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Drought impacts on the water quality of freshwater systems; review and integration

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ABSTRACT

Droughts are increasing in frequency and severity in many regions of the world due to climate change. The meteorological drivers of drought often cause subsequent hydrological effects such as reduced catchment runoff, river flows and lake levels. Hydrological droughts may also result in significant changes in water quality. This review provides a synthesis of past observational research on the effects of drought on the water quality of freshwater systems (rivers, streams, lakes, reservoirs). Over the last 10–20 years there has been an increasing amount of studies on the water quality effects of drought, mostly in North America, Europe, and Australia. In general droughts, and the immediate recovery period, were found to have profound water quality effects. These effects were varied, depending on the characteristics of the water body and its catchment. Key drivers of water quality change were identified and integrated across different systems using quantitative analysis where possible. Water flow and volume decreases during drought typically led to increased salinity due to reduced dilution and concentration of mass. Temperature increases and enhanced stratification occurred during drought in some systems due to air temperature increases and longer hydraulic residence times. This also enhanced algal production, promoted toxic cyanobacterial blooms, and lowered dissolved oxygen concentrations. Nutrient, turbidity and algal levels also often increased in lake systems due to reduced flushing and enhanced productivity, and resuspension in some shallow lakes. In contrast, nutrients and turbidity often decreased during droughts in rivers and streams with no significant loading from point and agricultural non-point sources. This was due to disruption of catchment inputs and increased influence of internal processes (e.g. biological uptake of nutrients, denitrification, settling). Where point sources of pollution were present, water quality generally showed deterioration due to less dilution, particularly for nutrients. Storage and buildup of material and changed geochemistry (e.g. sulfide oxidation) in catchments during drought resulted in mobilisation of large post-drought flood loadings of constituents such as major ions, nutrients and carbon. In some cases this caused severe downstream water quality effects such as deoxygenation. Key areas for further research are process-level understanding of the key drivers of water quality change in catchments and receiving water bodies during drought, development of predictive models, and studying the resilience of systems to the predicted increase in frequency of drought and floods. The maintenance of long term water quality monitoring programmes is also critical.

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1. Introduction

Droughts are increasing in frequency and severity in many regions of the world due to increased rainfall variability and heat additions with anthropogenic climate change (Dai, 2013; Trenberth et al., 2014). The predicted future changes in climate will not be uniform and regional variations in precipitation (Trenberth et al., 2014) may result in more extreme drought–flooding hydrological patterns. Natural climatic variability also has a large influence, with severe droughts occurring globally during the El Niño phase of the El Niño/Southern Oscillation (ENSO). During droughts, the climate water deficit propagates through the hydrological cycle and can subsequently reduce groundwater levels, streamflows, and lake levels. This is often termed a hydrological drought to denote that these effects can be separated spatially and temporally from the climatic drivers of drought (Tallaksen and van Lanen, 2004).

Over the next 30–50 years most of the world's major rivers are predicted to show large increases in frequency of hydrological drought conditions relative to the historic records over the last century (Hirabayashi et al., 2008). Many lake and reservoir systems are likely to be similarly affected. Increased water extraction for consumptive purposes also increases the likelihood of hydrological droughts occurring, regardless of changing climatic factors. There is also medium confidence that anthropogenic influences are also contributing to an intensification of extreme precipitation at the global scale (IPCC, 2012), with many rivers predicted to increase their flood frequency this century (Hirabayashi et al., 2008). A transition to more extreme drought–flooding hydrological patterns could have profound consequences for freshwater ecosystems (Mulholland et al., 1997), and severe social and economic impacts.

The water quality of freshwater systems is controlled by climatic variability, hydrological, biogeochemical, and anthropogenic influences. These influences operate at various temporal and spatial (e.g. global, river basin, local catchment) scales. Droughts are a perturbation in the natural climatic and hydrologic regime which can affect the determinants of water quality in multiple ways. For example, low flows and water levels observed during hydrological droughts increase the residence time and reduce the flushing rate of water bodies. Reduced water flows/levels and elevated temperatures during some droughts may change the rates of processes such as productivity, respiration, and reaeration. Droughts may also change the delivery pattern of water quality constituents, retaining them in catchments during dry conditions, releasing them during wet conditions (Worrall and Burt, 2008). At the local scale, water quality effects of drought and floods can be quite variable and specific depending on the biophysical characteristics of water bodies and their catchments (Caruso, 2002; Sprague, 2005).

There have been several observational studies at local and regional scales on the water quality impacts of drought. Given the predictions of increasing frequency and severity of droughts in freshwater systems, it was considered beneficial to undertake a review and synthesis of the relevant literature on this topic. A previous review by Delpla et al. (2009) assessed the impacts of climate change on surface water quality in relation to drinking water production. Some drought-related studies were included, but wider non-drinking water impacts were not assessed. Similarly, Murdoch et al. (2000) and Whitehead et al. (2009) reviewed the wider potential effects of climate change on surface water quality and ecology. These studies include some coverage of drought impacts on water quality, but a more specific review is warranted given the likelihood of increasing drought risks.

The aim of this paper is to review and synthesise findings on the impacts of drought on the water quality of freshwater systems (rivers, streams, lakes, reservoirs). The intent is that this information will help enable improved recognition, assessment and management of the impacts of drought on water quality.

2. Methods

Three large scientific databases (Scopus, Science Direct, Web of Science) were queried for key words e.g. “drought” and “water quality” in title, abstract, or keywords. The search of Scopus returned 2192 results while Science Direct returned 398 results. Using “drought” as a topic & “water quality” as a title in the Web of Science returned an additional 365 results. The abstracts were scanned online to check relevance. Only observational (field-based) studies conducted in rivers, streams, lakes and reservoirs were assessed with estuary, wetland and groundwater-specific studies excluded. Publications as conference proceedings and reports were also excluded. Additional studies were reviewed that were obtained from reference lists in the selected publications and/or were relevant to understanding the observed water quality changes during drought.