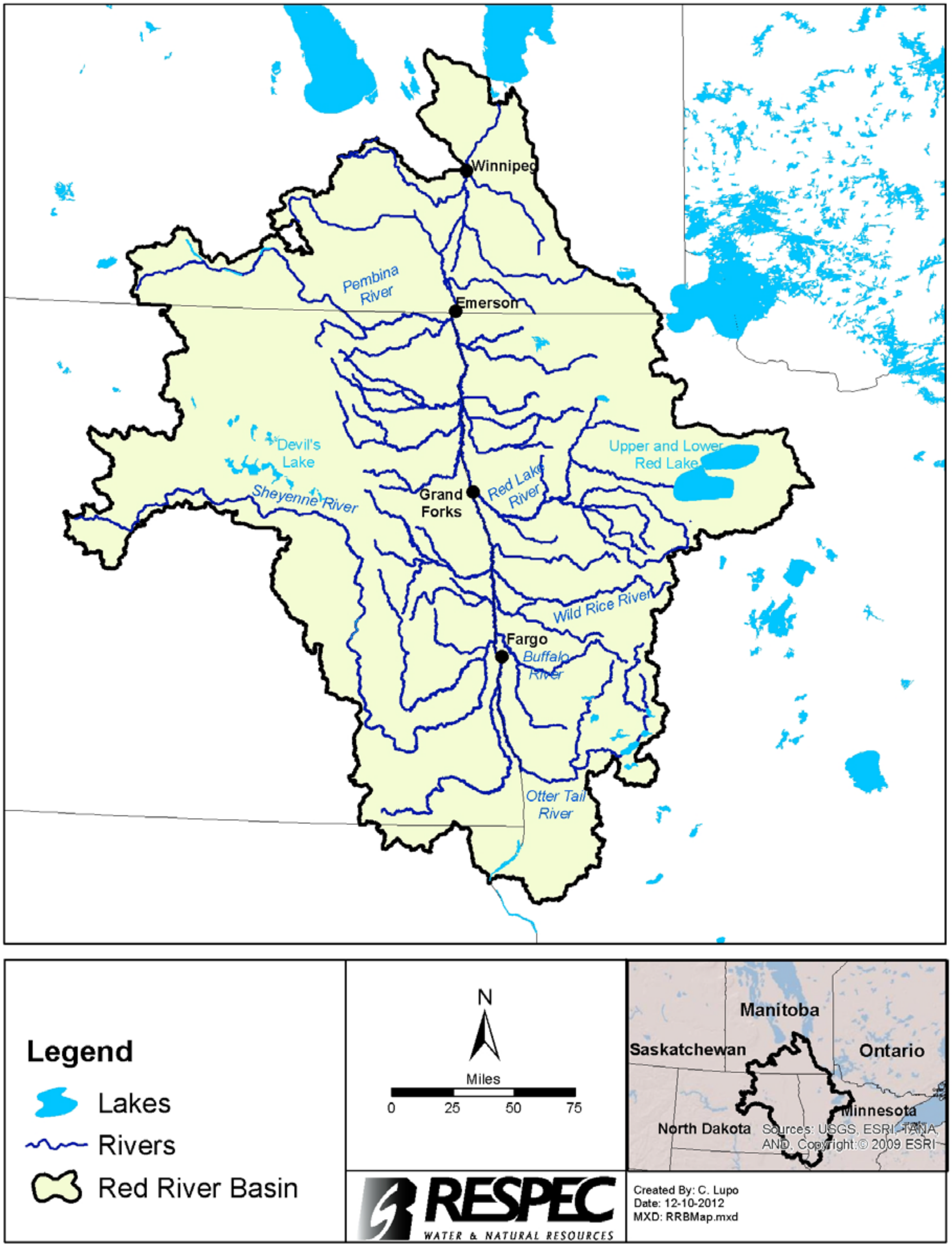

Figure 1-2. Red River Watershed.

A large portion of the Red River Watershed consists of silt and clay lake bottom sediments from what was Glacial Lake Agassiz over 10,000 years ago, while sandy and gravelly soils are more frequently found in the beach ridge areas[2]. The result is an extremely flat landscape that consists largely of phosphorus-rich, fine sediment soils. When they enter surface water from the watershed, the fine-textured soil particles remain suspended in the water column, which leads to a degraded condition [Paakh et al., 2006]. While much of the high turbidity in the Red River has been attributed to the nonpoint-source runoff within the watershed, the system likely was more turbid than other rivers in the region even before human settlement occurred because of its geologic origin. Because the Red River flows in a northerly direction, flooding and erosion problems are exacerbated during spring snowmelt conditions. The southern portions of the basin thaw before the northern portions, and the flowing water from the south is blocked by frozen waters in the north.

Approximately 75 percent of the land area in the Red River Watershed is agricultural [Red River Basin Board, 2000]. The other major land use categories include forests, wetlands, and developed areas. The main point-source inputs into the Red River are the wastewater discharges from the cities of Fargo, Moorhead, Grand Forks, East Grand Forks, and Winnipeg.

With the majority of the landscape in the Red River Watershed being dominated by intensive agriculture, there are few minimally disturbed waterbodies in the watershed. Some minimally disturbed small streams may exist in the beach ridge area of the watershed. These small streams, however, do not represent reference conditions in the larger river reaches. There are no large river reaches on the main stem of the river with minimal anthropogenic disturbance that could be used as a reference condition.

1.4 LAKE WINNIPEG

Lake Winnipeg, the Red River's receiving waterbody, is a large, shallow, eutrophic lake located in Manitoba, Canada. Even though algal blooms are not commonly observed in the Red River, Lake Winnipeg has undergone multiple stages of lake eutrophication as a result of excessive nutrient inputs. In the 1900s, overall algal abundance in the lake increased by approximately 300–500 percent as a result of increased nitrogen influx into the lake from crop and livestock production [Bunting et al., 2011]. The increase in algal abundance was mostly due to diatoms and cryptophytes, but not cyanobacteria. Increased nutrient loading attributed to crops and livestock accounted for most of the changes in lake trophic status during this time. Around 1990, an ecosystem state change occurred, which saw an increase in the spring variability in algae populations, a 50 percent reduction in pigments from summer-blooming algae (e.g., cyanobacteria and chlorophytes), and a 1,000 percent increase in the deposition of nitrogen-fixing cyanobacterial akinetes (resting stages). Bunting et al. [2011] state that failure

[2] A map of the beach ridge areas and other glacial formations can be found in Figure 3 of Paakh et al. [2006] at http://www.pca.state.mn.us/index.php/view-document.html?gid=6039.

to reduce nutrient influx may lead to a subsequent stage of eutrophication characterized by toxic low-light adapted cyanobacteria, which has been seen in agricultural regions around the world.

1.5 EXISTING NUMERIC TARGETS FOR RED RIVER

Because watershed boundaries typically do not follow jurisdictional boundaries, multiple nutrient targets often exist for a waterbody; this is the case for the Red River. The Red River flows through the states of Minnesota and North Dakota on the United States side and through the province of Manitoba in Canada. Each of these jurisdictions manages waterbodies differently; a summary of the nutrient targets that apply to the Red River as it flows through these jurisdictions follows.

The U.S. Environmental Protection Agency (U.S. EPA) recommended criteria for total phosphorus, total nitrogen, chlorophyll-*a*, and turbidity for rivers and streams across the country. The recommendations are meant to serve as starting points for states and tribes to develop more refined criteria. The recommended criteria were derived for each aggregate nutrient ecoregion and are estimates of reference condition within each ecoregion based on 25th percentiles of all nutrient data within the ecoregion [U.S. Environmental Protection Agency, 2000a]. Reference conditions were also estimated for each Level III ecoregion within the aggregate ecoregions (Table 1-1). The portion of the Red River Watershed that is in the United States is in Nutrient Ecoregion VI (Corn Belt and Northern Great Plains) and Level III ecoregion 48 (Lake Agassiz Plain).

Table 1-1. U.S. Environmental Protection Agency's Recommended Numeric Criteria

Parameter	Aggregate Nutrient Ecoregion VI Reference Conditions	Level III Ecoregion 48
Total phosphorus	< 76 µg/L[(a)]	< 88 µg/L[(a)]
Total nitrogen	< 2.18 mg/L[(b)]	< 1.16 mg/L[(b)]
Chlorophyll-*a*	< 2.7 µg/L[(a)]	NA
Turbidity	6.4 FTU[(c)]	6.14 FTU[(c)]

(a) µg/L – micrograms per liter

(b) mg/L – milligrams per liter

(c) FTU – Formazin turbidity unit

The state of Minnesota is in the process of developing numeric standards for streams and rivers. Heiskary et al. [2010] describe the analysis and derivation of the proposed numeric criteria. For purposes of stream and river criteria, the state is divided into three regions: north, central, and south. These divisions are based mostly on the U.S. EPA's aggregate nutrient ecoregions, and the Red River Watershed is located in the southern region [Heiskary and Parson, 2010]. The proposed numeric criteria (Table 1-2) include limits for total phosphorus, chlorophyll-*a*, dissolved oxygen diurnal flux, and biochemical oxygen demand; numeric criteria for nitrogen were not proposed. Additionally, a numeric translator is proposed to address nuisance periphyton concentrations and their adverse effects on aquatic life and recreation (Table 1-2). The proposed criteria were developed using multiple lines of evidence, including conceptual models, exploratory analysis, stressor-response modeling, and comparison with literature values. The public comment period for these standards will likely take place in spring 2013 with promulgation expected near the end of 2013.

Table 1-2. Minnesota's Proposed Numeric Criteria

Parameter	Proposed Criteria for South Region
Total phosphorus	< 150 μg/L
Chlorophyll-*a*	< 40 μg/L
Dissolved oxygen flux	≤ 4.5 mg/L
Biochemical oxygen demand	< 3.5 mg/L
Numeric translator for periphyton	150 mg chl-a/m^2

The state of North Dakota does not have existing or proposed numeric nutrient criteria for rivers or streams. North Dakota collects water-quality and biological data and is developing an index of biological integrity for fish and macroinvertebrates.

Water-quality guidelines within Manitoba are used to help interpret water-quality data and could be advanced to an objective if management intervention is needed. General water-quality guidelines include the following numeric goals for total phosphorus in rivers: total phosphorus should not exceed 25 μg/L in a tributary at the point where it enters a reservoir, lake, or pond; and total phosphorus should not exceed 50 μg/L in streams in general [Manitoba Water Stewardship, 2011].

Environment Canada's phosphorus guidance framework consists of a tiered approach in which phosphorus in a waterbody should not exceed a predefined trigger range and should not increase by more than 50 percent over reference conditions [Environment Canada, 2004; Canadian Council of Ministers of the Environment, 2004]. A similar guidance framework does not exist for nitrogen. In their guidance, the first step to determine a waterbody's phosphorus target is to define its reference condition. The phosphorus trigger range for a waterbody is then defined based on the trophic status of its reference condition (Table 1-3). If the current phosphorus concentration is below the upper boundary of the trigger range and has not increased by more than 50 percent above its reference condition, then the waterbody continues to be monitored periodically. If the current concentration is above the trigger range or if the concentration is below the trigger range but has increased by more than 50 percent above the reference conditions, then various tools are recommended to assess the waterbody and determine if management actions are needed.

Table 1-3. Total Phosphorus Trigger Ranges for Canadian Lakes and Rivers [Environment Canada, 2004]

Trophic Status	Trigger Range for Total Phosphorus (µg/L)
Ultra-oligotrophic	< 4
Oligotrophic	4–10
Mesotrophic	10–20
Meso-eutrophic	20–35
Eutrophic	35–100
Hyper-eutrophic	> 100

Applying this process to the Red River is difficult because of the river's highly disturbed watershed and the lack of existing reference sites or modeled reference condition for the Red River. The river's reference condition would need to be modeled, or the "best available condition" of the Red River could be used to represent the reference condition. Table 1-4 summarizes the existing numeric targets for nitrogen and phosphorus that apply to the Red River within its multiple jurisdictions.

Table 1-4. Summary of Numeric Nutrient Targets Applicable to the Red River

Jurisdiction	Total Phosphorus Numeric Target (µg/L)	Total Nitrogen Numeric Target (mg/L)
U.S. EPA, Aggregate Ecoregion VI and Level III Ecoregion 48	76–88	1.16–2.18
State of Minnesota, South Region	150	NA
Province of Manitoba	50 (all streams) 25 (where streams enter receiving lakes, ponds, or reservoirs)	NA

2.0 LITERATURE REVIEW METHODS

The literature review consisted primarily of searching peer-reviewed papers that present approaches to setting nutrient criteria. Reports and other grey literature documents were included if they were brought to our attention through communication with water-quality professionals during the course of this project.

