



Notes

The effect of a flood pulse on the water column of western Lake Superior, USA



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ABSTRACT

On June 19 and 20, 2012, western Lake Superior was impacted by a “mega-rain event” that raised lake levels by 8 to 10 cm. Within the flood plume on June 21, 2012, total suspended solids, total phosphorus, and soluble reactive phosphorus concentrations were elevated, with measurements of 87 mg/L, > 100 µg/L, and 5.8 µg/L, respectively. Despite the initially high phosphorus loadings, little impact was seen on water column particulate chlorophyll content, which remained in the range 0.7–1.9 µg/L, in the weeks to months following the flood. Both total phosphorus and soluble reactive phosphorus levels tracked those of total suspended solids, returning to background levels within two weeks. However, the availability of photosynthetically available radiation (PAR) was impacted for a month after the flood event, due mainly to colored dissolved organic matter that remained in the surface layer of the stratified lake water column. It appears that the mismatch in timing of nutrient and light availability acted as a check on phytoplankton biomass production in the flood-impacted portion of the lake.

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Introduction

Heavy rainfall events in the United States, including the Midwestern region, are exhibiting increases in prevalence and intensity (Angel and Huff, 1997; Karl and Knight, 1998; Villarini et al., 2011). Globally, large-basin 100-year flood events are also increasing in frequency and modeling predicts them to become more common as climate continues to change (Milly et al., 2002). The impacts of heavy rainfall and discharge events on receiving basins, however, remain poorly constrained. The 2012 “Solstice Flood” in the western Lake Superior watershed provided an opportunity to investigate the effects of this 100-year flood event on its receiving basin. On June 19–20, 2012, a “mega-rain event” delivered up to 25 cm of rain to northeastern Minnesota and northwestern Wisconsin (www.climate.umn.edu/doc/journal/mega_rain_events.htm, accessed June 2013), with recorded instantaneous rainfall of up to 5 to 10 cm per hour (Czuba et al., 2012). This event, occurring after an already wet spring, caused flooding and damage in nine counties in Minnesota to the extent that they were the subject of a Presidential Disaster Declaration. Thirteen USGS stream gages recorded their highest recorded streamflows during this storm, including the St. Louis River gage at Scanlon, which has been active for over 100 years (Czuba et al., 2012). The rainfall and subsequent river, stream, and overland

flow significantly impacted Lake Superior, the world's largest freshwater lake, raising the overall water level by 8 to 10 cm based upon averaging data from two USGS water level stations: 9099064 (Duluth) and 9099004 (Point Iroquois), located, respectively, at the western and eastern ends of the lake (Austin, Jay. A., Large Lakes Observatory and Dept of Physics, University of Minnesota Duluth, personal communication, February 12, 2014). The inputs of total suspended solids and colored dissolved organic matter had visibly stained nearshore regions in the far western lake (turning them a bright orange color) by mid-day on June 21. By June 26 (Fig. 1) these inputs impacted over half the areal extent of the far western arm (the region to the west of the Apostle Islands, south of Station SU19 in Fig. 1).

Lake Superior, the receiving basin for the June 2012 flood event, is responding rapidly to climate change in terms of increasing surface temperatures and duration of summer stratification (Austin and Colman, 2008). However, it has experienced minimal basin disturbance, e.g., few anthropogenic inputs, little impact from invasive species as of yet, and little recent change in land use (Dobiesz et al., 2010). It can therefore give a fairly clear response to climatic stress.

Located along the border between the United States and Canada, Lake Superior is the largest freshwater lake on Earth by area (Herndendorf, 1990); its basin contains approximately 10% of our planet's surface freshwater (Cotner et al., 2004). In addition, its position in the Laurentian Great Lakes system, which has a total area of about 242,000 km² (Einsele et al., 2001) makes Lake Superior regionally important, both as a remarkably pristine end-member for comparison with the less remote Great Lakes, and as a source of water to the

