Criteria for Land and Water Management to Sustain Healthy Aquatic Ecosystems in a Changing Climate

Streams and wetlands of Minnesota's North Shore of Lake Superior are a critically important natural, economic, and recreational resource to the state of Minnesota, the Great Lakes region, and the nation. Climate change threatens to significantly alter freshwater ecosystems, functions, and services in many parts of the world, including the North Shore of Lake Superior, especially when coupled with land use changes and other human activities that impact natural systems. These alterations represent significant risks and impacts to local communities and economies.

This project aims to expand understanding of the relationships between and use, management, flow and water quality that govern the health and resilience of Lake Superior streams in Minnesota under future climate scenarios. The project will address identified climate adaptation needs by developing models and outreach materials for understanding likely future response of streams to climate and land use change to aid land and water use planning, stream management and restoration, and climate adaptation.

Ecological criteria and decision support tools–at multiple scales from the site to the watershed-- are needed to ensure ecological maintenance of freshwater flow regimes for North Shore streams, lakes, wetlands, and estuaries to help sustain healthy functioning ecosystems and the many benefits derived from them upon which local communities and economies depend.

Improved understanding of flow-ecology relationships is needed to assess degree of alteration already experienced by watersheds relative to reference conditions and to understand vulnerability of native fish species to watershed, land use, and climate change. A stream classification will be developed in conjunction with flow ecology analyses. This understanding will help prioritize the healthiest and most resistant and resilient streams for protection, identify stream and watershed management criteria most likely to maintain or enhance stream resilience, and more efficiently target limited resources.

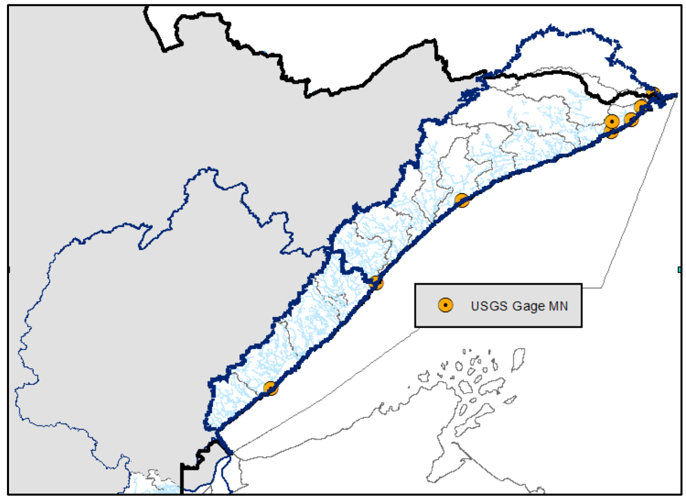


Figure 1. North Shore of Lake Superior, Minnesota. Watersheds of North Shore streams

Recent comprehensive, multi-stakeholder water-resource assessments and reports have identified significant unmet needs related to climate change adaptation, as well as gaps in the state's existing water appropriations and water-resource planning processes. Under the Great Lakes Compact (2008), all states within the Great Lakes watershed are required to "prevent significant adverse impacts of withdrawals and losses on the Basin's ecosystems and watersheds by 2012."

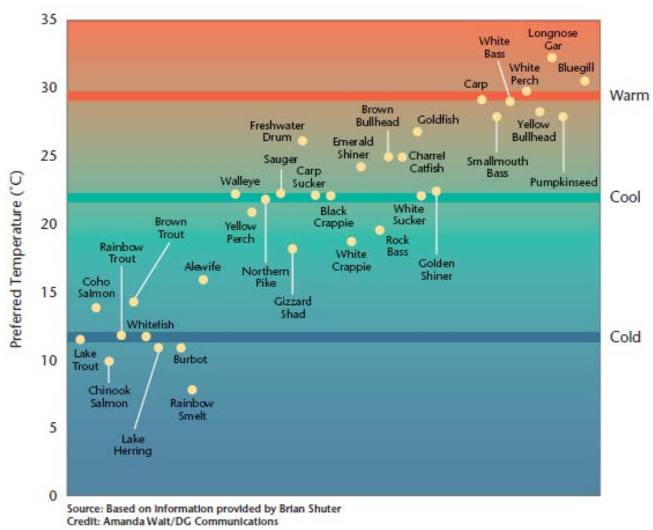
To develop capacity for regional climate adaptation, major national and regional assessments have identified the need for coordination and relationship building between organizations at the federal, state, and local levels for the sake of efficient knowledge exchange through improved communication, decreased redundancy, and reduced regulatory/cross-jurisdictional conflicts.

Project activities include: (1) development of models that predict stream flow and ecological response based on climate, land use, and other physical inputs; (2) analysis of flow-ecology relationships; (3) identification of management strategies to enhance stream resilience based on these models; and (4) development of outreach materials and workshops to inform restoration and management actions. Information produced by the project is designed to be shared with "decision makers" (defined as those who work on the ground, creating and implementing management strategies).

North Shore of Lake Superior flow ecology

Water quality, stream geomorphology, habitat availability, and aquatic species and communities are all governed by the natural patterns of variability in hydrology and flow in streams, rivers, lakes, and wetlands. The magnitude, timing, frequency, and rate of change of different flows or water levels (i.e., flow regimes) are key attributes governing the structure of native fish and aquatic communities. For example, along the North Shore, stream discharge and water temperature are the major signals influencing the timing of the juvenile steelhead emigration. Significant alterations to natural patterns of hydrology inevitably alter the suitability of those systems for native aquatic biodiversity.

Lake Superior tributaries in Minnesota have some of the most important coldwater trout habitat in the State, streams that are significant to the local economy. North Shore tributaries currently support naturalized populations of coho, Chinook, and pink salmon, steelhead, and brown trout, as well as reduced populations of native brook trout, the only salmonid truly native to North Shore streams.