The review of peer-reviewed literature began with a search using the Web of Science database and the following search criteria: nutrient criteria AND (stream* OR river*), and "nutrient criteria" AND (method* OR approach*). The resulting papers were reviewed and additional papers were gathered from the works cited within the first set of papers. The main goal of this literature review was to gain an understanding of the various approaches to deriving numeric nutrient targets for a waterbody such as the Red River. The review was not meant to be exhaustive of all peer-reviewed papers and reports in the grey literature that mention approaches to setting numeric nutrient targets; such an exhaustive review was beyond the scope of this project. (For example, see Hawkins et al. [2010] for a review of reference conditions, a common component of nutrient targets, in which over 1,000 papers were examined.)

The approaches that were evaluated for setting numeric criteria were not limited to nutrient criteria in rivers. While the majority of the reviewed studies present approaches used to derive nutrient (mostly nitrogen and phosphorus) criteria, some of the criteria developed were for other water-quality parameters, for example, sediment or chlorophyll. Similarly, while many of the studies applied these approaches to rivers and streams, many approaches were applied to lakes and a smaller number to wetlands. Regardless of the specific parameter selected for numeric criteria and the waterbody type, the methods themselves were determined to be applicable to nutrient criteria in rivers.

3.0 CONSIDERATIONS

The topics in this chapter were identified in the literature review. While they are not actual approaches *per se* to setting numeric nutrient targets, these topics factor into developing nutrient targets and merit a discussion of their own.

3.1 CLASSIFICATION SCHEMES

When developing nutrient targets for a waterbody, it is helpful to classify or delineate groups of waterbodies that have similar characteristics that affect water quality, such as land use, land cover, soil type, surficial geology, land surface slope, climate, annual runoff, waterbody morphometry (e.g., size, depth), and trophic state. In doing so, variability in water quality is minimized within groups, and reference conditions and/or water-quality targets can then be established for each waterbody class.

One such classification system involves ecoregions, which are regions of relative homogeneity in ecological systems or in the relationships between organisms and their environments. Omernik's [1987] ecoregion scheme for the United States is based on multiple geographic characteristics (e.g., soil, climate, vegetation, geology, land use) and is the classification basis for developing reference conditions and nutrient targets across the United States [Heiskary and Wilson, 2008; Dodds et al., 2006; Florida Department of Environmental Protection, 2012; Lamon and Qian, 2008; Smith et al., 2003; Suplee et al., 2007]. Omernik's [1987] Level III ecoregions were combined into 14 national nutrient ecoregions [U.S. Environmental Protection Agency, 1998], which are sometimes referred to as aggregate ecoregions. The 14 national ecoregions are sometimes considered too coarse of a scale for setting criteria, and it is recommended to use the Level III ecoregions or a finer classification system [Herlihy and Sifneos, 2008; Robertson et al., 2006].

Environment Canada's *National Ecological Framework for Canada* [Ecological Stratification Working Group, 1995] was used to develop phosphorus guidelines in Ontario [Gartner Lee Limited, 2006]. The spatial ecological framework developed ecozones, ecoregions, and ecodistricts to serve monitoring and reporting needs. Other classification schemes may involve factors such as lake depth or mixing status [Heiskary and Wilson, 2008], frequency of hydrologic disturbance [Biggs, 2000; Snelder et al., 2004], susceptibility to algal growth in response to nutrients [Lin et al., 2007], or groupings of environmental factors similar to ecoregions [Robertson et al., 2006]. Classification schemes that account for the most variation among waterbodies should be used, and models can be developed that test possible classification frameworks. While classifications based on ecoregion are commonly used, other models that consider the effects of human disturbance can replace the ecoregion framework, as measures of human disturbance often account for most of the variation explained by ecoregion [Cheruvelil et al., 2007].

A method that has been used recently to categorize ecological data into class types is regression tree analysis [Herlihy and Sifneos, 2008; Robertson et al., 2006], which explains the variability in a single response variable (e.g., phosphorus) using one or more explanatory variables (e.g., soil type, land cover). The statistical approach repeatedly splits the data into two groups, each of which are as homogeneous as possible [De'ath and Fabricius, 2000]. Regression tree analysis is discussed in more detail in Section 4.2.

3.2 FORMS OF NUTRIENT TARGETS

Different fractions of nitrogen and phosphorus can be used to set numeric nutrient targets. Even though a portion of the total nutrient is made up of living algae or detritus and, therefore, is not immediately available for uptake, total concentrations are often more appropriate than the dissolved and/or inorganic fractions. The dissolved inorganic forms of nutrients (e.g., phosphate and nitrate) are directly available for uptake by plants and algae. However, when nutrients limit primary production, the pool of dissolved inorganic nutrients may be low, as any newly available nutrient is quickly taken up by plants or algae. While there have been some studies that related soluble nutrient concentrations to algal biomass, total concentrations are generally thought to be more valid. Additionally, total nutrients are easier to measure and most monitoring programs include total nutrients, whereas dissolved and/or inorganic forms are less commonly measured.

Even though nutrient targets may be developed for total nutrients, it is still beneficial to sample and evaluate nutrient fractions, because relationships between nutrients and other ecological components will be different in different systems. For example, Heiskary et al. [2010] found that in Minnesota, the relationship between total Kjeldahl nitrogen (TKN)[3] and algae was stronger than the relationship between total nitrogen and algae. This was because at lower concentrations (1–2 mg/L), total nitrogen is mostly TKN; as concentrations increase, nitrate-nitrogen becomes a more significant component of total nitrogen and is the largest component of total nitrogen when total nitrogen is greater than 4 mg/L.

Nutrient targets can be set based on nutrient concentrations or nutrient loads, depending on the goal of the nutrient target. If the target is to protect the aquatic ecosystem within the waterbody for which the target is being set, then concentration is more appropriate. Organisms "see" concentration in a waterbody, whereas nutrient load is not directly relevant. On the other hand, if a nutrient target for a stream or river is designed to protect a downstream lake, the target is often set in terms of the nutrient load that the lake can assimilate and still meet its own water-quality goals.

[3] Total Kjeldahl nitrogen consists of organic nitrogen plus ammonia-nitrogen.

3.3 WEIGHT OF EVIDENCE

Instead of using just one approach to establish nutrient targets for a waterbody, multiple methods are often used in a weight-of-evidence approach. In establishing reference conditions, Dodds and Oakes [2004] modeled the reference condition for a stream class and compared the results to a known pristine stream and to the 5th to 25th percentile of all of the streams in the stream class (see Section 4.1 for a discussion on reference condition). Heiskary et al. [2010] began with data exploration and then used multiple approaches to stressor-response modeling to identify biologically relevant candidate criteria. The candidate criteria were then pooled together and the 25th percentile of all candidate criteria for a stream class was recommended as the numeric target. Smith and Tran [2010] also developed multiple candidate criteria; the criteria were weighted based on the strength and the significance of the analysis, the authors' confidence in the data, and best professional judgment. When the biological thresholds identified in multiple approaches to stressor-response modeling are consistent, the results suggest that the thresholds are ecologically relevant [Black et al., 2010].

4.0 APPROACHES

The approaches to setting nutrient criteria were divided into groups. Figure 4-1 categorizes the various approaches and includes a short description of each. The following sections discuss each approach in more detail.

4.1 REFERENCE CONDITION

One of the most common approaches to setting nutrient targets is through the use of a reference condition. The reference condition represents a relatively undisturbed waterbody and serves as a benchmark to which the current condition of a waterbody is compared. The phrase “reference condition” has multiple meanings, and the specific meaning that is used in a study should be explicitly defined. Stoddard et al. [2006] suggest that consistency needs to be brought to the terminology and that the phrase “reference condition” should be used to describe the reference condition for biological integrity. Other concepts that the phrase represents are minimally disturbed condition, historical condition, least-disturbed condition, and best attainable condition [Stoddard et al., 2006]. The U.S. EPA defines reference condition as minimally disturbed and further states that primary water-quality indicators such as total nitrogen, total phosphorus, chlorophyll-*a*, and turbidity should reflect this minimally disturbed condition [U.S. Environmental Protection Agency, 2000b].

The use of the reference condition to set a water-quality target is not based on biological endpoints and is not directly linked to achieving a biological goal such as biological integrity. However, the approach assumes that nutrient concentrations comparable with those in the reference condition would be protective of a waterbody’s goals [Herlihy and Sifneos, 2008]. The approach assumes that the reference condition can be defined or at least approximated.

An expected reference condition for a waterbody can be defined in multiple ways. One approach is to find an existing reference site or a group of existing reference sites. A second approach is to model the reference condition. This approach can be used when reference sites do not exist because of widespread disturbance of similar waterbodies. A third approach is to approximate the reference condition through assuming a certain frequency distribution of reference conditions among all sites within a given stream class. The fourth method is to reconstruct reference conditions by evaluating paleolimnological records. Reference conditions often are determined using multiple methods, and a weight-of-evidence approach is used to evaluate and select the reference condition to be used [Dodds et al., 2006]. These approaches are discussed in more detail below.

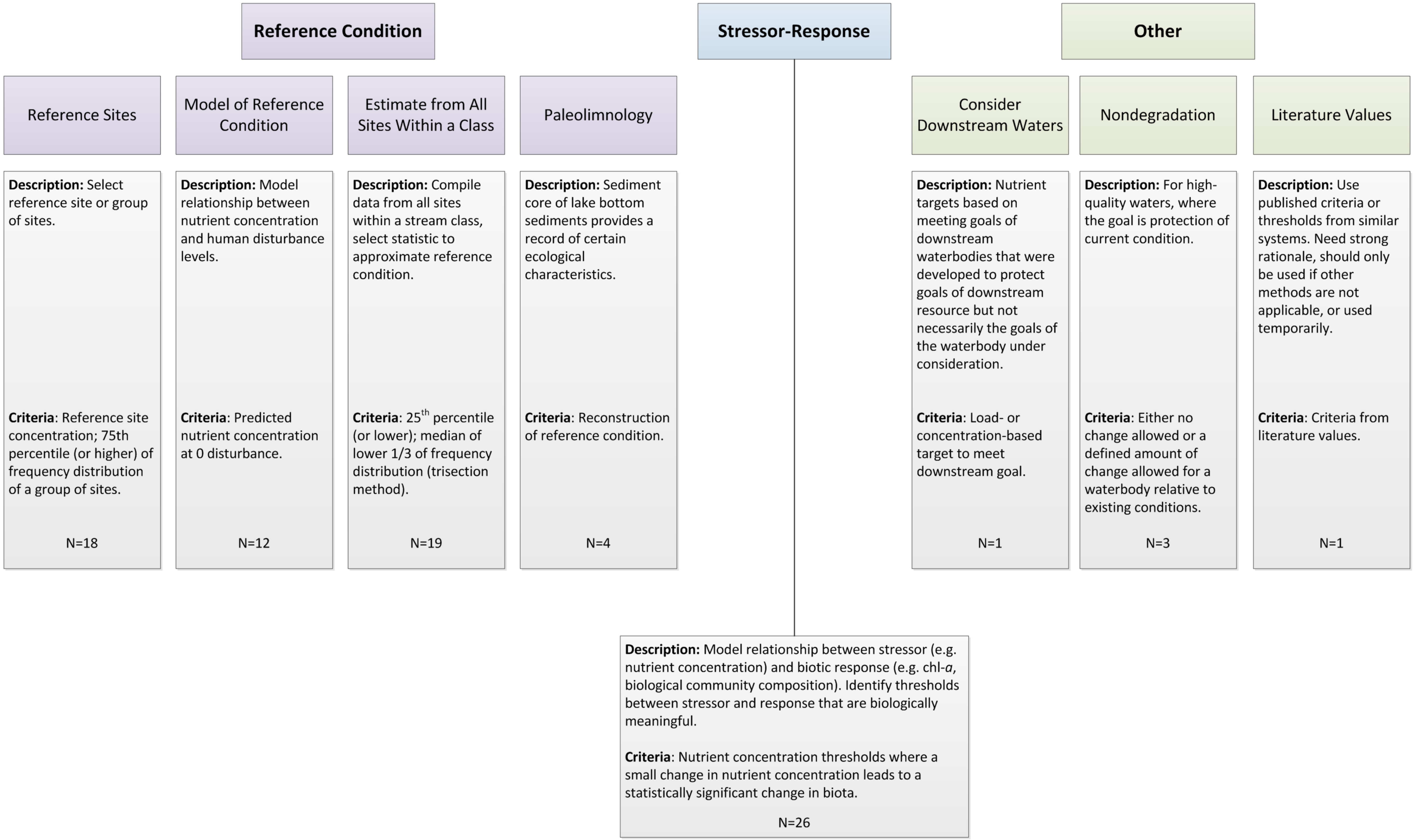

Figure 4-1. Approaches to Setting Nutrient Criteria. N indicates the number of papers and reports reviewed that use the approach.

