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Evaluating a Great Lakes scale landscape stressor index to assess water quality in the St. Louis River Area of Concern

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ABSTRACT

The St. Louis River drains an area of 9412 km^2 into the western arm of Lake Superior. The river's lower section, including a 48.5 km^2 estuary, was designated as a Great Lakes Area of Concern due to degradation from industrial activities. Part of the estuary is occupied by the largest port in the Great Lakes. A GIS-based stressor index was previously developed to characterize anthropogenic stress within the watershed. The components of the stressor index were road density, point-source pollution permit density, population density, and percent agricultural and developed land. Water quality sampling was conducted at 27 sites in the estuary in tributaries and associated nearshore areas during multiple flow regimes in 2010–2011. Additional data were analyzed from 34 upper watershed sites sampled in 2009–2010. Stressor scores were significantly ($p < 0.1$) and positively correlated with TSS, turbidity, TP, NO_2^-/NO_3^--N, dissolved oxygen saturation, pH, specific electrical conductivity, chloride, sulfate, and *E. coli* in the upper watershed. In the estuary, the index was significantly and positively correlated with NO_2^-/NO_3^--N, NH_4^+-N, and chloride at multiple flow regime and location combinations. Soil K factor (an erosivity index from recent NRCS SSURGO soil surveys) was found to have stronger relationships with sediment related parameters than the stressor gradient. Although originally designed to help stratify sampling across a gradient of landscape stress and identify reference areas for restoration projects, the stressor index was shown to have substantial predictive power for multiple water quality parameters.

Introduction

The watersheds of the Laurentian Great Lakes underwent rapid population growth and heavy industrialization during the 19th and 20th centuries. As a result of this, many areas of the Great Lakes suffered from extensive pollution. In 1987 the International Joint Commission (IJC) identified 43 Areas of Concern (AOC) across the Great Lakes with water quality, habitat, fish and wildlife, and other sources of degradation severe enough to impair the beneficial uses of those water resources (SLRAC, 1992). The St. Louis River, which drains to the western arm of Lake Superior, is the second largest tributary to the lake and includes the westernmost headwater of the Laurentian Great Lakes system. The lower portion of the river was designated as an AOC in 1989. It includes the watershed of the lower 63 km of the river and the far western arm of Lake Superior (Fig. 1). The St. Louis River AOC currently has nine Beneficial Use Impairments (BUI; LimnoTech, 2013) of the 14 possible IJC BUIs. BUI #6, the excessive loading of sediments and nutrients, is directly connected to development and land use within the watershed.

Human development of watersheds, particularly urbanization and agriculture, has a strong impact on the quality and ecological functions of aquatic systems (Booth and Jackson, 1997; King et al., 2005; Galster et al., 2006; Brown et al., 2009; Johnson and Host, 2010). Urbanization is typically positively correlated with the concentrations and loads of many contaminants, including nutrients, sediments, heavy metals, petroleum products, salts, fecal indicator bacteria, organic contaminants and others (Paul and Meyer, 2001). High levels of agriculture have also been found to be associated with poor water quality, including increased levels of nutrients and suspended sediment (Johnson et al., 1997; Crosbie and Chow-Fraser, 1999; Reavie et al., 2006; Trebitz et al., 2007; Morrice et al., 2008).

Terrestrial impacts to aquatic systems have been quantified by assessing individual or aggregate stressors summarized at the watershed scale (Danz et al., 2005, 2007; Host et al., 2005, 2011; King et al., 2005; Allan et al., 2013). Stressor indices can be as simple as ranking watersheds along a single component such as percent impervious surface, or as complex as summarizing dozens to hundreds of components as metrics or indices (Brabec et al., 2002; Danz et al., 2005, 2007). Spatial data from components that are believed to impact water quality can be compiled and organized within a Geographic Information System (GIS), and sampling units in a specific study area can be ranked relative to each other based on the level/intensity of individual or combined components. These stressor indices can provide an indicator of water

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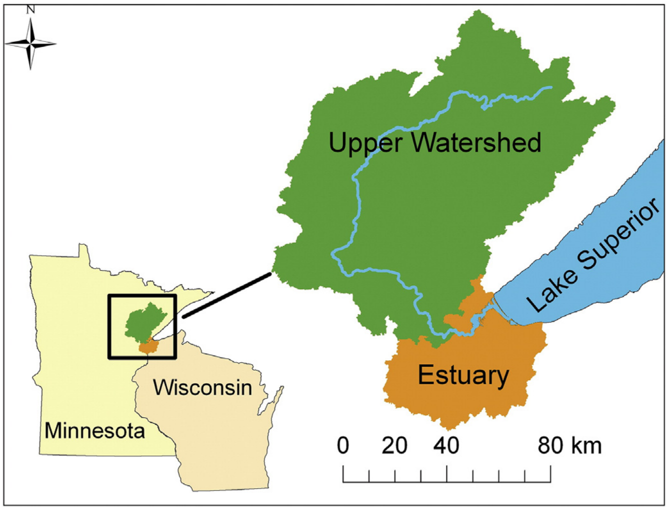

Fig. 1. St. Louis River watershed study area in Wisconsin and Minnesota, USA, showing the boundaries of the Upper watershed and Estuary.

Table 2
Spearman rank correlation coefficients relating water quality parameters to the soil K factor erosivity index in the St. Louis River Estuary. Bold values represent correlations significant at p < 0.1.

