Science of the Total Environment 650 (2019) 2314–2324

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Water-quality trends in U.S. rivers, 2002 to 2012: Relations to levels of concern

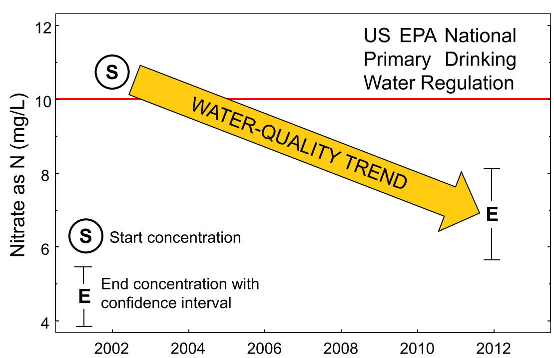
Megan E. Shoda [a,*], Lori A. Sprague [b], Jennifer C. Murphy [c], Melissa L. Riskin [d]

[a] U.S. Geological Survey, Ohio-Kentucky-Indiana Water Science Center, 5957 Lakeside Boulevard, Indianapolis, IN 46278, USA
[b] U.S. Geological Survey, Denver Federal Center, Box 25046, MS 415, Denver, CO 80225, USA
[c] U.S. Geological Survey, Lower Mississippi-Gulf Water Science Center, 640 Grassmere Park, Suite 100, Nashville, TN 30211, USA
[d] U.S. Geological Survey, New Jersey Water Science Center, 3450 Princeton Pike, Suite 110, Lawrenceville, NJ 08648, USA

HIGHLIGHTS

- 1956 trends in nutrients, chloride, sulfate, and TDS assessed at hundreds of sites
- Rare to cross the level of concern threshold, either from above or below
- Most sites and constituents had concentrations below the LOC.
- Most TN and TP trend sites were in exceedance of the USEPA ecoregional criteria.
- At current rates, decreasing TP trends will fall below the LOC in a median of 15 yrs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 August 2018
Received in revised form 27 September 2018
Accepted 29 September 2018
Available online 02 October 2018

Editor: Jay Gan

Keywords:
Surface water
Drinking water
Human health
Aquatic health
Nutrients

ABSTRACT

Effective management and protection of water resources relies upon understanding how water-quality conditions are changing over time. Water-quality trends for ammonia, chloride, nitrate, sulfate, total dissolved solids (TDS), total nitrogen (TN) and total phosphorus (TP) were assessed at 762 sites located in the conterminous United States between 2002 and 2012. Annual mean concentrations at the start and end of the trend period were compared to an environmentally meaningful level of concern (LOC) to categorize patterns in water-quality changes. Trend direction, magnitude, and the proximity of concentrations to LOCs were investigated. Of the 1956 site-constituent combinations investigated, 30% were above the LOC in 2002, and only six (0.3%) crossed the LOC threshold, either from above or below, indicating that waterquality conditions are not substantially improving, nor are they degrading, in relation to the LOCs. The concentrations of ammonia, nitrate, sulfate, chloride, and TDS tended to be below the LOC, and in cases where the trend was increasing (concentrations approached the LOC from below), the increases were varied and small in magnitude. In contrast, concentrations of TN and TP tended to be above the LOC, and where the trend was decreasing (concentrations approached the LOC from above), the decreases were larger in magnitude and more consistent. These results indicate that if water-quality conditions continue to trend in the same direction, at the same rate, for all sites and constituents studied, elevated concentrations are more likely to drop below an LOC before low concentrations will exceed an LOC.

* Corresponding author.
E-mail addresses: meshoda@usgs.gov (M.E. Shoda), lsprague@usgs.gov (L.A. Sprague), jmurphy@usgs.gov (J.C. Murphy), mriskin@usgs.gov (M.L. Riskin).

https://doi.org/10.1016/j.scitotenv.2018.09.377

1. Introduction

Water-quality conditions in rivers and streams are frequently changing. The tracking of changing conditions can be performed through trend analysis, in which a trend, or change, in a water-quality constituent concentration can be identified. The analysis of water-quality trends is important for water resource managers, stakeholders, and regulators to assess the impact of natural and anthropogenic factors on water quality over an extended time period. Previous analyses of water-quality trends focused on the direction of a trend (Oelsner et al., 2017; Ryberg et al., 2014), the cause of a trend (Ryberg, 2017; Ryberg et al., 2017; Diamantini et al., 2018), or the effect of a trend in a specific constituent (Corsi et al., 2015; Sprague et al., 2011; Stets et al., 2017). The importance of water-quality constituent trend analysis has been demonstrated in the assessment of threats to drinking water sources (Stets et al., 2017), and the efficacy of conservation practices (Miltner, 2015).

One way to investigate the influence of a water-quality trend is to assess the statistical significance of the trend. While trend analysis is able to assign this statistical significance, a consideration of how a trend might be environmentally significant is not typically addressed (Chang, 2008; Oelsner et al., 2017; Ryberg et al., 2014). One approach to assess the environmental significance of changing water-quality conditions has been to compile the occurrence of drinking water violations and assess if those violations have significantly increased or decreased (Pennino et al., 2017). Another approach used the change in a surrogate, bottled water sales, to assess consumer behavioral changes associated with water-quality violations, and therefore link water-quality changes to perceived human health threats (Zivin et al., 2011). These approaches provided more context to understand water-quality conditions but did not provide insight into where water-quality conditions approached a level of concern (LOC), or how substantially conditions were improving relative to an LOC, because in the first example, the trend was determined based on the violations, and in the second example, the studied response was a change in a surrogate. Neither one of these approaches analyzed the trend in the actual constituent of concern.