4.1.1 Reference Sites

Reference sites can be selected based on best professional judgment [U.S. Environmental Protection Agency, 2000b] or on an objective evaluation of minimal disturbance in the watershed and in the waterbody itself (e.g., Pardo et al. [2012]; Sánchez-Montoya et al. [2012]). A single site can be selected with which to compare the test site [Dodds and Oakes, 2004], or a group of reference sites can be identified [Dodds et al., 2006; Huo et al., 2012]. With the latter, a specific value from within the frequency distribution must be selected. The U.S. EPA recommends the 75th percentile [U.S. Environmental Protection Agency, 2000b], which is the most commonly used statistic, but higher percentiles can also be used [Florida Department of Environmental Protection, 2012; Suplee et al., 2007]. The use of the 75th or higher percentile (Figure 4-2A) takes into account the fact that all of the reference sites are already assumed to be in a relatively undisturbed state. The values at the upper end of the distribution, while having relatively high nutrient concentrations among the reference sites, still represent more than acceptable conditions.

Rohm et al. [2002] caution that pooling data from multiple studies with different goals used to select reference sites is not a statistically valid approach to determining the reference condition. A sampling design developed explicitly for evaluating regional reference conditions is preferable to merging disparate datasets.

Because the temporal variability of water quality can be high, assessing compliance with a nutrient target developed from reference sites needs to consider the statistic used to represent the nutrient condition in the reference sites [Knowlton and Jones, 2006]. For example, if the 75th percentile of the average annual concentration in a set of reference streams is used as a nutrient target, compliance should be assessed by evaluating the average annual concentration at the test site as opposed to individual observations of nutrient concentration.

The reference site approach assumes that reference sites and sites to which the reference is being compared would have similar characteristics in the absence of human impacts. Therefore, sites must be classified appropriately (see Section 3.1).

Reference sites are more commonly found in small headwater streams than in medium to large rivers [Dodds and Oakes, 2004]. If reference sites for a medium to large river do not exist, but reference headwater streams do exist within the watershed, background nutrient loadings from headwater streams can be combined with instream nutrient loss rates from previously calibrated large watershed models to estimate downstream background nutrient levels [Smith et al., 2003].

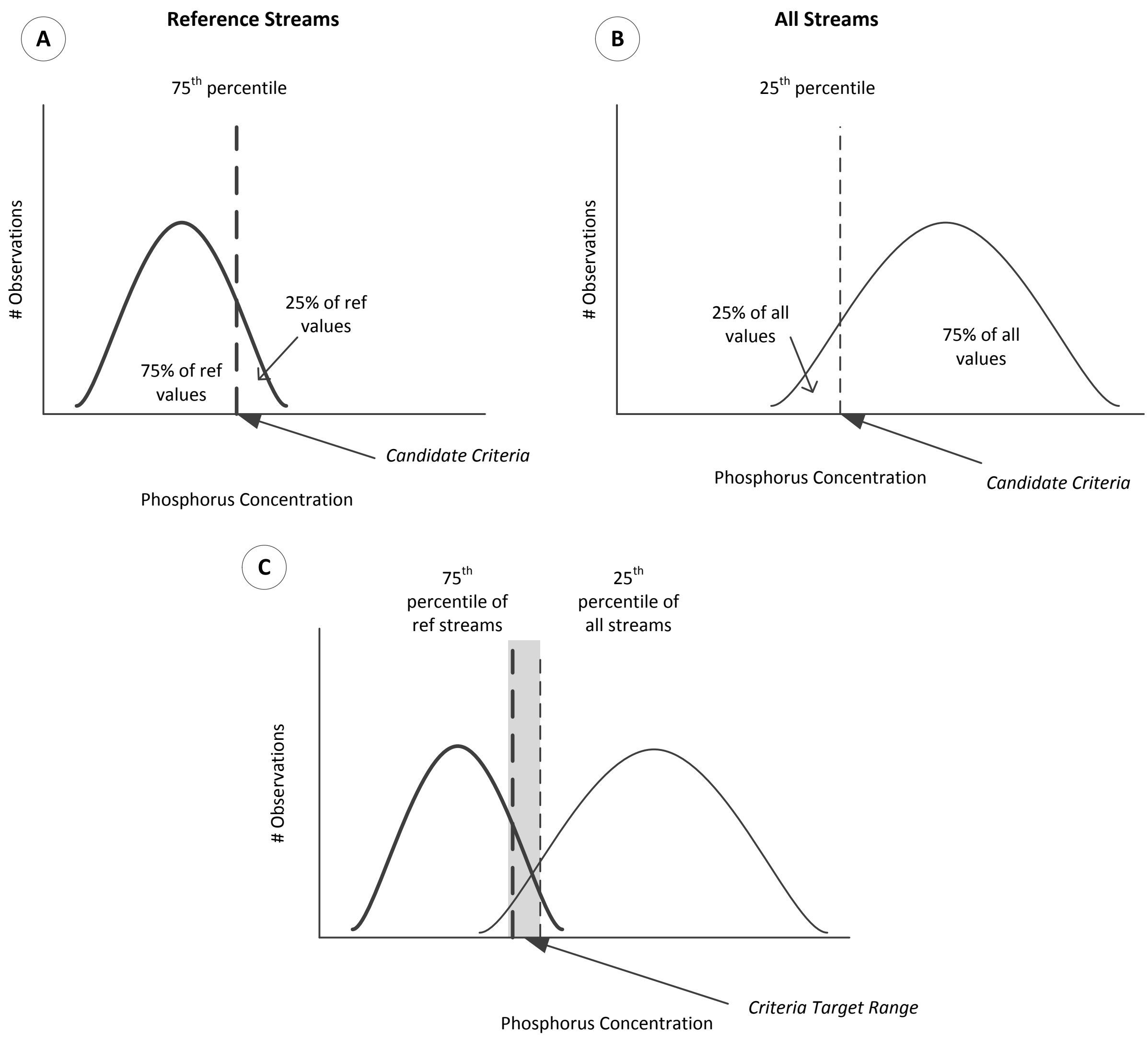

Figure 4-2. Selection of Reference Values Using Frequency Distributions From (A) Reference Streams Within a Class, (B) All Streams Within a Class, and (C) a Comparison of Both Approaches (modeled after Figure 8 in U.S. Environmental Protection Agency [2000b]).

When compiling data from a group of reference sites to establish reference conditions for a waterbody classification, at least three reference sites should be selected [U.S. Environmental Protection Agency, 2000b], and several years of nitrogen and phosphorus data (approximately six to ten samples each year, representing a range in hydrologic conditions) at the reference sites are preferred.

If reference sites exist and are easily identified, the reference site approach is relatively simple and straightforward to use, and it is easily understandable by stakeholders. However, the reference site approach is not directly linked to use attainment, in that a reference site does not necessarily meet the waterbody's designated use. Additionally, the reference site approach is not based on biological endpoints. Lastly, if appropriate reference sites do not exist in the area or class of interest, then this approach cannot be used.

Box 1 lists and provides short summaries of the papers and reports that were reviewed for this project that identified reference sites.

Box 1. Papers and reports reviewed that identified reference sites. List includes author and year of document and a brief summary of the method used, the geographic location, and the waterbody type. See *Chapter 6.0 References* for the complete citations.

Reference Condition: Reference Sites

Chambers et al. 2008, 2011, 2012
75th percentile of least disturbed streams; 7 regions in Canada

Dodds and Oakes 2004
Known pristine stream; Kansas streams

Dodds et al. 2006
50th and 75th percentile of minimally developed lakes; Kansas lakes and reservoirs

Environment Canada 2004
Historical records from pre-disturbed conditions; use of either pristine or best available condition sites; 75th percentile of reference sites; included in reference condition approaches for Canada

Florida Department of Environmental Protection 2012
90th or 75th percentile of reference sites; streams in Florida

Herlihy and Sifneos 2008
75th percentile; nationwide (US) and Pacific Northwest

Huo et al. 2012
75th percentile of minimally developed lake catchments; Yungui Plateau, China

Mukherjee et al. 2009
75th percentile of TP (total phosphorus) concentration in wetland soils of least impacted wetlands; SE US (FL, AL, GA, SC)

Newall and Tiller 2002
75th percentile of TN (total nitrogen) and TP concentration in reference sites determined from macroinvertebrate community; streams in State of Victoria, Australia

Pardo et al. 2012
ID reference sites with minimally disturbed condition; rivers in Central Baltic region of Europe

Rohm et al. 2002
Direction regarding data selection to identify reference sites

Sánchez-Montoya et al. 2012
75th percentile of reference sites based on predetermined pressure criteria; Mediterranean streams in Spain

Sheeder and Evans 2004
Midpoint between impaired and unimpaired (reference) watersheds' 95% CI of the median, streams in PA

Smith and Tran 2010
Median of 75th percentile of reference sites; nonwadeable rivers in NY

Stevenson et al. 2008
75th percentile of sites with low levels of human disturbance; streams in Mid-Atlantic Highlands (US)

Suplee et al. 2007
86th percentile of reference sites; streams in Montana

Tiller and Newall 2003
75th percentile of TN and TP in reference sites; streams in State of Victoria, Australia

U.S. Environmental Protection Agency 2000b
Reference conditions from reference reaches, or 75th percentile of reference streams; streams in US

4.1.2 Model of Reference Condition

If reference sites do not exist, the reference condition can be modeled. A model of the relationship between environmental factors (independent variables such as percent agriculture in the watershed, soil type, climate) and the instream nutrient concentration (response variable) is developed. Human disturbance is then set to zero in the calibrated model and the predicted instream nutrient concentration represents the reference condition (Figure 4-3). Models of reference condition can be statistical models [Dodds and Oakes, 2004; Soranno et al., 2011], mechanistic, or a blend of the two [Smith et al., 2003].

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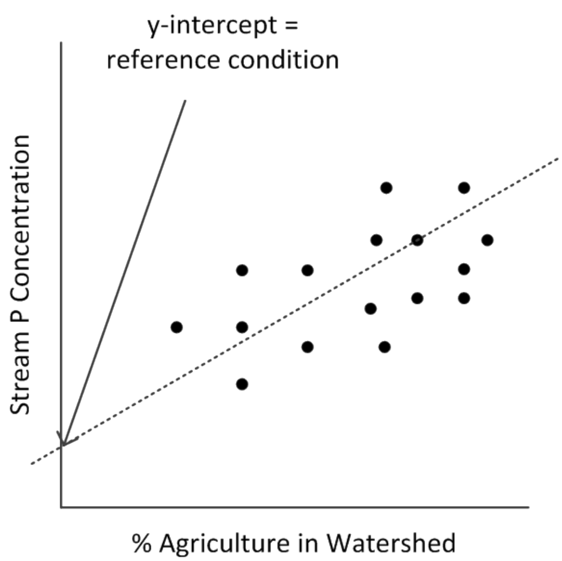

Figure 4-3. Hypothetical Example of Linear Regression to Model Reference Condition.

Landscape-context regression models are a statistical approach to modeling a reference condition in which a linear relationship is assumed between landscape-scale data and nutrient concentrations [Soranno et al., 2011]. Dodds and Oakes [2004] used widely available digital land cover and population density data to generate reference nutrient concentrations using a dataset from Kansas and another dataset from across the United States. Land cover classifications assumed to include anthropogenic impacts were cropland, pastureland, rangeland, farmland, and urban land. Multiple linear regression was used to develop statistically significant relationships between land cover and nutrient concentrations, and the y-intercept was used to extrapolate the nutrient concentrations in the absence of the modeled anthropogenic factors. An estimate of uncertainty was provided by the 95 percent prediction band. Not all sources of human impacts are quantifiable and, therefore, cannot be incorporated into the model.

Soranno et al. [2011] present an approach in which multiple regression is used to relate the response variable (e.g., nutrients, biota) to hydrogeomorphic data in addition to characteristics of human disturbance. The final regression model only includes the human disturbance variables that were statistically significant in the original model. The regression coefficients for the human disturbance variables are then set to zero to predict the reference condition; the "hindcasting" model, therefore, still accounts for natural variability in the hydrogeomorphic characteristics [Soranno et al., 2011]. Simple linear regression has also been used to develop reference conditions, with the regression representing the relationship between nutrient concentration and percent of agricultural land in the watershed [Chambers et al., 2012].

The landscape-context regression modeling approach assumes that the human disturbances included in the model are the main drivers of the waterbody's nutrient response to disturbance, that the model is valid at values of low or zero human disturbance, and that the waterbodies used in the model development are a representative and unbiased sample of waterbodies in the region [Soranno et al., 2011]. The main disadvantage of this approach is the need to extrapolate beyond the data points used to develop the model. The uncertainty estimate reflects this, and broader prediction bands will result from predictions made farther away from the observed data.