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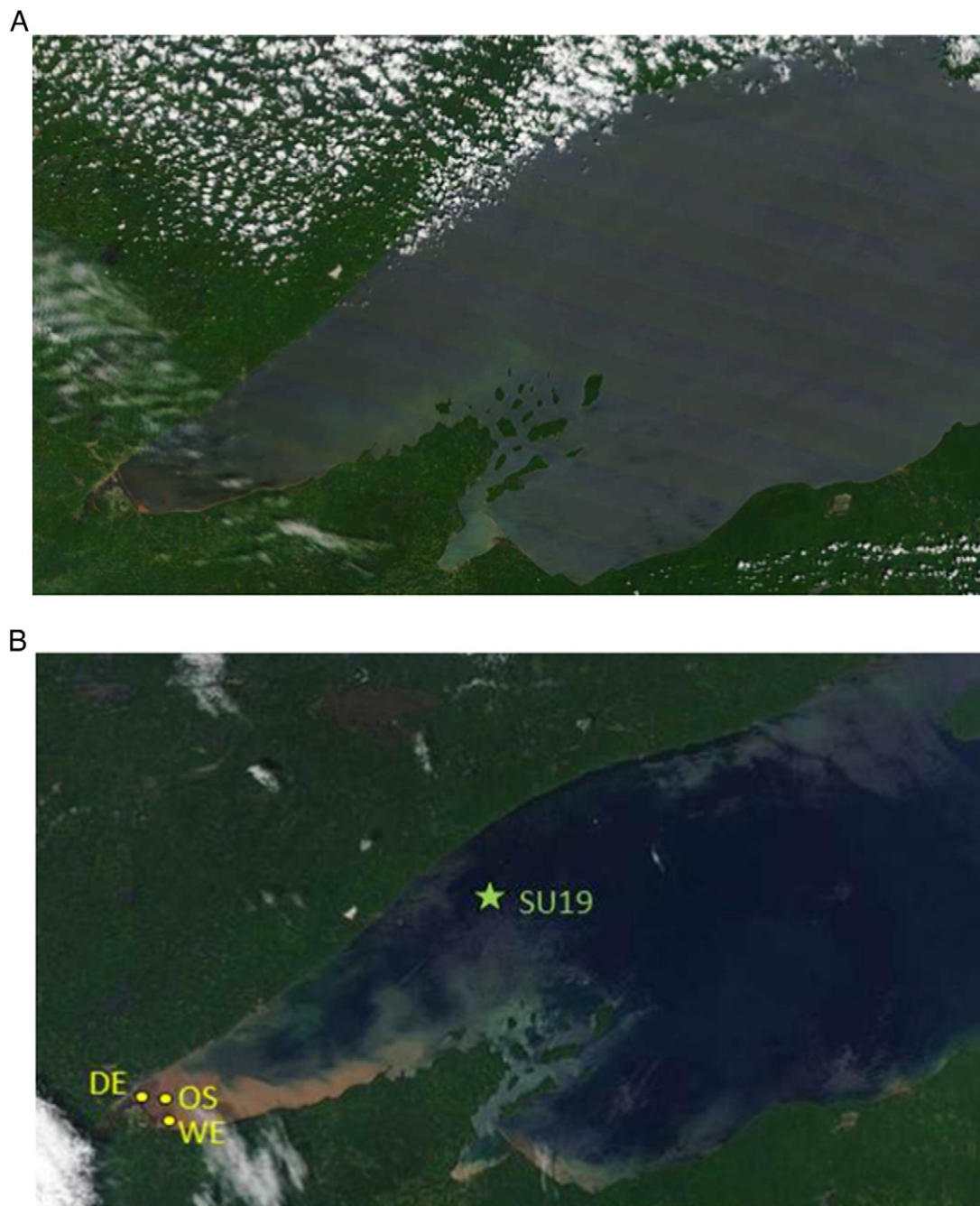


Fig. 1. MODIS data from A) 18 June 2012 and B) 26 June 2012 (NOAA CoastWatch–Great Lakes Region, <http://coastwatch.glerl.noaa.gov/modis/modis.cgi/modis?region=s&page=1>) with sampling sites superimposed. Sites DE, OS and WE were visited as part of the post-flood sampling project, site SU19 is the closest sampling site in the US EPA's Great Lakes Environmental Database (GLENDa, http://www.epa.gov/greatlakes/monitoring/data_proj/glenda/index.html).

downstream Great Lakes. Lake Superior has been an oligotrophic system with low primary productivity and nutrient concentrations and a pronounced deep-chlorophyll maximum (e.g., Barbiero and Tuchman, 2004; Russ et al., 2004) although this may shift on a short-term or long-term basis due to perturbations in nutrient inputs, such as seen during floods, and changes in its temperature regime, as have been identified over the past twenty years (Austin and Colman, 2008). Currently primary production in the lake appears P-limited with some indication of iron co-limitation (Sternner et al., 2004). Investigations of Lake Superior's carbon cycle have concluded that the lake appears to be net heterotrophic (Cotner et al., 2004; McManus et al., 2003; Russ et al., 2004; Urban et al., 2004, 2005), especially in spring (Atilla et al., 2011); but the magnitudes of carbon fluxes are poorly constrained temporally and spatially and this knowledge gap prevents quantitative

evaluation of the C budget (Atilla et al., 2011). Consistent with newer estimates indicating that the lake is closer to balance in terms of productivity and respiration, in-lake production appears to be the main source of organic carbon to lake mesozooplankton, with little evidence of zooplankton biomass production resulting from consumption of allochthonous organic matter (Zigah et al., 2012).

This study investigated the response of western Lake Superior to the June 2012 flood event through water quality analyses of discrete water samples (total suspended solids, UV–visible light absorption, nutrients, total and dissolved organic carbon and chlorophyll *a* concentrations) and in situ profiles of chlorophyll, colored dissolved organic matter (CDOM) fluorescence and light transmission. Sampling took place on a weekly to biweekly basis (Table 1) for the summer and fall of 2012. These data were placed in a longer term context by comparison with

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