Confronting Climate Change in the Great Lakes Region
Technical Appendix

River And Stream Ecosystems

This document is a technical appendix providing further detail on the water resource information in the Report on **Confronting Climate Change in the Great Lakes Region** *available at* http://www.ucsusa.org/greatlakes/ (Kling et al. 2003). *The principal author contact for this background paper is Lucinda Johnson, and co-authors include (alphabetically) Katharine Hayhoe, George Kling, John Magnuson, and Brian Shuter.*

Great Lakes Rivers and Streams – An Introduction

Rivers provide many critical goods and services, including drinking water, power generation, nutrient recycling, organic matter retention, and habitat for many unique plants and animals and recreational activities. Rivers in the northern Great Lakes region have a rich history, and the roles they play are reflected in the land use and vegetation associated with that region. Northern streams, such as the Nipigon River in western Ontario, are cooler than the southern and eastern streams, and support an economically important coldwater fishery (The Nature Conservancy 1998). Coniferous forests and acidic soils cause many of the rivers to be tea-colored, indicating high concentrations of dissolved organic carbon (DOC). Because of the surrounding thin soils and the low buffering capacity of the waters, these ecosystems are vulnerable to acid precipitation. As described in the section on Forests (see Kling et al. 2003), fire suppression has reduced the frequency and extent of wildfires, but when fires do occur they have large impacts on the biological and chemical processes occurring at the land—water interface and in streams (Schindler et al. 1996, Schindler 1998). Forest harvest and mining are now the major disturbances in the watersheds of these streams. Stream flow is generally stable in areas with coarse-textured sediments and large expanses of lakes and wetlands, while areas with exposed bedrock or thin soils have very flashy flow regimes (The Nature Conservancy 1998). In these northern areas, riparian zones (stream bank areas and their associated vegetation) and wetlands are well developed and their ecosystem functions such as shading, filtering nutrients and sediments, providing organic matter to the stream, and serving as wildlife habitat and corridors are still largely intact.

In the southern and eastern portions of the Great Lakes region where residential and commercial development is concentrated (*Figure 2* in Kling et al. 2003), rivers such as the Maumee in Ohio and the Saginaw in Michigan are typically low-gradient and have higher sediment and nutrient loads than do their northern counterparts (The Nature Conservancy 1998; Roth et al. 1996; Richards 1996, 1997). Dominant disturbances result from riparian vegetation disruption or removal, nutrient and pesticide loading from agricultural fields, industrial discharge, and stormwater discharge from urban areas. Many farmers have installed field tiles to drain wetlands and reduce local threats of flooding. In addition, both agricultural and urban streams are channelized, which disrupts the natural hydrologic flow patterns and increases nutrient and contaminant loading. In conjunction with both agricultural activities and residential development, loss of riparian corridors is more widespread in the south, threatening the beneficial services provided by riparian vegetation.

The Synergistic Threats to Stream Ecosystems

Stream ecosystems are regulated by features and processes occurring at a range of spatial scales. At the largest scale, climate, geomorphology, and land use control channel morphology and stream hydrology, thermal regime and water chemistry, and biotic community structure. At finer scales, the availability of suitable habitat and food resources, as well as species interactions regulate organism populations. When superimposed on climate changes, anthropogenic disturbances including land use activities, nitrogen and acidic deposition, and species exchanges will undoubtedly alter the way in which stream ecosystems respond to change. Changes in climate variables relevant to streams include increased air temperature and a general drying of watersheds especially during summer and autumn, due mainly to increased air temperatures and higher rates of evaporation during a longer ice-free period (Kling et al 2003). Past trends of longer ice-free periods, earlier spring flows, and increased frequency of mid-winter breakup events and ice jams (Beltaos and Prowse 2001; Knox 2001) are expected to persist. Despite a general drying, model predictions for the region (*Figure 13* in Kling et al 2003; see also the technical appendix on precipitation) suggest that over the next 100 years precipitation will increase during winter and spring, which would increase the magnitude of spring floods, especially when intense rain storms coincide with snowmelt when soils are still frozen. The magnitude of stream responses will vary greatly across the region mainly because of the relative contribution of groundwater versus surface water to flow regimes (Richards 1990). The impacts of these changes are described in detail below and summarized in *Table 1*.