The above models all assume a linear relationship between the stressor (human disturbance) and response (nutrients, biota) variables. Nonlinear models can also be used. Chambers et al. [2011] used regression tree analysis to identify changepoints in the relationship between agricultural land use and nutrient concentrations. Regression tree analysis is a nonparametric statistical technique and is discussed in more detail in Section 4.2. With all of these statistical approaches, the dataset must be robust so that the statistical tests will be able to detect effects.

The above approaches are statistical approaches that relate field observations to causative environmental factors. On the other end of the range of water-quality modeling approaches are mechanistic models, which estimate water-quality conditions through mass or energy balance models for explicit physical environmental processes. Some models incorporate aspects of both statistical and mechanistic approaches, such as Spatially Referenced Regression on Watersheds, or SPARROW [Preston et al., 2009]. SPARROW integrates monitoring data with landscape information and is used to predict long-term average values of water-quality characteristics. While a SPARROW model would not be used on its own to model a reference condition, values from a calibrated SPARROW model can be used with other models to estimate the reference condition. To circumvent the difficulties of identifying reference reaches in medium to large river systems, Smith et al. [2003] used instream nutrient loss rates estimated in a SPARROW model of a watershed and applied these rates to estimates of the background nutrient yield in headwater streams of the same watershed that were modeled using multiple regression. The resulting nutrient concentrations represent reference conditions of the downstream, higher order stream reaches. This approach assumes that background nutrient concentrations do not substantially change the nutrient loss rate coefficients.

One major advantage of modeling the reference condition is that the approach does not require *a priori* identification of reference sites. Additionally, some of the statistical approaches are typically feasible with available landscape and hydrogeomorphic data [Soranno et al., 2008]. However, there is more uncertainty if the model development dataset does not include sites with a low disturbance level (Figure 4-4). In some watersheds, there may be a small number of undisturbed headwater streams to represent the low end of the spectrum of human disturbance. Sites with low human disturbance in otherwise highly disturbed watersheds often have other characteristics that make them undesirable for human uses, such as rocky terrain that is unsuitable for cropland [Dodds and Oakes, 2004]. Therefore, one needs to be aware of the particular setting when using landscape-level data.

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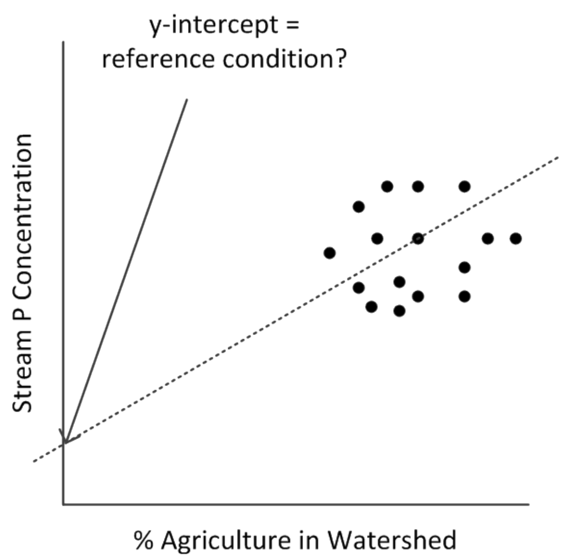

Figure 4-4. Hypothetical Example of Linear Regression for a Watershed With Few Undisturbed Streams.

Box 2 lists and provides short summaries of the papers and reports that were reviewed for this project that modeled the reference condition.

Box 2. Papers and reports reviewed that modeled the reference condition. List includes author and year of document and a brief summary of the method used, the geographic location, and the waterbody type. See *Chapter 6.0 References* for the complete citations.

Reference Condition: Models

Baker et al. 2005
Multiple linear regression including anthropogenic disturbance as independent variable, extrapolated to zero disturbance; streams in Northern Lakes and Forests Ecoregion (MN, WI, MI)

Dodds and Oakes 2004
Multiple linear regression (land use as independent variable, nutrient concentration as dependent variable, y-intercept is reference condition); Kansas streams

Chambers et al. 2008, 2011, 2012
Regression tree analysis, agricultural land use (independent) nutrient concentration (dependent); streams in 7 regions in Canada

Chambers et al. 2012
Hindcasting with linear regression, % agricultural (independent), TP and TN concentration (dependent); streams in 7 regions in Canada

Dodds et al. 2006
Regression-based extrapolation; Kansas lakes and reservoirs

Environment Canada 2004
Hindcasting using models that relate shoreline development to trophic status; included in reference condition approaches for Canada

Herlihy and Sifneos 2008
Regression-based extrapolation; nationwide (US) and Pacific Northwest

Smith et al. 2003
Regression model to predict background nutrient yield, nutrient loss rates from SPARROW model applied to predict downstream reference condition; headwater streams across US 14 ecoregions

Soranno et al. 2008
Hindcasting with multiple regression, hydrogeomorphic factors (independent) and TP (dependent); lakes in Michigan

Soranno et al. 2011
Describes use of landscape-context statistical models that use hydrogeomorphic data and human disturbance

Stevenson et al. 2008
Hindcasting with linear regression between % watershed altered (independent) and TP (dependent); 75% CI for predicted TP when % watershed altered was zero; streams in Mid-Atlantic Highlands (US)

Zheng et al. 2008
Hindcasting with linear regression and multiple regression between land cover (independent) and N/P (dependent); streams in eastern panhandle region of West Virginia

4.1.3 Estimate From All Sites Within a Class

If reference sites have not been identified in a watershed or waterbody class, a frequency distribution approach may be used that assumes that reference waterbodies occur in the overall population of waterbodies within a certain class at a predetermined frequency [U.S. Environmental Protection Agency, 2000b]. The U.S. EPA recommends using the 5th to the 25th percentile of observed nutrient concentrations to approximate the reference condition. If the 25th percentile is used, the approach assumes that 25 percent of the sites in a region represent reference condition and, therefore, it also assumes that 75 percent of the sites do not represent the reference condition (Figure 4-2B). If it is believed that almost all of the streams within the class are impaired, then the 5th percentile is recommended. In certain datasets, the 25th percentile of the general population equals the 75th percentile of reference sites (Figure 4-2C) [U.S. Environmental Protection Agency, 2000b].

The U.S. EPA's recommendation of using the 25th percentile in the general population has led many researchers to compare this statistic to reference conditions obtained using other methods (e.g., Chambers et al. [2012]; Herlihy and Sifneos [2008]; Huo et al. [2012]). While there are examples of the 25th percentile approach agreeing in a general sense with other approaches to define reference condition in a system [Dodds and Oakes, 2004], there are some drawbacks. The approach assumes that a fixed percentage of sites within a class are reference sites, regardless of the level of disturbance within a watershed. However, the proportion of reference sites varies among watersheds and can also change over time within a watershed [Herlihy and Sifneos, 2008]. Multiple years of data from an unbiased, representative group of sites within a stream class is needed.

Another frequency distribution approach is to represent the reference condition with the median of the lower third of a parameter's frequency distribution; this approach is sometimes referred to as the trisection approach. It is more commonly used to describe reference conditions in lakes [Dodds et al., 2006; Cunha et al., 2012], although one instance of its use in rivers was found [Cunha et al., 2011]. The same drawbacks apply to this approach as the drawbacks to the 25th percentile approach. These approaches should, therefore, be considered only as a last resort if there are no other options to establishing the reference condition.

Box 3 lists and provides short summaries of the papers and reports that were reviewed for this project that estimate the reference condition from the frequency distribution of all sites within a class.

Box 3. Papers and reports reviewed that estimate the reference condition from the frequency distribution of all sites within a class. List includes author and year of document and a brief summary of the method used, the geographic location, and the waterbody type. See *Chapter 6.0 References* for the complete citations.

Reference Condition: Estimate from all sites within a class

Alberta Environment 2012a
25th percentile of general population

Chambers et al. 2008, 2011, 2012
25th percentile of all streams; 7 regions in Canada

Cunha et al. 2011
Trisection; Sao Paolo State (Brazil) tropical streams and rivers

Cunha et al. 2012
Trisection; Sao Paolo State (Brazil) subtropical reservoirs

Dodds and Oakes 2004
5-25th percentile of general population; Kansas streams

Dodds et al. 2006
Median of lower third; Kansas lakes and reservoirs

Environment Canada 2004
25th percentile of all sites; included in reference condition approaches for Canada

Gartner Lee Limited 2006
25th percentile to identify triggers, Ontario as a case study of Environment Canada 2004 recommendations; rivers and lakes in Ontario

Herlihy and Sifneos 2008
25th percentile; nationwide (US) and Pacific Northwest

Huo et al. 2012
25th percentile, median of lower third; Yungui Plateau, China

Longing and Haggard 2010
Compared 25th percentiles to EPA-recommended ecoregion nutrient criteria; Red River Basin (AR, LA, NM, OK, TX)

Sánchez-Montoya et al. 2012
25th percentile of population; Mediterranean streams in Spain

Smith and Tran 2010
25th percentile of all sites; nonwadeable rivers in NY

Suplee et al. 2007
25th percentile of general population; streams in Montana

U.S. Environmental Protection Agency 2000a
25th percentile in Ecoregion VI and for Level III ecoregions within; streams in Corn Belt and Northern Great Plains Nutrient Ecoregion VI

U.S. Environmental Protection Agency 2000b
25th percentile of general population; trophic state classification of general population; streams in US

Wang et al. 2006
25th percentile of all data; wadeable streams in Wisconsin

4.1.4 Paleolimnology

Paleolimnological records can be used under certain circumstances to reconstruct reference conditions in a region or for a specific waterbody. A core of lake bottom sediments provides a record of certain ecological characteristics and can be used to reconstruct historical rates of sediment deposition [Kelley and Nater, 2000] and limnological conditions such as algal community composition [Bunting et al., 2011; Charles et al., 1994] and in-lake phosphorus concentration or trophic state [Heiskary and Swain, 2002; Reavie et al., 2002; Bunting et al., 2011; Whitmore, 1989].

Reconstruction from paleolimnological records is only appropriate in standing waters such as lakes where the sediment provides a relatively undisturbed record; the sediments in riverine systems are typically not preserved in the same manner. However, if a river flows into a lake, certain paleolimnological records from the lake can be applied to the river. Historical rates of sedimentation in a downstream lake can be used to establish reference conditions with respect to sediment load in a river [Kelley and Nater, 2000]. If multiple tributaries flow into a lake, techniques can be used to distinguish the sediment signatures among the different tributaries if the deposited sediments originate from glacial deposits of different episodes and different geographic origins. This approach was used for the primary tributaries in the watershed of Lake Pepin, Minnesota [Kelley and Nater, 2000]. However, paleolimnological techniques cannot be used to define the reference condition with respect to nitrogen or phosphorus concentrations in a stream or river. Box 4 lists and provides short summaries of the papers and reports that were reviewed for this project that used paleolimnological techniques.

Box 4. Papers and reports reviewed that estimate the reference condition using paleolimnological techniques. List includes author and year of document and a brief summary of the method used, the geographic location, and the waterbody type. See *Chapter 6.0 References* for the complete citations.

Reference Condition: Paleolimnology

Bunting et al. 2011
  Reconstruction of trophic state through analysis of algal pigments, algal microfossils, and nutrient fluxes; Lake Winnipeg, Manitoba

Heiskary and Swain 2002
  Reconstruction of water quality from fossil diatoms; lakes in Minnesota

Kelley and Nater 2000
  Apportioned sediment influx from major river basins to Lake Pepin, Minnesota, based on geologic signature in core sediments

Reavie et al. 2002
  Reconstruction of water quality from fossil diatoms; lakes in Ontario

4.2 STRESSOR-RESPONSE RELATIONSHIPS

Whereas the reference condition approach assumes that biological integrity is protected under low levels of human disturbance, a more explicit approach to evaluating biological integrity examines how a biological community responds to a human disturbance gradient. This can be done through modeling stressor-response relationships or using professional judgment.

The terms "stressor" and "response" were used in the above discussion of modeling reference condition, with the stressor being human disturbance (such as percent agriculture in a watershed) and the response being the nutrient concentration in a waterbody. In the discussion in this section, the phrase "stressor-response relationships" is used to mean the *biological* response in a waterbody to a stressor such as nutrients.

A stressor-response relationship between nutrients as the stressor and biological response can be linear (Figure 4-5A). In this case, there is little justification for selecting a specific nutrient concentration along the response gradient. However, stressor-response relationships are often nonlinear and thresholds in the relationships can be quantified (Figure 4-5B). In this case, a nutrient target can be set at or below the threshold and can provide a biologically meaningful endpoint below which biological integrity is likely to be maintained.

