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Modeling the water quality impacts of the separation of the Great Lakes and Mississippi River basins for invasive species control

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ABSTRACT

In 1900, the Chicago Sanitary and Ship Canal (CSSC) was opened to reverse the flow of the Chicago River and divert wastewater away from Lake Michigan and toward the Mississippi River. This reversal has been a public health success, but the CSSC and other components of the Chicago Area Waterway System (CAWS) have become conduits for invasive species to move between the Great Lakes and Mississippi River basins. The Great Lakes and Mississippi River Interbasin Study evaluated methods to prevent the migration of invasive species between the basins. The DUFLOW model was adapted to simulate water quality in the CAWS. This model is used to simulate conditions in the CAWS for the No Project (NP), Lakefront Separation (LS), and Midsystem Separation (MS) alternatives. Three representative water years (wet year, dry year, and normal year) are considered to compare the dissolved oxygen (DO) results and pollutant loads to Lake Michigan for the alternatives. The LS alternative results in large increases in noncompliance with DO standards with increases greater than 1000 h for several locations. The MS alternative results in large increases in noncompliance with DO standards in the waterways made stagnant by the placement of barriers with the Calumet-Sag Channel experiencing increases greater than 1000 h for nearly all locations evaluated. The loads to Lake Michigan for the MS alternative are greatly increased compared to the NP alternative with even the dry year modeled yielding loads of nitrogen, phosphorus, and chloride, 5.7, 0.73, and 150 million kg, respectively.

Introduction

The city of Chicago, Illinois, is located at the southern end of Lake Michigan, the fifth largest freshwater lake in the world (by surface area) that serves as the water supply for Chicago and surrounding communities. In the 1800s, Chicago built a network of combined sewers to drain stormwater and wastewater from the city to the Chicago River and then to Lake Michigan. During large storms the polluted combined sewer overflows (CSOs; all acronyms used are listed in Appendix 1) would extend far enough into Lake Michigan that they would enter the water supply intakes for Chicago. This contributed to very high levels of death by typhoid fever in Chicago, peaking at more than 170 per 100,000 residents in 1891 (Hill, 2000).

In 1889, the Sanitary District of Chicago (now known as the Metropolitan Water Reclamation District of Greater Chicago, MWRDGC) was formed by the State of Illinois, and charged with building a canal that would carry flow from the polluted Chicago River away from Lake Michigan through the low continental divide west of Chicago to the Des Plaines River, Illinois River, and ultimately the Mississippi River (Lanyon, 2012). In 1892 construction began and in 1900 the Chicago Sanitary and Ship Canal (CSSC) was opened to reverse the flow of the Chicago River, thus, diverting the wastewater and CSOs from Chicago away from Lake Michigan and toward the Mississippi River. Two additional channels were later opened to improve water quality in the Chicago area: (1) the North Shore Channel (NSC, completed 1910) to flush water of poor quality from the North Branch Chicago River (NBCR) and (2) the Calumet-Sag Channel (completed 1922) to divert the Calumet River away from Lake Michigan. The lower portion of the NBCR, South Branch Chicago River (SBCR), Chicago River, Calumet River, and Little Calumet River (north) also have been widened, deepened, and straightened to efficiently carry treated wastewater away from Lake Michigan.

The system of constructed and altered waterways described previously is known as the Chicago Area Waterway System (CAWS). In total, the CAWS is a 133.9 km branching network of navigable waterways controlled by hydraulic structures in which the majority of flow is treated sewage effluent with periods of substantial CSOs. The dominant uses of the CAWS are conveyance of treated municipal wastewater, commercial navigation, and flood control. The CAWS receives pollutant loads from three of the largest wastewater treatment plants (referred to as water reclamation plants, WRPs) in the world, nearly 240 gravity CSOs, 5 CSO pumping stations, eleven tributary streams or drainage areas, and direct diversions from Lake Michigan. The water quality in

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the CAWS also is affected by the operation of five Sidestream Elevated Pool Aeration (SEPA) stations (Robison, 1994) and two in-stream aeration stations (IASs). The Calumet River and Chicago River systems are shown in Fig. 1.

The operation of the CAWS has been a great public health success for the Chicago area (Hill, 2000; Lanyon, 2012), but the CAWS has created a pathway for non-indigenous aquatic species to migrate between the Great Lakes and Mississippi River basins. If an invasive, non-indigenous species has the potential for populations to grow to such an extent that it is deemed undesirable, the species is known as an aquatic nuisance species (ANS) (USACE, 2011). The U.S. Fish and Wildlife Service (USFWS) has developed a list of 21 non-indigenous aquatic species in the Mississippi River system but not yet observed in the Great Lakes, and a list of 120 non-indigenous aquatic species in the Great Lakes but not yet observed in the Mississippi River system (USACE, 2010). Among these species are the silver and big head Asian carp that have the potential to dominate a water body.

