A third approach for setting nutrient criteria seeks to identify nitrogen or phosphorus values associated with a low risk of ecological impairment. This approach uses knowledge of ecosystems' responses to nutrients to define maximum nutrient concentrations above which unacceptable ecological impairments occur and below which preferred ecological conditions are maintained. This requires that specific species, groups of related organisms, or sets of co-existing organisms be identified that are responsive to changes in nutrient concentrations. Biotic responses to increasing phosphorus or nitrogen concentrations are analyzed to determine the maximum concentrations of nutrients (and, ideally, the frequency and duration of specific concentrations) to ensure that desirable assemblages are protected and persistent populations of undesirable organisms are avoided (e.g. approach 3, Figure 2). Examples of risk indicators for this approach include undesirable quantities of bottom dwelling (benthic) or suspended algae, loss of sensitive benthic invertebrate, and loss of sensitive benthic diatoms. As with other strategies that produce cumulative results, development and maintenance of long-term databases are essential to protect preferred ecological conditions.

Regardless of the approach used in setting criteria, consideration should be given to protecting flora and fauna in the waters of immediate concern and protecting larger downstream rivers, lakes or coastal waters. This may require different sets of criteria, such as concentration criteria to protect waters of immediate concern and load criteria to protect downstream systems. Load criteria are needed to minimize nutrient impact on downstream waters and allowing lake sediments to remain oxidized to the greatest extent possible. This is needed to support near-shore fish habitat and reduce excessive growth of submerged and floating plants, particularly toxin-producing cyanobacteria that depend on ferrous iron released from anoxic sediments (Molot et al, 2010).

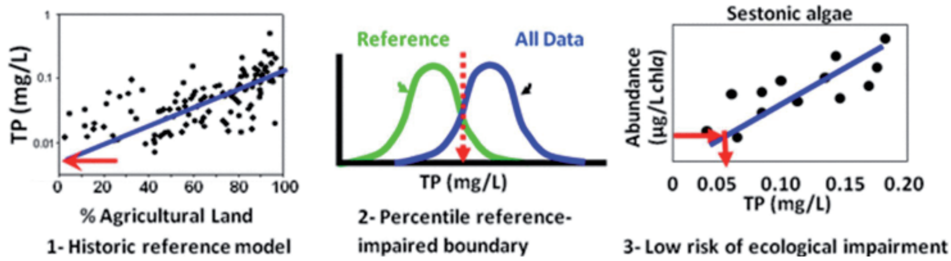

Figure 2: Science-based approaches to setting criteria

Example frameworks and proposals

In the US, legal responsibility for establishing nutrient criteria is delegated to states through the EPA. As of this writing, no state has voluntarily established nutrient criteria since the 1972 law was passed. However, guidance was provided for managing nutrients under total maximum daily load (TMDL) assessments (EPA, 1999). Subsequently, a federal court ordered EPA to propose standards for streams and lakes in Florida and those standards went into effect on 14 November 2010. The standards (Table 1) include a range of concentrations (EPA, 2010, p. 1492-1493) that 'reflect the inherent differences in the natural factors that contribute to nutrient concentrations in streams (e.g. geology, soil composition, and / or hydrology)'. For example, the standards include geographic subdivisions used to classify streams based, in part, on the presence of naturally phosphorus-rich soils.

Canadian environmental quality guidelines (EQGs) are nationally endorsed, science-based goals that include aquatic resources, although provincial or territorial jurisdictions may employ individual criteria. The Canadian Council of Ministers of the Environment (CCME) published national nutrient EQGs to protect aquatic life from the toxic effects of nitrate (interim values of 13 mg/l nitrate in freshwater and 16 mg/l nitrate in marine water) and nitrite (60 µg/l nitrate) (CCME, 2007). The CCME recommends that if total phosphorus (TP) concentrations increase more than 50% above the baseline, or exceed the trigger range for least-disturbed waters in that ecoregion, there is a risk of eutrophication and further investigation is warranted (CCME, 2004). Some provinces have established guidelines for nitrogen and phosphorus to prevent eutrophication of their surface waters. In addition to the national and provincial / territorial activities, a research programme was conducted by two Canadian federal departments (Environment Canada and Agriculture and Agri-Food Canada) to identify environmental thresholds for nutrients to protect ecological condition of agricultural streams (Table 1). While provisional adoption of these criteria should result in good ecological condition with respect to benthic algal abundance, diatom composition and macro-invertebrate composition.

