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Water quality in the St. Louis River Area of Concern, Lake Superior: Historical and current conditions and delisting implications

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ABSTRACT

Water quality in the St. Louis River Area of Concern (AOC) was assessed at two stations over a 60 year period (1953–2013) and system-wide for 2012–2013 to determine if the AOC beneficial use impairment (BUI) of "Excessive loading of sediment and nutrients" should be considered for removal. Based on the time-series analysis, concentration and loading of total suspended solids and total phosphorus to Lake Superior from the St. Louis River have decreased over time, and episodic hypoxia in the mainstem of the estuary was eliminated after 1975. Detection of temporal patterns in nitrogen concentration and loading, particularly in the lower estuary, were complicated by Lake Superior nitrogen inputs and changes in wastewater treatment practices. For the system-wide assessment, sample locations were based on a probabilistic survey design. In 2012 and 2013, there was significant monthly (May–October) variability in water quality constituents. Based on area-weighted estimates, 60–85% of the estuary surface area was below BUI criterion for total phosphorus, total suspended solids, and chlorophyll *a*. Water quality in the western arm of Lake Superior in 2013 was indicative of oligotrophic conditions, satisfying delisting requirements. The long-term improvements in water quality followed improvements in watershed land-use practices and treatment of wastewater. The stratified system-wide survey provided unbiased estimates of spatial and temporal condition and identified some outlier sites. The data from this study supports the BUI removal process for the St. Louis River AOC.

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Introduction

The St. Louis River Estuary (SLRE), located at the western end of Lake Superior, is the largest estuary of the Great Lakes (50 km^2; Fig. 1). The SLRE is bordered by the port cities of Duluth, MN, and Superior, WI. The Duluth–Superior area developed rapidly during the late 1800s and early 1900s, a period of widespread deforestation throughout the watershed that increased sediment and nutrient loading to surface waters (Hartig and Thomas, 1988; Meyers, 2003). Industrial and urban development resulted in uncontrolled discharges of sewage, industrial waste, organic contaminants (e.g., polychlorinated biphenyls, polyaromatic hydrocarbons, and dioxins), and heavy metals into the estuary (Dole and Wesbrook, 1907; MPCA and WDNR, 1992). Early water quality surveys reported sediment contamination from sawmill waste, tar substances, and organic matter, and episodic anoxia during summer (MSBH et al., 1929). These conditions virtually eliminated aquatic life in some areas of the estuary. Tertiary treatment of municipal and industrial wastewater began in 1978 with the establishment of the Western Lake Superior Sanitary District (WLSSD; MPCA and WDNR, 1992).

The Great Lakes Water Quality Agreement between the United States and Canada (http://epa.gov/grtlakes/glwqa/1978/annex.html#annex 2; site accessed 1/2015) designated 43 coastal ecosystems across the Great Lakes as areas of concern (AOC), defined as locations having significantly degraded chemical, physical, and biological attributes (referred to as beneficial use impairments, or BUIs). Nine BUIs were identified for the SLRE: restrictions on fish and wildlife consumption; degraded fish and wildlife populations; fish tumors and other deformities; degradation of benthos; restrictions on dredging; excessive loading of sediment and nutrients to Lake Superior; beach closings/body contact; degradation of

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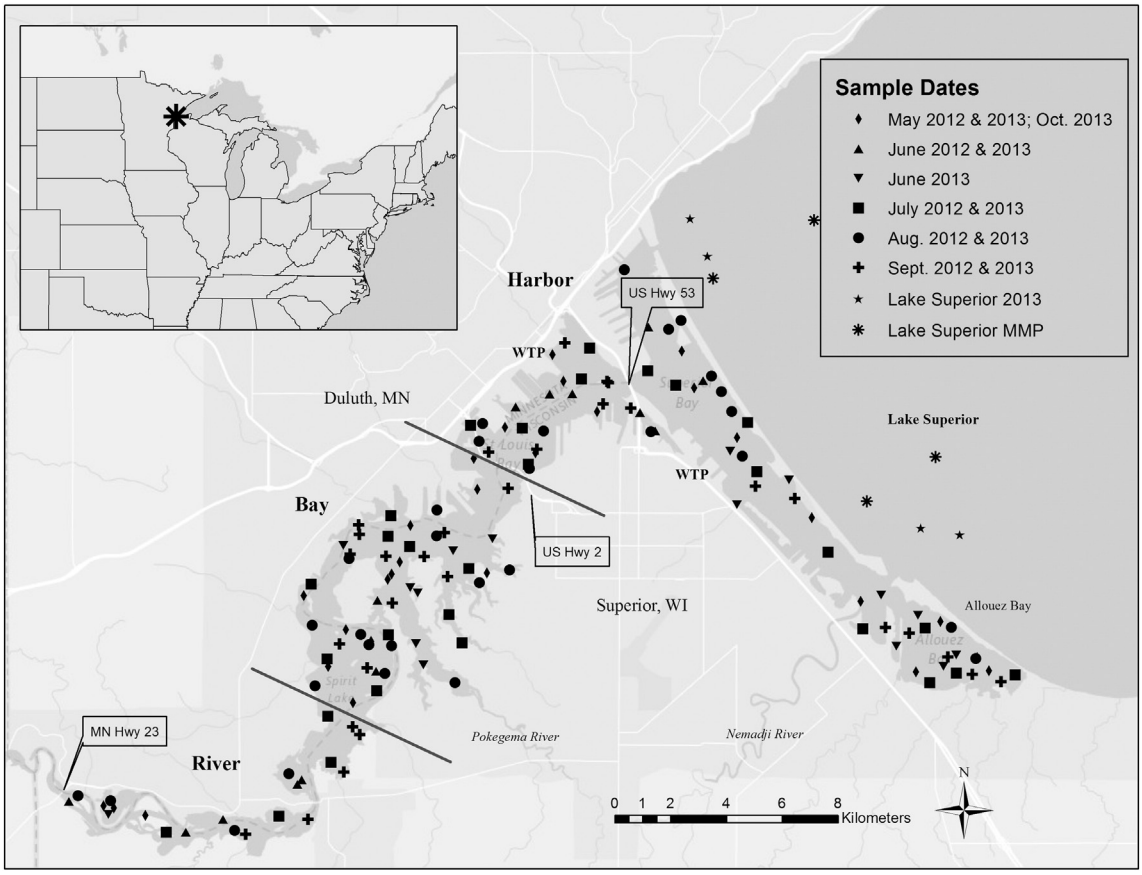