Changes in Hydrology and Resulting Impacts

Current evidence indicates that storm events and flooding is increasing in the Great Lakes region. Since the 1950's increases in precipitation of 10 to 20% have occurred in the upper Mississippi River region (Karl et al. 1996). Similarly, intense summer storms are occurring more frequently over the last 25 years (*Figure 10* in Kling et al. 2003; Kunkel et al. 1999a), and there have been increasing floods in small to medium-sized streams in the central U.S. from 1921 to 1985 (Changnon and Kunkel 1995). Projected increases in precipitation during winter and spring will intensify these responses, as will changes in land use (Kling et al. 2003; Knox 2000, 2001). Land-use alterations that increase the risk of flash flooding include channelization, tile drainage in agricultural fields and wetlands, water diversion, and floodplain development. These alterations are likely to exacerbate climate change effects on stream flow by increasing flood frequency and height. For example, the agricultural areas with fine textured soils and flat topography at the eastern end of Lake Erie have stream flows that are very responsive to rain events, and we anticipate that such streams will be especially vulnerable to the deleterious effects of intense summer storms.

Floods exert their greatest physical influence by reshaping river channels and inundating floodplains, and by moving large wood and sediments. Intense floods can scour the channel, resulting in mass mortality to algal, invertebrate, and vertebrate species. Under high flow regimes, water quality is often degraded when untreated human, commercial, or agricultural wastes overflow from treatment facilities or when soils are eroded from agricultural fields treated with pesticides and fertilizers (U.S. EPA 1993; Adams et al. 1999). High water flow also diminishes the capacity of the stream to recycle nutrients and sequester suspended or dissolved organic matter because of reduced water contact with the stream bank and substrate (Mulholland et al. 1985; D'Angelo et al. 1991) and reduced retention structures such wood dams (Munn and Meyer 1990; Wallace et al. 1995). Channelized urban and agricultural streams have very low water retention capabilities, and the anticipated increases in spring runoff by the end of the century are expected to result in increased height of spring floods and lower nutrient and sediment retention in these streams.

Predicted reductions in summer precipitation, especially in the southern and western portions of the region (*Figure 12* in Kling et al. 2003) will translate into lower summer stream flow and less stream habitat (e.g., Larimore et al. 1959; Ladle and Bass 1981; Erman and Erman 1995; Hanratty and Stefan 1998; Arnell et al. 2001). At the extreme, streams may become isolated pools connected only by underground flow. This situation would be expected in regions where there is little groundwater contribution to streamflow. Drought effects are associated with higher water temperatures, depleted oxygen, higher concentration of contaminants resulting from lower water volume (Lake 2000), reduced in-stream nutrient and organic matter transport (Golladay et al. 2000), and disruptions of food webs (Stanley et al. 1997; Power 1995; Hax and Golladay 1998; Miller and Golladay 1996). Drought conditions may also create a legacy effect for recovering the diversity and density of organisms in the streams (Boulton et al. 1992; Hax and Golladay 1998). Although this legacy effect has been mainly documented for arid streams, ephemeral streams in temperate regions should have similar responses.

Headwater streams are probably the most vulnerable of all aquatic ecosystems under warmer and drier conditions. They tend to comprise more than 75% of the river miles within a watershed (Leopold et al. 1964; Meyer and Wallace 2001), and they interact closely with the adjacent terrestrial system and the groundwater. When groundwater is withdrawn the water table lowers and turns perennial headwater streams into an ephemeral trickle, which may be aggravated by water withdrawal for irrigation or drinking (Frederick and Gleick 1999). In small streams where flow is regulated by surface water discharge, one scenario predicts that ~50 % of the streams will stop flowing with a 10% reduction in annual runoff (Poff 1992).