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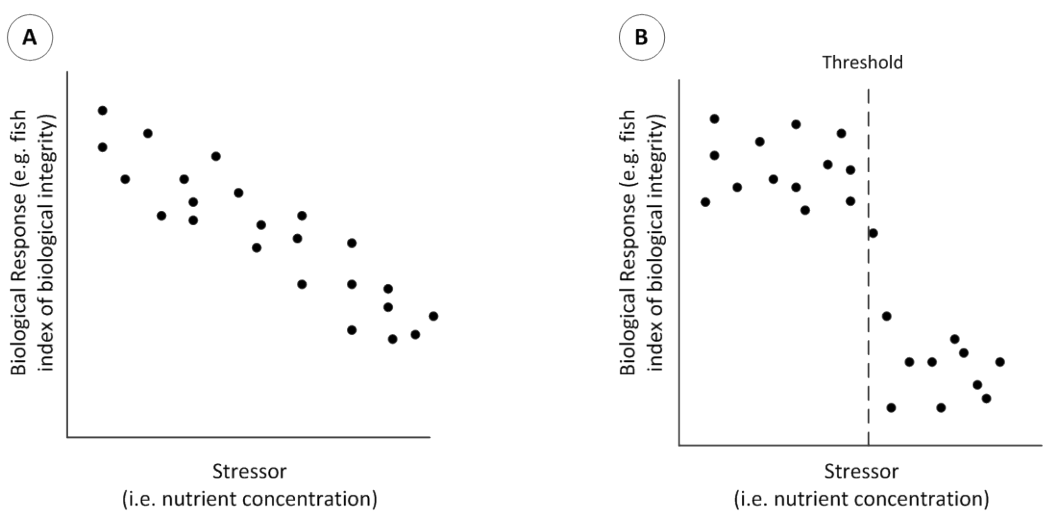

Figure 4-5. Hypothetical Relationships Between Stressor and Biological Response: (A) Linear, (B) Nonlinear With Threshold.

The U.S. EPA's *Using Stressor-response Relationships to Derive Numeric Nutrient Criteria* [U.S. Environmental Protection Agency, 2010] includes comprehensive guidance on how to use stressor-response modeling to derive numeric nitrogen and phosphorus criteria. The summary discussion below begins with conceptual models and exploratory data analysis and then describes various methods of modeling stressor-response relationships.

4.2.1 Conceptual Models

The first step to evaluating stressor-response relationships is to develop a conceptual model for the system being studied. A conceptual model includes a visual representation of the relationships among human disturbance, the biological communities, their stressors (such as excessive nutrient or sediment inputs), and the goals of a waterbody (Figure 4-6). The conceptual model illustrates the understanding of the system, and it guides development of the stressor-response models. The model can identify confounding factors that can modify the effect of stressors in the stressor-response relationships, with more possibilities of confounding factors the further away the stressor and response variables are in the conceptual model. Confounding factors, which often are stressors, should be controlled for in the data analysis. For example, if one is investigating the relationship between increased nutrients and changes in the macro-invertebrate community health with the goal of deriving nutrient criteria, multiple potential pathways exist that can explain the relationship (Figure 4-6). Increased nutrients may increase primary productivity, leading to more organic matter, higher rates of cellular respiration from the microbes breaking down the organic matter, and decreased dissolved oxygen, which in turn negatively affects the macroinvertebrate community. An alternate pathway might be that increased nutrients lead to increases in nuisance plants or algal growth, which decreases the food quality for macroinvertebrates, thus impairing the macroinvertebrate community. To control for confounding factors, one needs to include in the analysis a variable that quantifies the confounding factor so that the estimated stressor-response relationships between nutrients and biology are accurate. In this example, data that quantify food quality would control for the effect that food quality has on the relationship between nutrients and macroinvertebrate community health.

An example of a factor that may covary with nutrients is suspended sediment. Increased suspended sediment often occurs with increased phosphorus in a river system, and suspended sediment can negatively impact biological integrity through its impact on light availability and physical habitat quality (Figure 4-6). Variables should be included in the analysis that quantify suspended sediment and other factors along the pathway between suspended sediment and biological integrity. Inclusion of these variables will increase the accuracy of the estimated stressor-response relationships.

Many of the causal pathways in a conceptual model are well established in the scientific literature (see U.S. Environmental Protection Agency [2010] for a list of references). The U.S. Environmental Protection Agency [2010] provides a conceptual model for streams with known causal pathways, which includes human activities such as nonpoint source runoff, primary stressor and response variables such as nutrients and suspended sediment, modifying factors such as light and temperature, and waterbody goals such as aquatic life support and recreation.

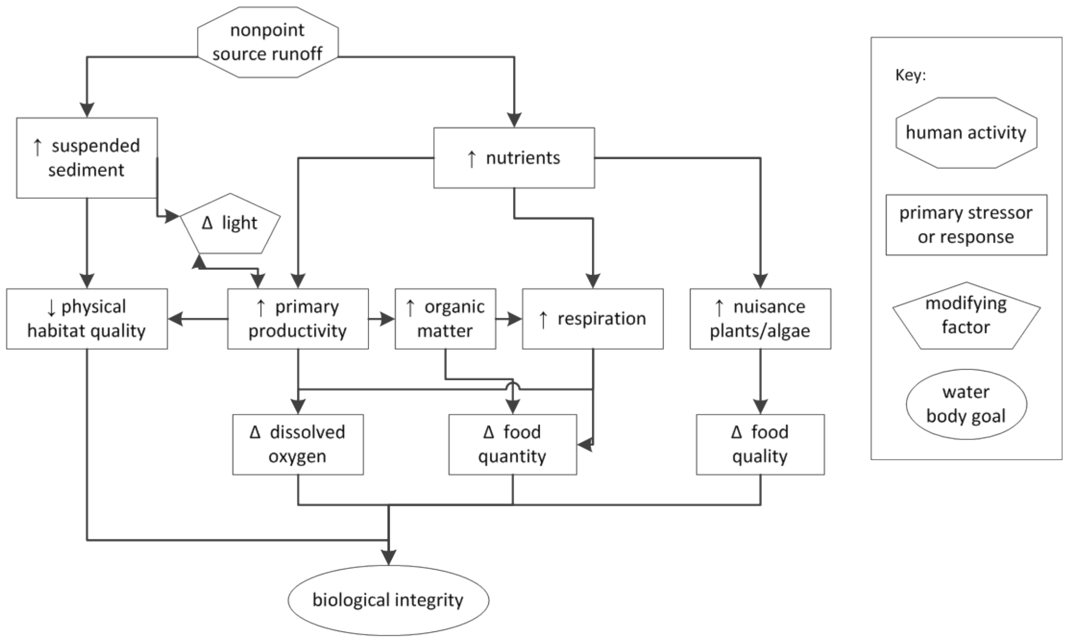

Figure 4-6. Example of a Simplified Conceptual Model for Streams (All Potential Variables Are Not Included) (modified from Figure 2.2 in U.S. Environmental Protection Agency [2010]).

4.2.2 Exploratory Analysis

The goals of exploratory data analysis are to understand relationships among the ecological components of the system, evaluate how human disturbance might impact these relationships, and suggest statistical approaches for stressor-response modeling. Variables are selected that represent the concepts in the conceptual model; variables should be selected that are along the hypothesized pathway in the conceptual model in addition to variables that are on alternate pathways. Selection of variables along the alternate pathways will allow evaluation of whether or not covariation of a variable along an alternate pathway with a variable along the hypothesized pathway confounds the hypothesized relationship between stressor and response. For example, an increase in nutrients may coincide with a decrease in biological integrity. If suspended sediment covaries with nutrients, such that an increase in suspended sediment also coincides with a decrease in biological integrity, other factors along the two pathways need to be evaluated in an attempt to control for the alternate pathways (Figure 4-6).

When setting nutrient criteria to protect biological integrity, the response variables selected for the analysis should measure whether or not the goal is being attained and should also respond to changes in nutrient concentrations. Response variables can range from chlorophyll-*a* (a surrogate measure for algal concentration), to biological metrics such as number of insectivorous macroinvertebrate species, to more integrative indices of biological integrity.

Approaches used to explore the dataset may include data distributions of individual variables (e.g., histograms, boxplots, cumulative distribution functions), relationships between two variables (e.g., correlations, scatter plots), and multivariate data exploration (e.g., principal components analysis, categorized scatter plots that show the relationship between two variables at different levels of a third variable). For example, Heiskary et al. [2010] used Spearman correlation, linear regression, quantile regression, and other related techniques in an effort to understand the ecological interactions as a first step to deriving numeric nutrient criteria for streams and rivers in Minnesota. The analysis led to the decision to develop numeric criteria for total phosphorus, chlorophyll-*a*, dissolved oxygen flux, and biochemical oxygen demand.

4.2.3 Stressor-Response Modeling

As with other approaches to establishing nutrient criteria, waterbodies should first be classified into groups that have similar characteristics and respond similarly to stressors; see the discussion in Section 3.1 on classification schemes. Statistical methods are then used to relate the stressor and response variables, and criteria are derived from these relationships.

Statistical models can be used to derive numeric criteria if the response value that supports the waterbody's goal is already known. For example, in Chambers et al. [2011], the predefined recommended limits for benthic and sestonic algal abundance, as measured by chlorophyll-*a* concentration, were translated into candidate nutrient criteria using linear regression between the stressors nitrogen and phosphorus and the response variable chlorophyll-*a* (Figure 4-7A). Snelder et al. [2004] used an equation that related maximum benthic chlorophyll-*a* concentration to dissolved nutrients and flood frequency to derive candidate nutrient criteria based on a predetermined periphyton biomass limit. Similar approaches have been used in lakes [Florida Department of Environmental Protection, 2012; Havens, 2003].

Biological data often show a wedge-shaped pattern [Wang et al., 2006; Heiskary et al., 2010] (Figure 4-7B), suggesting that there are other ecological factors that limit the biological response besides the factor under consideration (i.e., nutrients in this case). For example, in Figure 4-7B, at low phosphorus concentrations, the chlorophyll concentration is typically low and there is not a lot of variability in chlorophyll. As phosphorus concentration increases, the upper limit of chlorophyll increases linearly, but there is more variability in the chlorophyll response. At these higher phosphorus concentrations, other factors, such as light or habitat quality, limit the chlorophyll concentration; the chlorophyll concentration is lower than it would be if phosphorus were limiting.

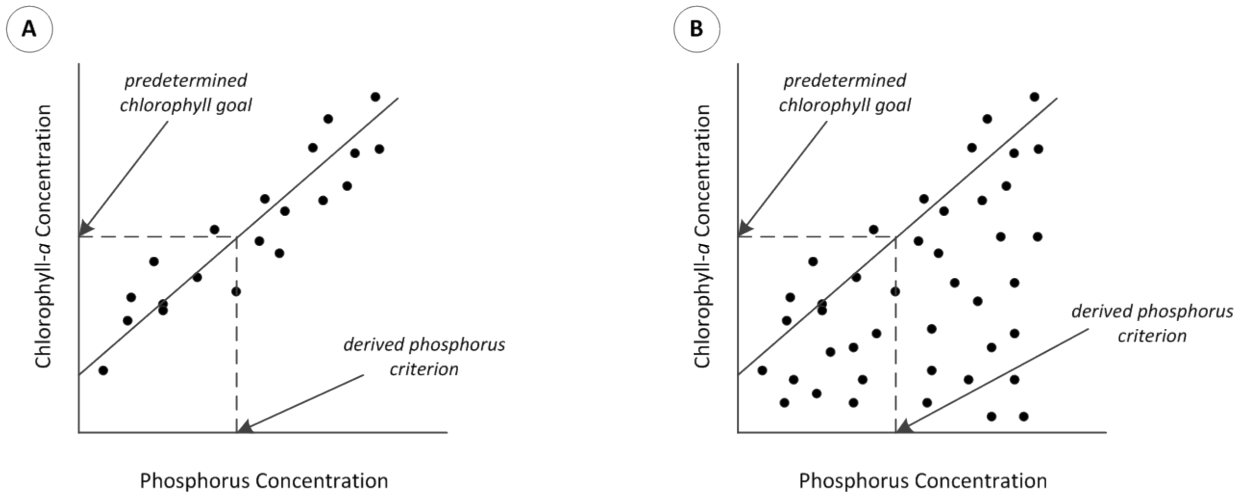

Figure 4-7. Conceptual Diagram of Use of Regression to Derive Nutrient Criteria From Predetermined Biological Goal: (A) Simple Linear Regression, (B) Quantile Regression.

Simple linear regression is not appropriate with wedge-shaped data because of the unequal variance of the response means, and other statistical approaches are used to describe the data. Quantile regression is often applied to wedge-shaped data. Whereas simple linear regression fits a line to the means of the response variable (Figure 4-7A), in linear quantile regression, a line is fit to other parts of the distribution of the response variable (Figure 4-7B) [Cade and Noon, 2003]. Quantile regressions at the upper end (75th to 90th percentile) of the probability distribution are often used in ecological datasets because the upper portions represent the conditions under which the response variable is limited by the stressor variable [Cade and Noon, 2003]. Quantile regression can be used to derive numeric criteria if the desired level of response variable is known (Figure 4-7B). Bryce et al. [2008] selected literature-derived index of biological integrity (IBI) thresholds as goals for the response variable; quantile regression between sediment concentration and IBI score was then used to select sediment criteria that correspond to the IBI goal.