	Spring		Base flow		Storm
	Tributaries	Nearshore	Tributaries	Nearshore	Tributaries
TSS (mg/L)			0.29		**0.40**
Turbidity (NTU)	**0.52**	**0.58**	0.27	**0.53**	0.37
1/T-Tube (cm^{-1})	**0.41**	**0.74**	0.28	**0.46**	0.38
TP (μg/L)	0.28	**0.44**	0.17	0.21	**0.43**
OP (μg/L)	0.06	**0.34**	0.23	0.22	0.40
TN (μg/L)	0.04	0.31	0.05	−0.04	0.28
NH4-N (μg/L)	**−0.38**	−0.14	−0.28	−0.08	**−0.51**
NO2/NO3-N (μg/L)	**−0.38**	0.00	−0.30	−0.11	**−0.50**
Chlorophyll-a (μg/L)	−0.25	−0.12	0.03	−0.11	
Phaeophytin (μg/L)	−0.12	0.13	0.07	−0.21	
Color (pt-co)	**0.39**	**0.36**	**0.38**	0.26	0.31
EC25 (μS/cm)	**−0.40**	**−0.48**	**−0.48**	**−0.33**	−0.05
Cl (mg/L)	**−0.42**	**−0.52**	**−0.46**	**−0.36**	−0.30
SO4 (mg/L)	0.17	**−0.39**	0.09	−0.22	**0.49**
DO (mg/L)	0.24	0.27	**−0.42**	−0.08	−0.16
DO (% saturation)	−0.15	−0.17	−0.20	0.00	−0.11
pH	0.01	**−0.38**	**−0.48**	0.06	−0.17
Temperature (°C)	−0.33	−0.32	**0.47**	0.18	0.08

quality at a specific site without having to physically sample the site. This attribute can make them valuable tools for predicting water quality, identifying reference areas, and managing watersheds.

Danz et al. (2005) developed stressor indices for the U.S. side of the Laurentian Great Lakes using 207 individual components for the Great Lakes Environmental Indicators (GLEI) project. These components were grouped into seven categories: agricultural/agricultural chemical, atmospheric deposition, land cover, human population/development, point and non-point pollution, shoreline protection and soils. Principal component analysis was conducted to summarize each category and the primary principal component from each category used as a stressor index.

The GLEI stressor indices were found to correlate well with many measures of water quality and biological integrity (Reavie et al., 2006; Danz et al., 2007; Peterson et al., 2007; Trebitz et al., 2007; Morrice et al., 2008; Niemi et al., 2011). This raised the question of whether stressor index analysis could be successfully applied to a smaller geographic area, making it more useful for local watershed management. As a large-scale study, the GLEI stressor index took considerable time and resources to compile and calculate, making it difficult to replicate or update on a periodic basis. Host et el. (2011) developed the *SumRel* stressor index in an effort to create an index that would require less effort and resources but could perform in a similar manner to the GLEI index. This was done by building on work from the previously developed *MaxRel* stressor index (Host et al., 2005). *MaxRel* was composed of five variables: percent agricultural land, percent developed land, road density, point source pollution discharge permit density and population density. It set the score for a site as the maximum (worst) of the individual component stressors. It was used to identify reference conditions: minimally impacted sites throughout the U.S. side of the Great Lakes. Subsequently, *SumRel* was developed using an additive approach to

Table 1
Spearman rank correlation coefficients relating water quality parameters to the SumRel stressor index in the St. Louis River Estuary and the upper St. Louis River watershed. Bold values represent correlations significant at p < 0.1.

	Spring		Base flow		Storm	Base flow
	Tributaries	Nearshore	Tributaries	Nearshore	Tributaries	Upper St. Louis
TVS (mg/L)						0.23
TSS (mg/L)			**−0.42**		−0.22	**0.58**
Turbidity (NTU)	**−0.46**	**−0.38**	**−0.42**	−0.13	−0.25	**0.40**
1/T-Tube (cm^{-1})	**−0.46**	**−0.36**	−0.31	−0.08	−0.28	0.06
TP (μg/L)	−0.15	−0.10	0.12	0.02	−0.22	**0.38**
OP (μg/L)	0.13	0.13	0.18	**0.33**	0.08	
TN (μg/L)	0.33	0.08	0.22	0.12	−0.29	0.00
NH4-N (μg/L)	**0.38**	0.17	0.33	**0.57**	0.31	0.14
NO2/NO3-N (μg/L)	**0.47**	**0.35**	**0.43**	**0.54**	**0.61**	**0.42**
Chlorophyll-a (μg/L)	**0.54**	0.02	−0.12	0.02		
Phaeophytin (μg/L)	**0.51**	**−0.37**	−0.08	0.03		
Color (pt-co)	−0.16	0.05	**−0.35**	−0.04	**−0.51**	
EC25 (μS/cm)	**0.44**	0.28	**0.49**	−0.03	0.38	**0.80**
Cl (mg/L)	**0.72**	**0.68**	**0.64**	**0.55**	**0.46**	**0.91**
SO4 (mg/L)	0.22	0.17	**0.40**	0.26	−0.37	**0.50**
DO (mg/L)	0.07	**−0.41**	**0.37**	0.20	0.27	**0.38**
DO (% saturation)	0.13	**0.36**	0.32	−0.09	0.33	**0.29**
pH	0.24	**0.35**	0.22	−0.16	0.34	**0.62**
Temperature (°C)	0.12	0.28	−0.20	**−0.65**	0.02	−0.28
E. coli (MPN/100 mL)						**0.58**

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