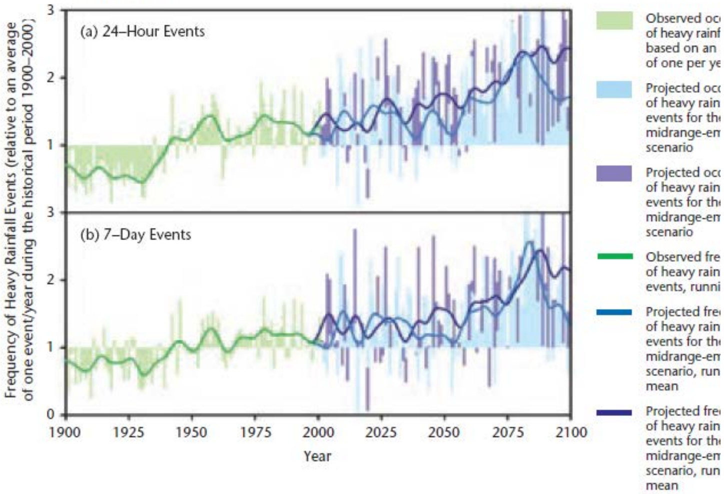
From Kling et al. 2003

Fish communities in Minnesota's North Shore streams have already changed considerably since the early 19th century. Development, overfishing, and introductions of other salmonids have resulted in vastly different fish communities today (Blankenheim 2014). Populations of coldwater species face limiting factors in Minnesota's North Shore streams including erratic flow regimes, warm water temperatures, lack of suitable spawning and nursery habitat, and reduced stream connectivity. Naturally, low base flow and high storm flow characterize North shore streams. Previous research has shown that maintaining baseflow is critical to support trout and other coldwater species in North Shore streams. Because groundwater input is often naturally limited by the area's bedrock geology, stream thermal buffering capacity is naturally low. Research has confirmed hydrologic response and declines in stream fish and biological community indicators as the percentage of "open" land (i.e., loss of mature forest cover resulting from forest harvest, natural disturbance, and/or development) in the watershed increases.

Climate Change

Climate change combined with land use change threatens to create significant alterations to stream ecosystems. The Midwest has experienced an increase in precipitation across all seasons of approximately 10% since 1900 (Minnesota Pollution Control Agency, 2010). The frequency of heavy rain events (defined as occurring once per year during the past century) doubled since the early 1900s across the Midwest and Northeast (Kunkel et al., 1999). Annual temperatures between 1970 and 2000 increased more than 0.4°F per decade for the Midwest, with winter temperatures rising 0.9°F per decade (Kling et al., 2003; Hayhoe et al., 2009). Great Lakes water levels have been highly variable with no clear trend towards lower water levels from 1860 to 2000 (Lofgren et al., 2002). Between 1997 and 2000, the Great Lakes experienced a severe decline in lake levels. This episode is the most severe three-year drop on record for Lake Erie and the second most severe for Lakes Michigan, Huron, and Lake Superior (Assel et al., 2004).

FIGURE 14
Increased Frequency of Heavy Rainfall Events in the Great Lakes Region
from page 19



Heavy downpours are now twice as frequent as they were a century ago (U.S. Global Change Research Program *Global Climate Change Impacts in the United States: Midwest)*. Both summer and winter precipitation has been above average for the last three decades, the wettest period in a century. The Midwest has experienced two record-breaking floods in the past 15 years (USGCRP). Average temperatures in the Midwest have risen in recent decades, with the largest increases in winter. There has also been a decrease in lake ice, including on the Great Lakes. Since the 1980s, large heat waves have become more frequent than any other time period in the last century, other than the Dust Bowl years of the 1930s. The observed patterns of temperature increases and precipitation changes are projected to continue, with larger changes expected under higher emissions scenarios.

Water levels and water temperature are intrinsically linked in coastal and tributary habitats. Shorter periods of ice cover and warmer temperatures can be expected to increase surface water temperatures in lakes and streams, and to result in less coldwater fish habitat.

Land use and Climate Connections

Land use is a major driver of water quality, temperature, and flow response. For example, stormwater runoff from roads and parking lots can cause Duluth trout streams to experience nighttime spikes in temperature as great as 3-6^{o}C (Axler, LakeSuperiorStreams.org) Even moderate rain events can cause a 5-11 ^{o}F jump as water moves across warm asphalt. Trout in these more developed watersheds are already near the upper range of their temperature tolerance in the summer.

There is growing consensus that future management of salmonids in North Shore streams must include a strong emphasis on watershed management. Sedimentation problems have pointed to a need to look upstream for understanding the longitudinal connections between past and present watershed hydrological processes and present and future stream channel response (Fitzpatrick 2014).

The combination of climate change and land use changes can be expected to drive a series of cascading impacts to streams, including higher temperatures, reduced dissolved oxygen (DO), increased primary production rates, increased biological oxygen demand (BOD), increased intensity of storm events, increased erosion (sedimentation, channel modification), increased runoff (contaminant, nutrient, sediment load). These changes in turn have effects on the fish and other organisms in the stream.

Stream temperature models developed by Johnson and Herb (2014) show trout are strongly impacted by temperature and flow. Land forms and forest cover add complexity to these relationships. Predictive models incorporating climate scenarios by the end of the century based on thermal tolerances show a north south gradient in responses. Local conditions including ground water input and riparian shading may help to mitigate impacts. Their results also suggest that some streams are likely to be more resilient than others. .

To understand future trout distributions, better projections of forest cover are needed, incorporating both the impact of forest management policy and decisions as well as climate change. Higher resolution vegetation and forest cover data may improve model predictions. Our study focuses on these linkages.

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