Another statistical approach that has been used to explore nonlinear stressor-response relationships is locally weighted scatterplot smoothing (LOESS or LOWESS are two similar variations) [Florida Department of Environmental Protection, 2012; Stevenson et al., 2008; Zheng et al., 2008]. With this technique, a regression model is fit to each data point and the points close to it; the result is a smoothed fit to the relationship.

There are multiple patterns that a stressor-response relationship can take, and these patterns may include biological thresholds in which a relatively small increase in the stressor leads to a relatively abrupt change in the biological response (Figure 4-8). When thresholds occur, they represent biologically meaningful candidate criteria below which biological integrity is maintained. Numeric criteria can then be set at or below the thresholds; setting the criteria below the thresholds provides an allowance for uncertainty in the models [Stevenson et al., 2008]. After a numeric threshold is identified, it should be confirmed that the waterbody's goals would be met at or below the threshold.

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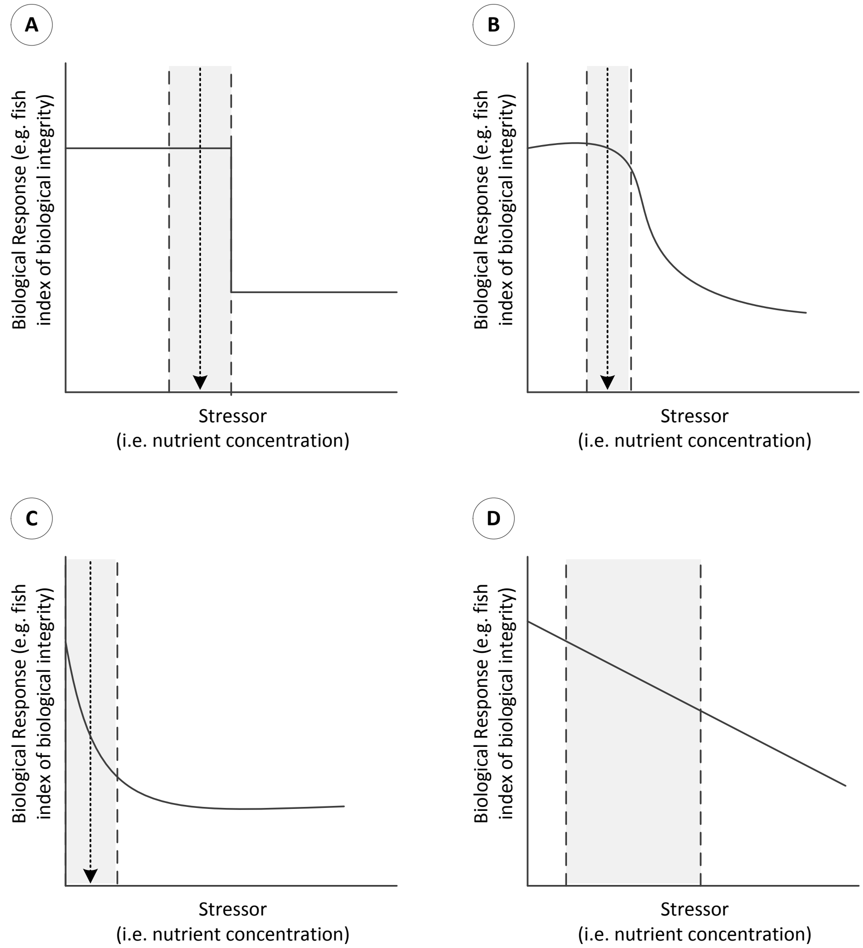

Figure 4-8. Conceptual Drawings of Stressor-Response Relationships and Candidate Criteria Levels (modified from Figure 2 in Stevenson et al. [2008]). (A) and (B) illustrate nonlinear relationships where stressor increases at low stressor levels do not show a biological response. The relationships in (C) and (D) show a biological sensitivity to stressor increases at low stressor levels. Arrows indicate candidate nutrient criteria based on the form of the stressor-response relationship. Shaded areas indicate acceptable ranges of criteria.

Thresholds can be apparent visually in some instances when the change in biological response is abrupt and dramatic [Carleton et al., 2009]. However, more often statistical approaches are used to identify thresholds in the stressor-response relationship. Nonparametric changepoint analysis and regression tree analysis are often used to identify biological thresholds, or changepoints. In these approaches, there is no *a priori* assumption of a specific nonlinear relationship between the stressor and response variables. The biological response observations are first ordered along the stressor (nutrient) gradient. The response variable is split into two subgroups based on the value of the stressor that maximizes the difference between the deviance for the entire dataset and the sum of the deviances of the two groups (Figure 4-9). The changepoint, or threshold, is identified at that stressor value. Bootstrap resampling can be used to quantify uncertainty by evaluating the cumulative probability of a changepoint [Qian et al., 2003; King and Richardson, 2003]. Chi-squared tests [Heiskary et al., 2010] or T-tests [Weigel and Robertson, 2007] of the biological response variable above and below the thresholds can be used to test the statistical significance of the thresholds.

Miltner [2010] identified thresholds in the relationship between two stressor variables (benthic chlorophyll-*a* and dissolved oxygen) and biological communities in small rivers and streams in Ohio. The variables used in the changepoint analysis were identified through exploratory data analysis such as correlations, scatter plots, and regression. A similar approach was used for nonwadeable rivers in New York. Spearman rank correlations were first used to identify the biological community metrics that were significantly correlated with nutrients, and changepoint analysis was then used to test for thresholds in the biological response [Smith and Tran, 2010].

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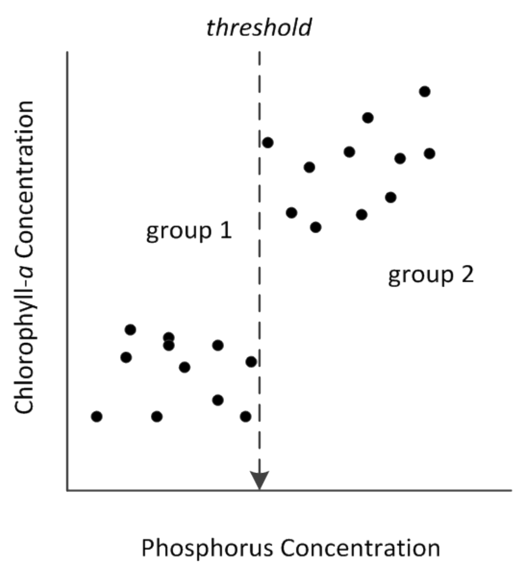

Figure 4-9. Conceptual Figure of Changepoint Analysis. The location of the threshold maximizes the difference between the deviance for the entire dataset and the sum of the individual deviances for group 1 and group 2.

In deriving proposed nutrient criteria for rivers and streams in Minnesota, Heiskary et al. [2010] used multiple methods, including changepoint analysis and additive quantile regression smoothing, to identify multiple breakpoints in the stressor-response relationships. Biological thresholds were determined and then pooled together for each stressor variable and stream class. The 25th percentile of the frequency distribution of thresholds for a specific parameter was proposed as a numeric criterion. Many more instances of changepoint analysis were identified in the literature; see Box 5 for a list of the studies. In most of these studies, exploratory data analysis was first conducted to inform the selection of variables and approaches for stressor-response modeling.

Other statistical methods that can identify disturbance thresholds are Kolmogorov-Smirnov techniques [Wang et al., 2006], piecewise regression [Black et al., 2010], Bayesian changepoint, quantile piecewise constant, and quantile piecewise linear approaches [Brenden et al., 2008]. These approaches differ with respect to their assumptions of the stressor-response relationships. They were not as common in the literature and will not be further discussed here.

An alternate approach to stressor-response modeling is to use structural equation modeling to evaluate data derived from professional opinion of whether or not a water-quality goal (e.g., biological integrity) is being met at a certain set of observed water-quality measurements (e.g., phosphorus concentration) [Reckhow et al., 2005; Kenney et al., 2009]. Structural equation modeling can be used to calculate the probability of goal attainment given different levels of the stressor variable. Selecting the stressor concentration for numeric criteria is left to managers to determine the acceptable level of risk of nonattainment (Figure 4-10).

Mechanistic models have also been used to explore stressor-response relationships and derive nutrient criteria. With predetermined pH, dissolved oxygen, and benthic algae concentration goals, Flynn and Suplee [2011] used a river and stream water-quality model (QUAL2K) application to determine where along the nitrogen and phosphorus concentration gradient the Lower Yellowstone River in Montana would become impaired for these water-quality parameters. Carleton et al. [2009] used observed data and simulated data from an Aquatox model application to identify a threshold between phosphorus concentration and percent cyanobacteria in a medium-sized river. The threshold was visually apparent in a scatterplot between phosphorus and percent cyanobacteria; statistical methods were not used.

Box 5 lists and provides short summaries of the papers and reports that were reviewed for this project that modeled stressor-response relationships.

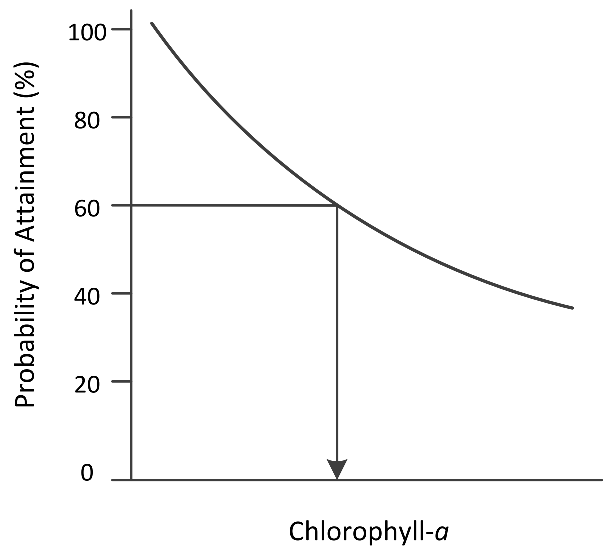

Figure 4-10. Hypothetical Results From Structural Equation Modeling and Professional Opinion. If water resource managers are comfortable with a 60 percent probability of attaining the response goal, then the chlorophyll-*a* criteria can be set at the arrow.

Box 5. Papers and reports reviewed that identify candidate criteria through modeling stressor-response relationships for the purpose of establishing water-quality and/or biological targets. List includes author and year of document and a brief summary of the method used, the geographic location, and the waterbody type. See *Chapter 6.0 References* for the complete citations.

Stressor Response Relationships: Modeling

Statistical Models

Black et al. 2010
Regression tree analysis, N or P thresholds for algal metrics; streams in WA, NE, western US

Brenden et al. 2008
Discussion of multiple methods

Bryce et al. 2008
Quantile regression areal % streambed fines (stressor) and aquatic vertebrate IBI (response), literature IBI threshold, used regression to set % fines target; mountain streams in western US

Chambers et al. 2008, 2011, 2012
Linear regression and regression tree analysis, TP and TN (stressor), chlorophyll-*a*, biotic metrics (response); streams in 7 regions in Canada

Evans-White et al. 2009
Nonparametric changepoint analysis (nCPA) to identify thresholds between TN, TP, turbidity (stressor), and macroinvertebrate species richness (response); streams in Central Plains (US)

Florida Department of Environmental Protection 2012
Regression, changepoint analysis, quantile regression used but statistical relationships were weak and thresholds not identified; streams in Florida

Heiskary et al. 2010
Explored (Spearman correlation, scatter plots, linear regression) relationships among nutrients, algae, and biology; quantile regression and regression tree analysis to ID thresholds between the various indicators; pooled thresholds and used 25th percentile as criteria; rivers in MN

Kenney et al. 2009
Expand Reckhow et al. (2005) to involve multiple experts and a region of waterbodies; 6 lakes in south-central Florida

King and Richardson 2003
Nonparametric changepoint analysis to identify thresholds between surface TP (stressor) and macroinvertebrate indices (response); wetlands in south Florida coastal plain ecoregion

Lougheed et al. 2007
Regression tree analysis to identify thresholds between wetland disturbance (land use, hydrological modification, water-quality: stressors) and biota (macrophytes, diatoms, zooplankton: response); depressional wetlands in Muskegon River Watershed, Michigan

Miltner 2010
Explored (Pearson correlation, scatter plots, regression) relationships among nutrients, algae, and biology; regression tree analysis to identify thresholds between the various indicators; small rivers and streams in Ohio