In this analysis, trends were calculated for seven constituents that, present in excess, can represent a threat to human health and quality of life, or aquatic life. Elevated concentrations of nitrate in drinking water, for example, can cause methemoglobinemia, or “blue baby” disease (Ward et al., 2005). At concentrations above the LOC, ammonia, chloride, sulfate, and total dissolved solids (TDS) can give drinking water an unpleasant taste (U.S. Environmental Protection Agency, n.d.a). Additionally, elevated chloride concentrations in source water can promote the galvanic corrosion of lead-bearing minerals (Ng and Lin, 2016; Willison and Boyer, 2012), and high concentrations of TDS in drinking water can result in colored water that can form scale deposits and stain surfaces (U.S. Environmental Protection Agency, n.d.a). Lastly, high concentrations of total nitrogen (TN) and total phosphorus (TP) can cause eutrophication, or the enrichment of water with excessive nutrients, a leading cause of impairment of freshwaters globally (Chislock et al., 2013).

The purpose of this paper is to provide a broad understanding of water-quality trends by contextualizing previously calculated trends in these seven constituents through comparison to human health and aquatic life levels of concern (LOCs). Trends in the selected constituents were analyzed at sites throughout the U.S. between 2002 and 2012. Concentrations at the start and the end of the trend period were compared with LOCs to determine the environmental significance of in-stream concentration trends in relation to human or ecological health. The overall environmental significance of water-quality changes over time was derived by determining whether concentrations cross or approach an LOC between the start and end of the trend period. In this manner, it was possible to evaluate whether meaningful improvement had been achieved, and in-stream concentrations have decreased to fall below an LOC threshold, or whether a deterioration in water-quality conditions had occurred and in-stream concentrations have increased and exceeded an LOC. In addition to investigating sites that crossed the LOC thresholds, this analysis identified increasing and decreasing trends and explained how close and how quickly these trends bring the constituent concentrations to an LOC. Sites and constituents that crossed the LOC threshold or approached the LOC during the trend period are highlighted as categories of interest throughout this paper. This paper provides a context to understand water-quality trends in relation to an environmentally meaningful concentration and therefore provides insight into constituents, sites, and trend patterns that warrant further investigation, or continued monitoring.

2. Methods

2.1. Trend analysis methods

Ammonia, chloride, nitrate (as nitrogen), sulfate, TDS, TN, and TP concentration data were compiled from multiple Federal, State, Tribal, regional, and local government agencies and nongovernmental organizations. Data were largely housed in the U.S. Geological Survey (USGS) National Water Information System (NWIS) database, the USEPA Water Quality Exchange STOrage and RETrieval (STORET) database, and other archives for monitoring data that are not included in STORET (Oelsner et al., 2017). Ambient monitoring data were used at sites that were screened and determined to be suitable for trends analysis, for years between 2002 and 2012. The screening process was developed to establish adequate coverage over the full trend period, during each season, and across a range of streamflow. Sites that passed the screening met the following criteria: (1) data were available in either 2002 or 2003 and in either 2011 or 2012; (2) the first two years and last two years and 70% of years overall in the trend period had at least quarterly samples; (3) at least 14% of the samples in the trend period were high-flow samples, defined as samples collected above the 85th percentile of all historical daily streamflows in the month of a given sample's collection; (4) >50% of the data were not reported as below the laboratory reporting limit; (5) the monitoring site was paired with a co-located or nearby streamgage with daily streamflow data available during the entire trend period. A site was only paired with a streamgage when the difference in respective watershed areas was <10% and there were no hydrologic influences between the sites. Oelsner et al. (2017) describes the data compilation and harmonization, streamgage pairing, and rationale for each screening criterion in detail.

The Weighted Regressions on Time, Discharge, and Seasons (WRTDS) model (Hirsch et al., 2010) was used to evaluate trends in concentration for the seven constituents between 2002 and 2012. WRTDS uses a process called flow normalization to estimate trends in overall water quality by removing the variability due to year-to-year fluctuations in streamflow. The original implementation of WRTDS assumed streamflow was stationary at a site over the trend period (Hirsch et al., 2010; Hirsch and De Cicco, 2015); however, recently, WRTDS has been extended to account for nonstationary streamflow (Hirsch and De Cicco, 2018). The trends used in this paper were estimated using the updated version of WRTDS, which accounts for nonstationarity in streamflow and provides the in-stream trend in water quality (Murphy et al., 2018).

Diagnostic plots for each model were examined for normality and homoscedasticity of the residuals and a reasonable relation between observed and estimated values. 762 sites met the screening criteria for model performance and were used in this analysis. These final sites included data from 47 different monitoring organizations. The number of sites for which a trend was estimated varied for each constituent due to the use of multiple sources of data and the screening of those data (Table 1; Oelsner et al., 2017). More detail on model specification and checking is available in Oelsner et al. (2017).

The updated WRTDS methodology generated an estimated annual mean concentration for the first year of the trend period, a trend