The possibility of the 141 species identified by the USFWS transferring between the basins and becoming ANSs harmful to the receiving ecosystem led the U.S. Congress to direct the U.S. Army Corps of Engineers to initiate the Great Lakes and Mississippi River Interbasin Study (GLMRIS). The specific tasks of GLMRIS reported in the "About the Study" website: (http://glmris.anl.gov/about-study/ accessed 3/21/2014) included:

- Inventory current and forecast future conditions within the study area (i.e. the Great Lakes and Mississippi River basins);
- Identify aquatic pathways that may exist between the Great Lakes and Mississippi River basins (the CAWS being the most prominent among these pathways);
- Inventory current and future potential ANS;
- Analyze possible ANS controls to prevent ANS transfer, to include hydrologic separation of the basins; and
- Analyze the impacts each ANS control may have on significant natural resources and existing and forecasted uses of the lakes and waterways within the study area.

These tasks were done to meet the overarching goal of the GLMRIS study to "develop a range of options and technologies to protect the Great Lakes and Mississippi River aquatic ecosystems from ANS that could transfer via aquatic pathways connecting the Great Lakes and Mississippi River basins" (USACE, 2014). The project described in this paper supports the last bullet in the foregoing list by analyzing the effects of potential hydrologic separation alternatives on the water quality in the CAWS and the pollutant loads to Lake Michigan.

The objectives of the study reported here are to determine the decreases in compliance with dissolved oxygen (DO) standards and changes in pollutant loads to Lake Michigan resulting from proposed Lakefront Separation and Midsystem Separation alternatives compared to the No Project alternative. To evaluate these changes three hydrologic inflow conditions (current, baseline, and future) were considered for three representative years (wet year, dry year, and normal year). These inflow conditions, representative years, and alternatives are described in the Methods and materials section.

Methods and materials

In this section the computer model used to simulate the effects of hydrologic separation on water quality in the CAWS and pollutant loads to Lake Michigan is described. Also, described in this section are the hydrologic and pollutant loading conditions for the alternatives considered in this study: No New Federal Action (i.e. No Project alternative), Lakefront Separation, and Midsystem Separation.

Whereas the DUFLOW model of the CAWS was tested and verified for the actual flow, WRP effluent load, and temperature conditions in water years (WYs) 2001, 2003, and 2008 in Melching and Liang (2013) and Melching et al. (2010), the evaluation of the GLMRIS project alternatives must reflect expected future conditions in 2017 and beyond. These conditions are dictated by already agreed to changes in WRP effluent permit limits (i.e. the requirement of a maximum total phosphorus concentration of 1 mg/L) and planned upgrades to the WRPs (i.e. institution of disinfection at the O'Brien and Calumet WRPs). Also, the changes in

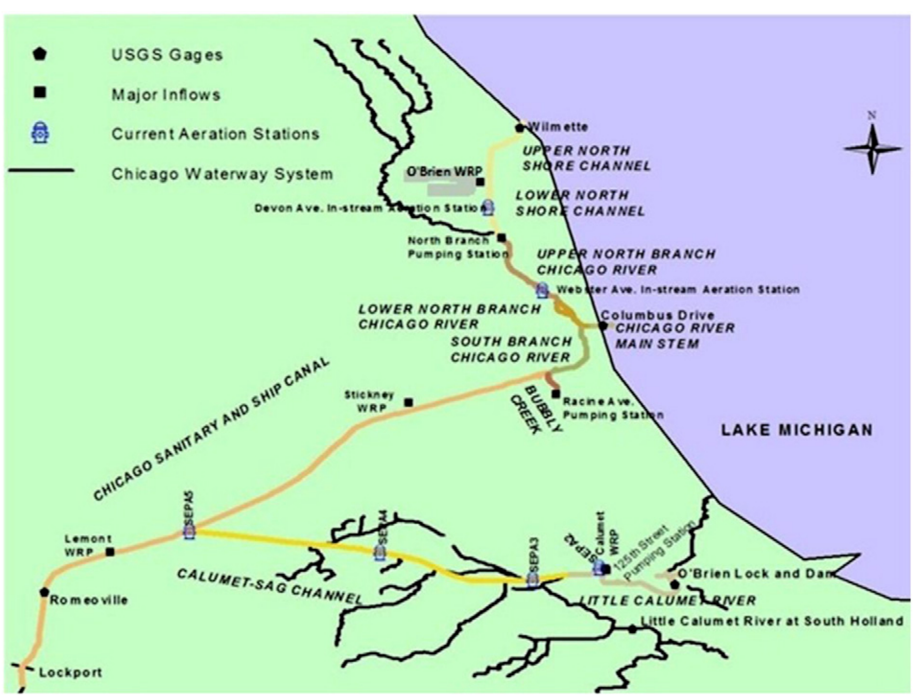

Fig. 1. Schematic diagram of the Calumet and the Chicago River systems (note: the different colors for the waterways are used the distinguish among the North Shore Channel, Upper North Branch Chicago River, Lower North Branch Chicago River, Chicago River Main Stem, South Branch Chicago River, Bubbly Creek, Chicago Sanitary and Ship Canal, Calumet-Sag Channel, and Little Calumet River (north) in gray and Little Calumet River (south) in black).