Reckhow et al. 2005
One expert per waterbody, relate potential criteria concentration to probability of compliance with designated use; case study with four waterbodies in US

Royer et al. 2008

Explored (Pearson correlation, linear regression) relationships between nutrients and chlorophyll-*a*; visual identification of threshold; streams and rivers in Illinois

Smith and Tran 2010

Nonparametric changepoint analysis for nutrients (stressor) and bio metrics (response); nonwadeable rivers in NY

Soranno et al. 2008

Linear regression and regression tree analysis to identify thresholds between TP (stressor) and biology (response); lakes in Michigan

Stevenson et al. 2008

Lowess regression and regression tree analysis to identify thresholds between TP (stressor) and algae (response); streams in Mid-Atlantic Highlands (US)

Thongdonphum et al. 2011

Visual inspection of scatter plots between N/P and chlorophyll-*a* to identify thresholds; Mae Klong River and Estuary, Thailand

U.S. Environmental Protection Agency 2000b

Dose-response relationships between biocriteria and nutrients could be used; identify thresholds in non-linear relationships between nutrients and biological response; streams in US

U.S. Environmental Protection Agency 2010

Presents multiple statistical approaches; no specific geographical extent

Wang et al. 2006

Spearman correlations and scatter plots between N/P and biotic metrics; regression tree analysis to identify thresholds; wadeable streams in Wisconsin

Weigel and Robertson 2007

Spearman correlations; regression tree analysis to identify thresholds between TN/TP (stressor) and biotic assemblages (response); non-wadeable streams and rivers in Wisconsin

Zheng et al. 2008

LOWESS regression and regression tree analysis to identify thresholds between N/P (stressor) and diatom and macroinvertebrate communities (response); streams in eastern panhandle region of western Virginia

Mechanistic Models

Carleton et al. 2009

Aquatox model of TP (stressor), % cyanobacteria, and benthic chlorophyll-*a* (responses), ID threshold; Blue Earth River, MN

Flynn and Suplee 2011

4.3 OTHER

The remaining methods discussed in this chapter do not directly use the reference condition or stressor-response modeling but can also be used to derive numeric nutrient criteria.

4.3.1 Consideration of Downstream Water Resources

The U.S. EPA encourages states to assess the potential effect of proposed criteria on downstream water quality and attainment of downstream water-quality goals [U.S. Environmental Protection Agency, 2000b]. In addition to assessing the impact of proposed criteria on downstream waterbodies, the criteria themselves can be derived based on the goals of downstream water resources. This will most commonly occur when a stream or a river discharges into a lake or wetland, as nutrient goals for standing waterbodies are often more restrictive than nutrient goals for flowing waters.

While this is a valid approach to setting water-quality targets and appropriate in many circumstances, it represents an overall approach to setting targets as opposed to an analytical method. In this approach, nutrient concentration goals are first established for the downstream waterbody, for example, a lake phosphorus goal. An evaluation of the lake's phosphorus concentration response to varying phosphorus loads to the lake is then used to select a phosphorus loading goal that will lead to attaining the lake's phosphorus concentration goal. If there are multiple tributaries to the lake, the phosphorus loading goal needs to be allocated among the tributaries. If stream or river concentration goals are preferred, the loading goal needs to be translated into a concentration goal using stream discharge data. Moving further upstream, if goals at upstream points within the tributary's watershed are desired, the loading goal needs to be allocated among the various subwatersheds within the tributary's watershed. This can be done using multiple approaches, including equal percent reductions among subwatersheds; a consistent instream nutrient concentration goal among subwatersheds; or loads most likely to be attained based on technological, political, and financial considerations.

This approach is helpful when reference conditions or stressor-response modeling is not appropriate for a stream or river, but when water-quality goals of downstream water resources are well defined.

4.3.2 Nondegradation

If the existing water quality of a waterbody is acceptable, nutrient criteria can be set with a nondegradation approach and numeric targets can be based on existing observed concentrations or loads. Bachmann et al. [2012] recommended an approach to setting nutrient criteria for Florida lakes, the majority of which are undisturbed and should be maintained in their current state. Proposed goals for oligotrophic lakes (using predefined chlorophyll-*a* and submersed aquatic macrophytes goals) are the long-term total nitrogen and total phosphorus concentrations of each lake. For lakes with nutrient concentrations below the 90^{th} percentile that do not meet the oligotrophic criteria, the proposed goal is that there cannot be a statistically significant increase in nitrogen, phosphorus, or chlorophyll-*a* over a 7-year period.

The North Saskatchewan Watershed Alliance [2009] proposed goals for different reaches of the North Saskatchewan River. For certain reaches with relatively good water quality, a nondegradation approach was taken and site-specific, water-quality objectives were based on maintaining the 50th percentile (used to represent average conditions) and the 95th percentile (used to represent peak concentrations). Alberta Environment proposed water-quality targets for the North Saskatchewan River based on existing conditions plus an allowance for a 20 percent increase in loads in a specific reach of the river [Alberta Environment, 2012b]. This approach is applicable only if the goal is to protect the current water-quality conditions.

4.3.3 Literature Values

Nutrient targets developed for other waterbodies or geographic regions can be applied to a waterbody that displays similar ecological characteristics. The U.S. Environmental Protection Agency [2000b] states that literature values may be used if other methods are not feasible or as temporary criteria until criteria for the stream of interest can be derived. They caution that literature values should only be used when there is clear evidence that the stream of interest is similar enough to the waterbodies used to derive the published value. In essence, this could be considered a "reference" approach, in that the waterbodies used to derive the published value are considered a reference waterbody for the stream of interest.

Box 6 lists and provides short summaries of the papers and reports that were reviewed for this project using other methods.

Box 6. Papers and reports reviewed that identify candidate criteria through other methods. List includes author and year of document and a brief summary of the method used, the geographic location, and the waterbody type. See *Chapter 6.0 References* for the complete citations.

Other

Consideration of Downstream Waters

U.S. Environmental Protection Agency 2000b
  Most likely when streams feed into lentic systems; streams in US

Nondegradation

Alberta Environment 2012b
  20% increase relative to existing conditions

Bachmann et al. 2012
  Lakes that are below the 90th percentile for N and P, but are not oligotrophic, cannot show a statistically significant increase in TP, TN, or chlorophyll-*a* over seven years

North Saskatchewan Watershed Alliance 2009
  For high quality reaches, maintenance of the 50th percentile and 95th percentile; North Saskatchewan River, Alberta

Literature Values

U.S. Environmental Protection Agency 2000b
  Can use published values if other approaches not appropriate, need strong rationale; streams in US

5.0 RECOMMENDED APPROACH

This chapter discusses the potential application to the Red River of each of the approaches and then provides recommendations for developing numeric nutrient targets for the Red River. The recommendations are based on the evaluation in Table 5-1, which provides a summary of the approaches, including the data needs, advantages and disadvantages, geographic considerations, level of effort, and applicability to the Red River. Without a thorough review of current data and identification of data gaps, more specific time and cost estimates cannot be provided.

5.1 Application to Red River

Numeric nitrogen and phosphorus targets are to be developed for the Red River at the outlet of the river into Lake Winnipeg, the international boundary at Emerson, and subwatershed discharge points in the watershed [International Red River Board, 2011]. Ecological characteristics at these locations along the river differ from one another; the upstream portions of the Red River may show a stronger biological response to instream nutrients than the downstream portions [Heiskary and Markus, 2003] and therefore the river may need to be split into two or more sections for the purpose of developing nutrient targets.

Concentration targets are appropriate to protect biological integrity within the Red River. Targets to protect Lake Winnipeg will likely be load-based where the Red River outlets to the lake.

5.1.1 Reference Condition

5.1.1.1 Reference Sites

There are no reference sites along the main stem of the Red River and few, if any, in the river's tributaries. There are likely high-quality headwater streams in certain portions of the watershed such as the beach ridge and the tributaries to Red Lake. The conditions in these streams however are not applicable to the expected conditions in the river itself. Because the reference site approach cannot be used if appropriate reference sites do not exist in the area or class of interest, this approach is not feasible for use in the Red River.

5.1.1.2 Model of Reference Condition

There are no Red River mainstem sites that represent reference conditions. Therefore, any hindcasting model would be an extrapolation of reference condition beyond the boundaries of the model development dataset. While this creates some uncertainty in the approach, the

Table 5-1. Summary Evaluation of Approaches[a] (Page 1 of 2)

Approach		Summary Description	Data Needs	Primary Advantages	Primary Disadvantages	Geographic Considerations	Level of Effort	Application to Red River	
Reference Condition	Reference sites (5.1.1.1)	Use conditions (i.e., concentration) at reference site or group of reference sites (75th percentile or higher).	Multiple years of nitrogen and phosphorus data from at least 3 reference sites.	Understandable by stakeholders.	Needs existing reference site.	Applicable where reference sites can be defined.	L	0	Applicable reference sites do not exist.
	Model of reference condition (5.1.1.2)	Model relationship between nutrient concentration and human disturbance levels.	Hydrogeomorphic data (e.g., waterbody size, water depth). Human disturbance data (e.g., land use). Multiple years of instream nitrogen and phosphorus data.	Does not require *a priori* ID of reference sites. Statistical models are feasible with available landscape and hydrogeomorphic data. Mechanistic models can approximate best attainable condition by simulating management practices.	More uncertainty if model development dataset does not contain sites with low human disturbance level.	Models are applicable to the regions for which the models were developed.	M (statistical) H (mechanistic)	L-M	Risk that statistically significant relationships are not found because of a lack of representation of sites with varying levels of human disturbance. Model uncertainties because of the need to extrapolate beyond model development dataset.
	Estimate from all sites within a class (5.1.1.3)	Compile data from all sites within a stream class, select statistic to approximate reference condition.	Multiple years of nitrogen and phosphorus data from unbiased, representative group of sites in stream class.	Simple.	The frequency distribution of overall sites can change over time; cannot know which point in the frequency distribution represents reference conditions.	Applicable to stream class of data source.	L	0	Reference sites do not exist in the stream class of interest.
	Paleolimnology (5.1.1.4)	Sediment core of lake bottom sediments provides a record of certain ecological characteristics.	Multiple lake sediment cores and associated analyses.	Reconstruction of past reference conditions.	Sediment layers are typically not preserved in rivers.	Applicable to lake from which core was taken. Certain techniques applicable to waterbodies that discharge into the lake.	M-H	L	Cannot be used to define nitrogen and phosphorus reference condition in a river. Could be used to define historical sedimentation rates from multiple tributaries to Lake Winnipeg.

Table 5-1. Summary Evaluation of Approaches[(a)] (Page 2 of 2)

Approach		Summary Description	Data Needs	Primary Advantages	Primary Disadvantages	Geographic Considerations	Level of Effort	Application to Red River	
Stressor-response modeling (5.1.2)		Model relationship between stressor (e.g., nutrient concentration) and biotic response (e.g., chlorophyll, biological community composition). ID thresholds between stressor and response that are biologically meaningful.	Multiple years of nitrogen, phosphorus, and biological (chlorophyll, macroinvertebrates, fish) data.	Provides biologically meaningful endpoint.	Doesn't assume that thresholds represent reference condition.	Models are applicable to the regions for which the models were developed.	M	M	Weak relationships in Red River between nutrient concentrations and biological response; approach might only be applicable upstream of Fargo/Moorhead. Total suspended solids or turbidity would be more appropriate.
Other	Consideration of downstream water resources (5.1.3.1)	Nutrient targets based on meeting goals of downstream waterbodies that were developed to protect goals of downstream resource but not necessarily the goals of the waterbody under consideration.	Nutrient load assessment of downstream waters and allocation for waterbody in question.	Reference condition or stressor-response relationships in downstream waters is often easier to define than within a tributary.	Does not consider biological integrity of waterbody for which goals are being developed.	Applicable to waterbody for which analysis was completed.	L	H	Biological response to nutrients is stronger in Lake Winnipeg than in Red River. Nutrient loading goal based on Lake Winnipeg's ecological health likely as stringent as the needs of the Red River.
	Nondegradation (5.1.3.2)	For high quality waters, where the goal is protection of current condition.	Multiple years nitrogen and phosphorus data to define current conditions.	Simple.	Only applicable if existing conditions are acceptable.	Applicable to any waterbody.	L	0	Existing conditions are not a stringent enough goal.
	Literature values (5.1.3.3)	Use published criteria or thresholds from similar systems. Need strong rationale, should only be used if other methods are not applicable, or used temporarily.	No new data collection needed (assuming that it is already known that literature values are appropriate for waterbody in question).	Simple.	Need strong rationale for using selected values; systems need to be similar.	Applicable in any geographic reason if the waterbodies have similar ecological characteristics.	L	0	Difficult to find targets that apply to a system as unique as the Red River.