Expected increases in the number and severity of extreme disturbance events such as floods and drought (Changon and Kunkel 1995; Kattenberg et al. 1996) may result in shifts in aquatic community composition as ecosystem conditions change (Poff et al. 1997, 2002). Species are adapted to a particular flow regime, and changing the timing, duration, intensity, and return interval of natural disturbances such as droughts or floods may disrupt breeding and other critical life cycles stages (Grossman et al. 1982; Poff and Ward 1989; Rood and Mahoney 1990; Satake et al. 2001). Midwestern streams with flashy flow regimes have been found to support aquatic insect taxa with short life spans and multiple cohorts per year (Richards et al. 1996, 1997); such life history strategies are required for rapid recolonization following disturbances such as floods.

Another consequence of periodic drought events is that sulfate and acidity that are mobilized during post-drought rains result in a strong acid pulse to streams and lakes in the watershed. This phenomenon is sufficiently general (DeVito and Hill 1997, Dillon et al. 1997; Warren et al. 2001) for us to expect that climate warming will slow down, or even stop, the recovery of many acid-stressed aquatic ecosystems. Streams most susceptible to acid precipitation lie on the Canadian Shield of Ontario, along higher gradient reaches in New York, and in northern Minnesota, Wisconsin, and Michigan.

Not all impacts of flooding are negative. Aquifer recharge is one benefit of increased rainfall, especially if the moisture falls on unfrozen ground. Floods also transport fine sediments downstream, increasing the quality and quantity of habitat for fish and invertebrates. In addition, several important fish species move upstream into the Great Lakes tributaries during spring (e.g., sturgeon, walleye, white sucker) or fall (steelhead, Chinook salmon, brook trout) to reproduce, cued by either increased flow or photoperiod. Many fish and invertebrate species coevolved with seasonal flood pulses (Junk et al. 1989; Sparks et al. 1998) to take advantage of the expanded habitat for spawning and nursery sites. In the Great Lakes region these species include bass, crappie, sunfish, and catfish (Sparks 1995) (see technical appendix on fish responses to climate change for more details).

Impacts of Higher Water Temperature

At the scale of a watershed, stream temperatures will closely mirror increasing air temperatures (Pilgrim et al.1998; Mohseni et al. 1999) but will be influenced by shade from riparian vegetation (Stefan and Sinokrot 1993), watershed storage in wetlands, and the proportion of forest in the watershed (Brazner et al. 1999). At smaller scales, groundwater seeps will counteract the water temperature increase that will follow air temperature increases. Experimental manipulations that increased stream temperature caused several insect species to increase growth rates, emerge earlier and have smaller size at maturity, decrease mean body size, alter sex ratios, or reduce fecundity (Hogg and Williams 1996). Physiological processes and production per unit biomass will increase with higher temperatures and longer growing seasons (Morin and Bourassa 1992; Shuter and Ing 1997), but the overall reduction in water volume, coupled with the possibility that flow in smaller streams will become intermittent, should lead to reductions in overall aquatic production (see technical appendix on fish responses). These effects from increased temperatures would be compounded by forest harvest, which opens up the canopy and itself promotes earlier snow melt (Verry 1986); northern Minnesota, Wisconsin, Michigan, and western Ontario will be most impacted by this phenomenon.

Nutrient cycling also is strongly influenced by warmer temperatures because as plants and animals die, tissues are decomposed at rates that depend upon oxygen concentrations and temperature. Decomposition releases nutrients that are usually taken up rapidly by primary producers, but this ability of streams to decompose human and agricultural wastes is likely to be altered under current climate change scenarios. For example, under prolonged low flow and higher temperatures, oxygen may become more depleted, which will slow decomposition processes and shift the system to an anoxic microbial food web (Palmer et al. 2000).