New Zealand widely uses the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). These include trigger values for toxicants and microbial guidelines for contact recreation and livestock drinking water. Nutrient-concentration standards (Biggs, 2000) were derived to prevent attached biomass (periphyton) from exceeding thresholds, accounting for hydrology and the major flood frequency. Thresholds (50-200mg chlorophyll α/m^2) are based on aesthetics, benthic biodiversity and trout habitat. These guidelines are under review to increase the range of river types beyond gravel-bed streams and to include nutrient limits for unwanted macrophyte plant growth. Recently, the Horizons Regional Council (a regional government authority) derived specific standards for stream reaches based on the ANZECC and periphyton guidelines (Biggs, 2000). New Zealand is also considering implementing a national freshwater policy and national water quality standards to assist local governments and avoid ad hoc application of guidelines.

The European Union Water Framework Directive (WFD) was adopted by the Swedish EPA. Both chemical and biological parameters are used to assess eutrophication. Assessments for rivers use TP concentrations, the diatom index IPS (Indice de Polluo-sensibilité Spécifique, Cemagref, 1982), macro-invertebrate DJ-index (Dahl and Johnson, 2005) and the fish index VIX (FAME consortium, 2004). Assessments are performed using class boundaries defined by deviation from TP reference conditions for each river using the ecological quality ratio

Table 1 Nutrient criteria and guidelines for various international jurisdictions

	TN (mg/l)	TP (mg/l)
US EPA rules for Florida	0.824-1.479 [a]	0.043-0.739 [a]
Canada regions	0.87-1.2[b]; 0.21[c]; 1.1[d]; 0.38-0.98[e]	0.01-0.03[b]; 0.02[c]; 0.03[d]; 0.10[e]
New Zealand guidelines	0.295-0.614 [f]	0.026-0.033 [f]
EU Water Framework Directive - Sweden		0.0125 [g]

[a] Concentrations are based on annual geometric mean not to be surpassed more than once in a three-year period. The long-term average of annual geometric mean values shall not surpass the listed concentration values. (Duration = annual; Frequency = not to be surpassed more than once in a three-year period or as a long-term average).
[b] Atlantic Maritime; [c] Montane Cordillera; [d] Mixedwood Plains; [e] Interior Prairies
[f] Concentration 'trigger values' are 80th percentile benchmark values for upland and lowland streams (ANZECC, 2000)
[g] In WFD assessment class boundaries are defined as deviation from reference conditions. Concentration in the table is an additional required value for high status / reference condition.

(EQR). Ecological problems associated with eutrophication are pronounced in lakes and coastal waters. Rivers generally show few effects of eutrophication, despite concentrations usually higher than in receiving lakes. Specific boundary values for river status are determined by EQR values that also regulate the load to recipient lakes and coastal waters. A boundary value of <0.0125 mg/l TP was defined for high / reference status. Measures have to be taken if the status is less than or at risk of becoming less than 'good', according to the WFD.

Socio-economic considerations
Although nutrient criteria are used to ensure healthy ecosystems, consideration needs to be given to the immediate, short-term, and long-term attainability of nutrient criteria. Potential solutions to stream contamination and their socio-economic cost need to be considered when establishing criteria. An important trade-off requiring consideration is the potential down-stream improvements that may benefit a relatively large number of water users compared to the cost to a smaller number of farmers of implementing changes.

One approach to accommodating both upstream landowners' and downstream users' concerns is to discuss watershed management and planning with watershed communities to define short-, intermediate- and long-term targets that allow progressive improvements in stream ecology through sequential and achievable targets generally diagrammed in Figure 3. Adaptive management of land in critical water-shed source areas can provide stepwise improvements if all watershed parties can find valuable societal benefits that justify costs. Watershed organizations and partnerships are essential to establishing the trust among watershed inhabitants and water users to discuss values that can be placed on healthy streams. Examples of organizations that advance long-term strategies for stream health and sustainable agricul-ture are the Fishers and Farmers Partnership for the Upper Mississippi Basin organized by the US Geological Survey (http://fishersand farmers.org) and, the Alberta (Canada) Riparian Habitat Management Society, commonly known as Cows and Fish (www.cowsandfish.org). These partnerships are dedicated to improv-ing the health of land and streams by encouraging rural landowners to voluntarily develop and implement science-based solutions to local water quality issues with the support of conservationists. Landowners who achieve their own conservation and prosperity goals are encouraged to measure and demonstrate the effects of successful land-management practices that can be shared throughout the basin. ●

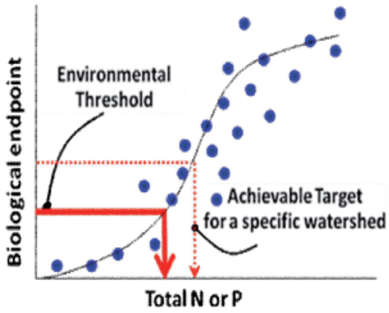

Figure 3: Setting achievable targets

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Confluence of the St Croix River and the Mississippi, USA. The Mississippi at this point drains cropland and forest, with the nutrient load from the cropland providing ample support for continuous algal production during the summer in the Mississippi river. Credit: US Geological Survey.

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