# Climatic Change and Global Warming of Inland Waters

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## Impacts and Mitigation for Ecosystems and Societies

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# Preface

The World Water and Climate Network (WWCN) was created during the Third World Water Forum in Kyoto Japan in 2003. Its objective is to gather and exchange science-based information on the current and future conditions of our limited surface freshwaters contained in the lakes and rivers of the world. Since then the impact of global climatic change and associated warming has resulted in WWCN sessions organized in conjunction with three international conferences in France, the United States, and China. A fourth session was held in conjunction with the meeting of the American Society of Limnology and Oceanography at Otsu, Japan, in 2012. An important feature of the WWCN activities has been to attract and provide advanced training and scientific exchange for promising young graduate students competitively selected from about ten different countries. Bringing them together for several days to attend student meetings and then to present their research at an international scientific conference provides a stimulating intellectual platform for them to exchange information and make contact with old and new generations of aquatic ecologists, limnologists, hydrologists modelers, and environmental engineers. The meetings take place at a very important and formative time in the students' career development. Following the WWCN in Nice, France in 2009 the editors recruited experienced scientists from the meetings to assemble information on the impact of climatic change on the world's inland waters culminating in a book that Wiley-Blackwell agreed to publish. The following chapters are the result of this initiative.

Little doubt remains in the scientific community that the planet's climate is changing. Notably, the earth continued to gain heat during 2005–2010, a period marked by the strongest solar minimum recorded since accurate monitoring began. In other words, we now have irrefutable evidence that the sun is not the only important nor even perhaps the dominant factor forcing this climate change and that carbon dioxide, the classic greenhouse gas, is being joined by increasing amounts of methane. This gas is over 20 times as potent a greenhouse gas as carbon dioxide and will continue to increase as permafrost melts. Furthermore, analysis of ice cores indicates that the current, rapid rate of warming has not occurred in the last 800 000 years. Some natural and healthy scientific debate will doubtless continue on the exact role of human activity, especially regarding the large but practically unmeasured role of human-made atmospheric aerosols and the feedback loop of water vapor rising from the warming oceans. Major volcanic eruptions could temporarily reduce the global warming trend, as may have occurred following the Novarupta eruption on the Alaska Peninsula on

June 6, 1912, and as was recorded following the Mount Pinatubo eruption in 1991 from the ash blown into the atmosphere. Regardless of periodic volcanic events and the need for refinements of existing models, the evidence for anthropogenic warming is overwhelming. We need to accept the fact that, in the coming years, we face a dangerously warming world accompanied by rising sea levels and the damaging weather extremes that are already occurring. The evidence indicates that the globe is now warming at a rate sufficient to greatly alter the quantity and quality of fresh and marine waters and thus the lives of plants, animals and humans in the current century and beyond. In the chapters that follow we concentrate on the changes that have occurred and are likely to occur to our vital surface inland waters, both fresh and saline, as warming proceeds. We recognized that these changes vary considerably in different locations and have therefore selected authors from around the globe who are experienced with a wide range of different ecosystems. Where possible, recommendations for reducing the anticipated negative impacts of global warming on aquatic ecosystems are included.

The authors of the following chapters are limnologists, hydrologists, modelers and environmental engineers. We explore, through the contributions of these talented scientists from many countries, the impacts that climate change and the associated warming effect have had and are likely to have on lakes, rivers, wetlands, and their watersheds. The chapters, with input from 80 authors, are organized from northern latitudes to the more southern regions since the most extreme conditions of climatic change have already been well documented in the Arctic. In contrast the least impact of climate change for inland waters appears to be in the southern hemisphere where the temperature of New Zealand lakes has not measurably changed. Here the ratio of surrounding ocean to land mass is particularly great. Together with the many lake studies included in this book, three major river systems and their watersheds are included. We have, through selection of the contributors, been able to explore the subject in Siberia and other far northern region bordering the Arctic Ocean, Europe, Asia, Africa, the Middle East, and North and South America, New Zealand and Antarctica. Following the first 20 chapters on lakes and rivers are two unique chapters, 21 and 22, on the impact of global warming on society with the final three chapters dealing with possible mitigation of negative impacts. Chapter 25 presents a new technology that may prove helpful where oxygen depletion in lakes occurs as eutrophication is stimulated by increasing water temperatures.