Impacts on Biodiversity

Globally, biodiversity is changing in response to many inter-dependent factors such as climate change, land use change, introduced and exotic species, nitrogen deposition, and acid rain (Sala et al. 2000). Models predicting aquatic biodiversity for the year 2100 attribute the majority of impacts on biodiversity in streams to changes in land use, followed by changes in climate and the spreading of exotic or invasive species. Species responses to changing temperatures and hydrologic regimes will differ widely; overall, species will adapt to warmer temperatures, expand their ranges northward, seek thermal or hydrologic refugia, or become extinct (e.g., Poff et al. 2001). Insect and plant species with resistant or mobile life history stages are likely to survive better during reduced flow or drought (e.g., Hax and Golladay 1998; Miller and Golladay 1996). Fish species with traits that include small geographic ranges, specific requirements for water flow (e.g., steady flowing or slack water habitats), reproduction at an older age, or specific food requirements are presumed to be at higher risk of extinction. Of 146 fish species in Wisconsin, 43% have two or more of the above traits that indicate potential sensitivity to global warming (Poff et al. 2001).

Impact on Food Webs

In laboratory and small field studies, elevated CO_2 levels appear to lower nitrogen and increase lignin and phenolic concentrations in plant leaves (Lindroth 1996; Tuchman et al. 2002; Lindroth et al. 2001). This, in turn, appears to lower microbial colonization and decomposition rates of organic matter in soils and streams (Tuchman et al. 2003 A; Rier et al. 2002; Ostrofsky 1997; Cotrufo and Ineson 1996), which may alter the nutritional value of leaves (Boerner and Rebbeck 1995; Cotrufo et al. 1994; Lindroth et al. 2001). These changes have been linked to reduced growth and survival in some stream insects (Tuchman et al., 2003 B). Although it is at present unclear whether changes in leaf chemistry and decomposition rates are an artifact of study protocols (Norby et al. 2001), reduced food quality for invertebrates could be magnified up the aquatic and terrestrial food chains. Therefore, it is important to understand the relationship between increasing CO_2 concentrations and how potential changes in leaf chemistry (Cotrufo et al. 1994; Norby and Cotrufo 1998) could affect aquatic ecosystems.

Table 1. *Summary and synthesis of the changes in stream ecosystems driven by climate change. Intensifying or confounding factors are described more fully and referenced in the text.*

Climate Driven Change	Likely Impacts on Physical and Chemical Properties	Likely Impacts on Ecosystem Properties	Intensifying or Confounding Factors
Earlier ice-out & snow melt	Peak flows occur earlier Ephemeral streams dry earlier in the season Backwater pools experience anoxia earlier	The timing of fish and insect life cycles could be disrupted	Snowmelt occurs earlier and faster in urban areas and where coniferous forest harvest has occurred
Decreased summer water levels	More headwater streams dry Perennial streams become intermittent Concentrations of dissolved organic carbon decrease, thereby reducing ultraviolet B attenuation through the water column. Groundwater recharge is reduced	Habitat decreases in extent Hydrologic connections to the riparian zones are reduced Groundwater recharge is reduced Species with resting life stages or rapid colonizers dominate communities	Impervious surfaces and impervious soils exacerbate stream drying due to reduction in infiltration and groundwater recharge
Increased winter & spring precipitation and water levels	Spring floods reach greater heights Surface runoff increases Nutrient and sediment retention decreases Groundwater recharge potential increases	Floodplain habitat for fish and invertebrates expands Hydrologic connections with wetlands increase	Precipitation occurring when soils are frozen or saturated result in higher runoff and increases flood height
Warmer temperatures	Stream and groundwater temperatures increase	The rates of decomposition and respiration increase Insects emerge earlier Primary and secondary production per unit of biomass increases when nutrients are not limited; however, total production could decrease with shrinking aquatic habitats under drought conditions	Impervious surfaces and both natural and human-made retention basins increase water temperatures Woody riparian vegetation can buffer stream temperatures In areas with porous soils and active groundwater connections, temperature extremes are smaller
Increased intensity and frequency of storms	Larger floods occur more frequently Erosion and pollutant inputs from upland sources increase Runoff increases relative to infiltration, especially when soils are frozen or saturated	Fish and invertebrate production decreases Fish and insect life histories and food webs are disrupted by changes in the intensity, duration, and frequency of flooding	Impervious surfaces increase runoff and stream flow Channelized streams increase peak flows
Elevated atmospheric CO_2		Possible changes in leaf litter quality could impact aquatic food webs	

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