Fig. 1. Extent of the St. Louis River Estuary (SLRE) from the Fond du Lac Dam (upriver) to the western arm of Lake Superior. Milestone Monitoring Program (MMP) historic monitoring sites were at MN Hwy 23 ("Upper Estuary"), US Hwy 53 ("Lower Estuary"), and Lake Superior. Approximate zone delineations for the probabilistic sampling design applied in 2012 and 2013 are the head of Spirit Lake (River-Bay) and the US Highway 2 Bridge (Bay-Harbor). Lake Superior sites sampled in 2013 were randomly selected but meant to be near the MMP stations. Abbreviations: WTP = water treatment plant.

esthetics; and loss of fish and wildlife habitat (MPCA and WDNR, 1992; MPCA, 2013). To remove BUIs and delist an AOC, the U.S. Environmental Protection Agency (EPA) requires that condition indicators and delisting targets be established by local advisory groups through a remedial action plan (RAP) (Hartig and Thomas, 1988; US Policy Committee, 2001). Goals of the RAP include making recommendations of necessary remediation and restoration actions and developing BUI removal indicators and targets (MPCA and WDNR, 1992; US Policy Committee, 2001; MPCA, 2013).

One of the most significant developments toward water quality improvement in the SLRE that occurred before AOC listing was the establishment of the WLSSD in Duluth in 1978 (MPCA and WDNR, 1992). Phosphorus loadings from municipal treatment plants were reduced 80%, after which nuisance algal blooms became infrequent. However, there was still concern about water quality and nutrient loadings to Lake Superior, necessitating the water quality BUI listing (MPCA and WDNR, 1992). Following the Water Quality Agreement and RAP development, efforts to identify and remove impairments included: controlling storm water overflows, protection of existing forest and riparian areas, enhanced erosion control efforts, and implementation of agriculture and construction best management practices (MPCA and WDNR, 1992; MPCA, 2013). These efforts have improved water quality to the extent that nutrient and sediment loadings may have been reduced to concentrations consistent with removal of the excessive sediment and nutrient BUI. Loading of phosphorus has only been quantified from its major source, the WLSSD treatment plant (Fig. 1). However, the cumulative effect of the improvements and actions through time and on current conditions has yet to be assessed. The SLRE benefits from having a long history of water quality monitoring. In this paper, we analyze 60 years of water-quality data (1953–2013) from two fixed stations to determine whether nutrient and sediment concentrations and loads have changed in the SLRE.

We also describe current water quality conditions, compare concentration estimates with BUI removal criteria established by stakeholders, and estimate the proportion of the SLRE surface area below threshold (criterion) concentration. To estimate current conditions, we applied a probabilistic system-wide sample design that allowed us to assess seasonal as well as spatial variability in 2012 and 2013 (Crane et al., 2005; Messer et al., 1991). This study documents changes in BUI indicator values over time and it shows the utility of a spatially-balanced monitoring design for whole-system characterization necessary for BUI removal and AOC delisting.

Materials and methods

Study area

The 288-km long St. Louis River (9412-km^2 watershed) has an estimated mean daily discharge of 73 m^3 s^{-1} at the U.S. Highway 53 Bridge (Fig. 1). Our study area comprised the estuarine portion of the river (i.e., the reach of river subject to seiche-induced bi-directional flow; Stortz and Sydor, 1980), which extends from below the Minnesota Highway 23 Bridge, near the Fond du Lac Dam, to Lake Superior (including the Duluth–Superior Harbor), and the Lake Superior portion of the AOC, which extends approximately 16 km into the lake. The SLRE is situated behind a natural sand bar that restricts river-lake exchange to inlets at Duluth, MN, and Superior, WI. The upper SLRE ("river" section; Fig. 1) has a lotic character with generally intact riparian and floodplain

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