(a) Numbers in parentheses under Approach indicate the report section that discusses the applicability of the approach. Data Needs is a summary of the data needed to use the approach; it is not a statement of additional data needs considering existing data. Level of Effort is a relative estimate of the resources needed to complete the approach assuming that the data needs are met. Under Level of Effort and Application to Red River, 0 = zero, L = low, M = medium, H = high applicability.

approach has the potential for describing reference conditions in the Red River. However, because of the high level of disturbance across the entire basin, the majority of sites in the Red River Watershed have watersheds with a high proportion of agriculture. In trying to develop a relationship between human disturbance, as measured by percent agriculture, there would likely be a cluster of data points at the upper end of the percent agriculture range with no points in the middle to lower portions (Figure 4-4). In addition to the fact that the reference condition lies relatively far from the model development dataset, a linear regression in a dataset such as this might not be statistically significant or ecologically meaningful because of the single cluster of data points.

5.1.1.3 Estimate From All Sites Within a Class

Use of the 25th percentile in the Red River Watershed for nutrient concentration goals would yield a value that is too high to represent the actual reference condition; this occurred in Dodds and Oakes's [2004] study to identify reference condition in the Corn Belt and Northern Great Plains ecoregion. Because there are few, if any, reference sites in the Red River Watershed, an estimate of the reference condition from the frequency distribution of the general population is not possible.

5.1.1.4 Paleolimnology

Paleolimnological studies have been performed on Lake Winnipeg in which historical trends in algal abundance and community composition were evaluated [Bunting et al., 2011]. Whereas the trends in the lake and even historical total phosphorus concentrations can be reconstructed through paleolimnological data from lake sediment cores, historical nutrient concentrations in the Red River itself cannot be reconstructed.

It might be possible in Lake Winnipeg to distinguish the lake bottom sediment's origins between the Red River and the Winnipeg River, the south basin's two main tributaries, similar to the approach taken in Lake Pepin, Minnesota [Kelley and Nater, 2000]. For this approach to work, the deposited sediments must have originated from glacial deposits of different episodes and different geographic origins. Historical sedimentation rates from the two tributaries could be defined, which would inform the development of tributary loading goals once loading goals for Lake Winnipeg are established.

5.1.2 Stressor-Response Modeling

Identifying biological thresholds through stressor-response modeling could provide biologically meaningful targets for the Red River. In the downstream reaches of the Red River, a disconnect exists between nutrient concentrations and biological (i.e., algal) response because of the high turbidity and the resulting light limitation of the algae. Stressor-response modeling might not identify biological thresholds in response to nutrient concentrations in these reaches but might yield suspended sediment and/or turbidity thresholds.

In the upstream portions of the river (upstream of Fargo/Moorhead), turbidity and nutrient concentrations are not as high, and algal production in the upstream reaches might be limited by nutrients at times. Stressor-response modeling in these upstream segments might yield statistically significant nutrient and/or sediment thresholds.

The lack of statistically significant biological thresholds with respect to nutrient concentrations exists in other systems. In a study to assist the state of Illinois with developing statewide numeric nutrient standards, Royer et al. [2008] found that nutrients did not limit algal biomass in many streams, because of high turbidity, high nutrients, and habitat constraints. The lack of a relationship between nutrients and benthic chlorophyll-a suggests that nutrients were already above a concentration at which periphyton growth is limited and that nutrient concentrations at all of the study sites were elevated.

5.1.3 Other

5.1.3.1 Consideration of Downstream Water Resources

Efforts are under way to establish nitrogen and phosphorus goals for Lake Winnipeg. Nutrient concentration goals for the Red River that are derived from the Lake Winnipeg nutrient loading goals would be protective of the biological integrity of Lake Winnipeg. The goals would also likely be protective of the biological integrity of the Red River, because biological integrity in lakes is typically more sensitive to the impacts of nutrients than is biological integrity of streams.

To derive nutrient targets for the Red River from Lake Winnipeg nutrient loading goals, the loading goal at the outlet to Lake Winnipeg will need to be translated into loading goals at the desired points upstream along the Red River; this can be done with flow data. The loading goals can also be translated into concentration goals; in this case, the nutrient goals would likely be annual flow-weighted means.

5.1.3.2 Nondegradation

The nondegradation approach is applicable only if the goal is protecting current water-quality conditions. Numerous studies on water quality in the Red River and in Lake Winnipeg have established that the water quality and biological integrity of the systems are impaired and need improvement.

5.1.3.3 Literature Values

The Red River's hydrology, geomorphology, and water quality are unique enough that nutrient targets from other systems should not be applied to the Red River.

5.2 Recommendations

Two integrated approaches to developing nutrient targets to address the goals of restoring and protecting the Red River and Lake Winnipeg are recommended. A stressor-response modeling approach for the Red River should be completed in parallel to considering the downstream nutrient targets for Lake Winnipeg (Figure 5-1). These two approaches may yield different candidate nutrient targets, which should be integrated to ensure that the ultimate targets selected protect both the Red River and Lake Winnipeg. For example, the Lake Winnipeg analysis will yield nitrogen and phosphorus candidate targets for the Red River. However, Red River stressor-response modeling may yield suspended sediment targets instead of nutrient targets because of the relationships between sediment, light, habitat, and the biota in the Red River. The relationship between suspended sediment and nutrients in the Red River could be used to evaluate which of the candidate targets is more protective. Ultimately, the individual jurisdictions in the Red River Watershed will determine their course of action with respect to the Red River targets, balancing protection, feasibility, and acceptance by stakeholders.

RSI-2168-12-013

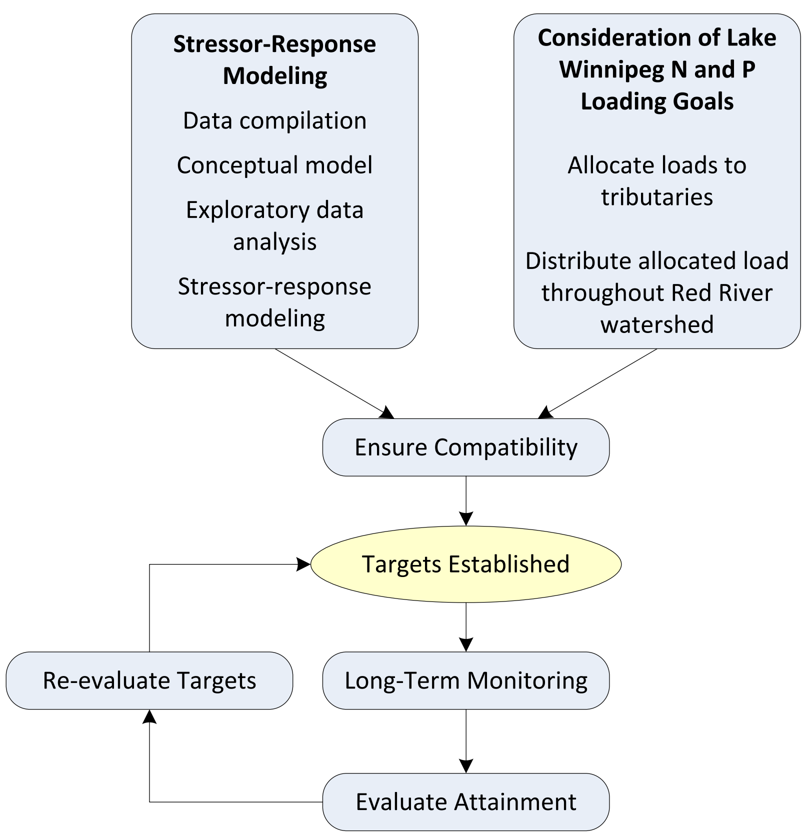

Figure 5-1. Summary Flowchart of Recommendations.

A comprehensive, long-term monitoring plan should also be developed and implemented, which will allow evaluation of goal attainment. The targets themselves should be evaluated periodically to ensure that they remain appropriate to the overall goals of the Red River and are feasible.

This approach is compatible with the approach recommended by Heiskary and Markus [2003]. Their analysis concludes that there may be an instream biological response to lowered phosphorus concentrations in the upstream reaches. Because of the low algal response in the downstream river portions, nutrient targets in those areas should focus on other uses that might be affected by excess nutrients, such as drinking water supply, and/or impacts to downstream waters (i.e., Lake Winnipeg).

The steps below elaborate on the recommended approach.

1. **Develop stressor-response models to investigate the relationships among nutrients, suspended sediment, and the biological response in the Red River.**

    - Compile data from multiple jurisdictions into one database. Ensure data compatibility. Expertise needed includes database management and water resource science.

    - Develop conceptual model of the Red River (see Section 4.2.1). The model may differ in the upstream and downstream portions of the river, with turbidity affecting the biota in the downstream segments more so than nutrients do. Expertise needed includes ecology.

    - Perform exploratory data analysis (see Section 4.2.2) to understand relationships among the ecological components of the system, evaluate how human disturbance might impact these relationships, and suggest statistical approaches for stressor-response modeling. Stressor-response modeling with data from the Minnesota portion of the Red River has already been completed [Heiskary et al., 2010] and can help guide the data analysis and modeling. In the Minnesota analysis, data from the Red River were combined with data from southern Minnesota into one stream class. The updated analysis and modeling recommended here will focus on data from the Red River and on different patterns in different portions of the river.

      The exploratory analysis should include an evaluation of total nutrients (e.g., total nitrogen and total phosphorus) versus nutrient fractions (e.g., nitrate, ortho-phosphate) as the basis for targets. The analysis should also explore the relationship between chlorophyll and higher trophic levels (e.g., macroinvertebrates and fish) to determine if there is a minimum chlorophyll concentration (i.e., algae) needed to support the food web. If there is a minimum chlorophyll concentration, this chlorophyll threshold could then be translated into a nutrient or sediment/turbidity target. Expertise needed includes ecology and statistics.

    - Complete stressor-response modeling (see Section 4.2.3) using the available dataset and statistical modeling approaches. Identify biological thresholds along a stressor gradient using approaches such as nonparametric changepoint analysis. The models should consider sediment and/or turbidity as a stressor in addition to nitrogen and phosphorus. Nutrient or sediment targets will be concentration based.

If relevant thresholds are not identified for one or both nutrients, then nutrient targets should be based, at least temporarily, on the loading goals for Lake Winnipeg. The monitoring plan should be tailored to fill in the gaps and strengthen the dataset to increase the likelihood of identifying biologically relevant thresholds. Expertise needed includes ecology and statistics.

2. **Consider nitrogen and phosphorus loading targets for Lake Winnipeg, and develop Red River targets to meet the lake's loading goals** (see Section 4.3.1).

    - Allocate nitrogen and phosphorus loading goals developed for Lake Winnipeg and its sources.
    - Based on the loading goals established for the Red River at its outlet to Lake Winnipeg, develop loading goals at multiple points along the Red River. Loading goals could be distributed based on long-term flow records, with the watershed's flood reduction goals taken into consideration. Expertise needed includes environmental hydrology.

3. **Ensure compatibility between the candidate targets identified in steps 1 and 2.**

    - If the targets to protect Lake Winnipeg are load-based, they will first need to be converted to concentration-based targets to allow comparison with the concentration-based targets identified in the stressor-response modeling. This conversion should be performed using long-term flow data; wet, average, and dry years should be considered.
    - Similarly, concentration-based targets identified through stressor-response modeling should be translated into loading targets to allow comparison and provide a range of acceptable loads based on the concentration goals.
    - Existing nutrient standards in the watershed should also be considered; the new Red River targets should be at least as protective as current standards, whether narrative or numeric.

4. **Develop a long-term monitoring plan.**

    - Developing the monitoring plan should consider input from Minnesota, North Dakota, and Manitoba and as much as possible be complementary to their monitoring programs.
    - Physical, chemical, and biological monitoring should be included.
    - Uniform quality assurance/quality control (QA/QC) and sampling protocols should be aligned for consistency in methodology and to allow for compatibility of results for data analysis.

- The monitoring plan should be designed so that progress toward attaining the targets identified in steps 1 and 2 can be evaluated.

5. Evaluate attainment of the targets.

- Concentration-based targets should be evaluated against concentration monitoring data. The statistic that the target is based on needs to be taken into account for the evaluation. For example, if the target is an annual mean concentration, then the annual mean concentrations should be compared to the target and not the individual observations of concentration.
- To evaluate load-based targets, long-term flow data need to be taken into account. One approach to consider is long-term flow normalization [Hirsch et al., 2010]. The goal of flow normalization is to consider long-term trends in data without focusing on the variation in water quality that is driven by flow.
- Biological response data should also be evaluated to determine if the biological goals of the Red River are being met.

6. Reevaluate targets

If targets are not attained, reevaluate the targets with new information to consider appropriateness. Sources of new information may include water-quality and flow monitoring data, point source discharges, and updated land use or land cover data. Changes in regulatory frameworks that influence target setting for the Red River and Lake Winnipeg should be considered.

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