Chapters 1 and 2 of the book deal with the physical-chemical and biological impacts of climate change on Arctic rivers and lakes. The aquatic resources of this region are vitally important to the indigenous people of the north who have depended on them for millennia and who now face the impacts of extremely rapid climatic change. The rivers of the far north have a profound influence on the Polar Sea, which receives them, since their volumetric contribution is relatively great when compared with the rivers discharging into the much larger world oceans. Chapter 2 is a comprehensive coverage of existent and future changes in the enormous number of large and small fresh water bodies to be found in the permafrost areas of the high arctic. Here conditions have already brought about extensive changes. Chapter 3 covers Lake Baikal, the oldest deepest lake in the world located in Russian Siberia. Its enormous volume of 24 000 cubic kilometers of largely unpolluted water is equivalent to all the water in the United States Great Lakes and may well turn out be Russia's most valuable natural resource. In this lake the annual period and extent of ice cover and thickness is already being

reduced with a variety of impacts on local conditions including the use of the lake's ice cover for north and south automotive and truck transport. Chapters 4 and 5 cover two major Chinese rivers, the Yellow and Yangtze, as well as their enormous watersheds. With the huge and growing population in the region dependent upon the water from these two great rivers it is not surprising that the Chinese government is attempting to predict their future water yield on the basis of existing studies. These efforts have underscored the necessity of collecting accurate longer term data to improve prediction on floods and droughts. This monitoring data is urgently needed for improving global water-resource management. This theme reappears in a number of chapters at a time when institutions and governments have been reducing funding for important research-driven data collection so essential for improving the predictive capacity of models used to plan for the future.

Chapters 6 through Chapter 9 all involve conditions in Lake Biwa, the largest lake in Japan, which provides domestic water for over 14 million people and has undergone considerable eutrophication from nutrient input from its large urban and agricultural watershed. Chapter 6 deals with the human impacts on Lake Biwa and the additional stress of warming. Chapter 7 examines the changes in the plankton population as eutrophication has proceeded. Anoxic dead zones now occur in the near bottom waters as the biological oxygen demand of decaying plant and animal material exceeds the replenishment of oxygen from photosynthesis and seasonal mixing. Chapter 8 provides a numerical simulation of deep Japanese lakes and their future mixing as warming increases their water column stability and their resistance to complete mixing. Chapter 9 is a modeling paper with the potential to predict future lake conditions.

Chapters 10 and 11 take the reader to the Scandinavian lakes of Denmark, with Chapter 11 extending the coverage to a wide range of other lake types from different climate zones of the world. All of these studies underscore the increasing importance of eutrophication control. In the shallow phosphorus-rich Danish lakes, the warming effect has promoted dominance of the cyanobacteria, while in the deeper stratified lakes the dinoflagellates are dominant. These important changes in plankton dynamics should serve to revitalize the ongoing struggle by lake managers to slow or reverse the progress of eutrophication which, for years, has degraded the water quality of so many of the world's lakes. Chapter 12 concerns the mid-latitude lakes of Europe with the emphasis on the warming of Lake Geneva, where Professor Forel first gave birth to and named the field of limnology. Warming in this region has tended to promote more radical weather conditions as the atmospheric boundary layer has warmed. The author reports on the importance of ice breakup in Lake Constance as further evidence of progressive lake warming.

Moving to Canada, in Chapter 13 the author examines the wetlands of the prairie pot hole region. Warming is progressing there with definite increases in violent weather conditions and the threat that some of these small wetlands may dry up if rainfall is significantly reduced in the area. Chapter 14 takes the reader to the western United States and the half-century of data collected on the intensively studied Lake Tahoe located between California and Nevada, near the crest of the Sierra Nevada. In the earliest stages of eutrophication Tahoe's entire water volume has warmed a degree in 30 years with warming of the surface water occurring at an astonishing ten times as fast as the whole lake. Although still one of the world's clearest large lakes, it is likely to be subjected to more frequent floods, increased water shed erosion, sediment