State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

Oklahoma Comprehensive Water Plan
Supplemental Report

Oklahoma Statewide Water Quality Trends Analysis

April 2011

This study was funded through an agreement with the Oklahoma Water Resources Board under its authority to update the Oklahoma Comprehensive Water Plan, the state's long-range water planning strategy. Results from this and other studies have been incorporated where appropriate in the OCWP's technical and policy considerations. The general goal of the 2012 OCWP Update is to ensure reliable water supplies for all Oklahomans through integrated and coordinated water resources planning and to provide information so that water providers, policy-makers, and water users can make informed decisions concerning the use and management of Oklahoma's water resources.

Oklahoma Statewide Water Quality Trends Analysis

Introduction

Freshwater is a vital environmental resource required by both humans and wildlife and provides many ecological services (Costanza et al., 1997) vital to all of us. As such, the management and protection of this resource is of utmost importance. For Oklahoma, the management and protection of our water resources focuses on its lakes, rivers, streams, and groundwater. Oklahoma overlays 23 major groundwater basins having a combined storage of 320 million acre-feet of water. Oklahoma is also home to more than 78,578 miles of streams and rivers and 11,611 miles of lake shoreline. In addition, there are over 1,120 square miles of surface area in Oklahoma's lakes and ponds. Oklahoma's water resources stretch across the entire state and its 11 ecoregions and is characterized by a wide variety of water quantity, quality, and naturally occurring conditions. For example, the specific conductivity of the Elm Fork of the North Fork of the Red River averages 80,000 µS (micro siemens) .This makes the Elm Fork much more salty than sea water which has an average specific conductivity of approximately 50,000 µS). In contrast, the average conductivity of Broken Bow Lake is approximately 35 µS. Such diversity always poses unique challenges in the development of water quality management and monitoring strategies.

Oklahoma works to protect and manage its water resources through the Oklahoma Water Quality Standards (OWQS). The OWQS are the cornerstone of the state's water quality management programs. The OWQS assign beneficial uses to waters and promulgates criteria to protect those uses and various water quality agencies implement the OWQS through an assortment of regulatory programs. Although numerous agencies have some responsibility for water quality standards implementation, the most comprehensive programs are housed in the Oklahoma Water Resources Board (OWRB), the Oklahoma Conservation Commission (OCC), and the Oklahoma Department of Environmental Quality (ODEQ). The OCC implements and oversees Oklahoma's non-point source activities. Among other regionally based monitoring efforts, OCC uses the Rotating Basin Monitoring Program (RBMP) to quantify non-point source pollution impacts and to measure the success of best management practices (BMP's) in mitigating or controlling adverse impacts.

Conversely, the ODEQ is responsible for regulating point source activities (waste water discharged from a pipe) through Oklahoma's National Pollutant Discharge Elimination Program (NPDES) and developing total maximum daily loads for impaired waterbodies. Additionally, several federal agencies conduct water quality monitoring across the state, including the United States Army Corp of Engineers (USACE) and the United States Geological Survey (USGS).

The Beneficial Use Monitoring Program (BUMP) was created by the Oklahoma State Legislature and placed under the direction of the OWRB in 1998. The program is designed to comprehensively monitor the water quality of Oklahoma’s lakes, rivers, and large streams. Specifically, the BUMP was designed to meet the following goals:

1) document beneficial use impairments;
2) identify impairment sources (if possible);
3) provide needed information for the WQS;
4) facilitate the prioritization of pollution control activities; and
5) detect water quality trends.

Over the last decade, the BUMP has matured to meet most of these goals. The OWRB publishes the Beneficial Use Monitoring Report to provide an analysis on all monitored waterbodies. The BUMP also provides data and data analyses to assist in creating Oklahoma’s Integrated Report of Water Quality, which includes the federally required 303 (d) list of impaired waterbodies and 305 (b) report of the condition of Oklahoma’s waters. Additionally, staff expertise and data are regularly utilized by a large number of entities, including other state and federal agencies, environmental consulting firms, universities and the general public. Specifically, they are used to facilitate important environmental management goals, including the development and revision of the OWQS and implementation protocols, creation and validation of total maximum daily loads (TMDL’s), and other pollution control activities.

While the BUMP has developed to effectively meet most of the program’s goals, a large enough data set was not available until recently to document statewide environmental trends for all surface waters. Historically, trends in water quality have been documented in a limited capacity, addressing only certain waterbodies or a particular waterbody type. The only statewide trend analysis was on flowing waters and utilized water quality data collected as part of the Oklahoma State Department of Health’s Ambient Trend Monitoring Network (Wright, 1994). A number of trend studies have also been completed on specific water bodies or basins. In 2004, the OWRB completed the Lake Wister Water Quality Trend Report as part of intensive study of the Lake Wister watershed (OWRB, 2004 Draft). As part of an ongoing effort to protect one of Oklahoma’s most valuable resources, several studies have been completed in the Illinois River watershed. The United States Geological Survey used data collected from 1970-2007 to quantify trends at a number of sites throughout the watershed (USGS, 2009a). Analyses were conducted for total nitrogen and phosphorus. Furthermore, as part of its annual water quality report to the Arkansas-Oklahoma Arkansas River Compact Commission, the OWRB has analyzed trends in total phosphorus on the Illinois River, Flint Creek, and the Barren Fork River (OWRB, 2010). Trends are reported annually for both historical and recent datasets, as well as baseflow and high flow data. As with the past monitoring programs, these analyses addressed specific areas of interest and were not meant to be a compendium of all available data or data types. Interestingly, this phenomenon is not unique to Oklahoma. Throughout the U.S., multi-parametric trend analyses of multiple waterbody types are not commonly conducted at the state level due to the lack of sufficient data to draw scientifically defensible conclusions. Such large trend reports usually focus on either flowing waters or lakes such as the reports done by the USGS (USGS, 2007, 2009b), or by certain states or regional planning districts.

In 2007, the Oklahoma Water Resources Research Institute (OWRRI) and the OWRB began collaborative work on updating the Oklahoma Comprehensive Water Plan (OCWP). The overarching goal of the OCWP is to provide information to ensure that safe, reliable, and quality water is present for the citizens of Oklahoma for the foreseeable future. Water quality was recognized early on as an important component of the OCWP and it was determined that a comprehensive trend analyses of available surface water data would provide an invaluable planning tool for not only water quality management, but water use planning activities. Understanding trends related to various water quality constituents will directly affect decisions related to the future allocation of surface waters. Cultural eutrophication can create serious taste and odor issues in drinking water supplies, through the formation of treatment byproducts such as trihalomethanes, and may cause serious human health concerns (e.g., toxins from harmful algal blooms). Increased ground and surface water depletion concentrates minerals impairing uses of those waters for agriculture, municipalities, and industry. Furthermore, increased sedimentation of Oklahoma's rivers and reservoirs decreases the amount of water storage and increases water pretreatment costs. These are merely a few examples of how decreased water quality has severe implications for future water use.

It is imperative that the decisions made about Oklahoma's water resources use all available information to accurately characterize and assess the quality and quantity of our waters. With that in mind, the water quality trend study has integrated data from many sources over extended periods of time to best assess the changing conditions of our lakes and streams. Adequate data to document trends on both lakes and streams exists and is available from a variety of sources, including the OWRB, the United States Army Corp of Engineers, the United States Geological Survey, the Oklahoma Conservation Commission, the Oklahoma Department of Environmental Quality, the Cities of Tulsa and Oklahoma City, and a variety of other local, state, federal, and academic sources. The OWRB identified 3 goals for the Water Quality Trend Report.

1) Identify, if any, water quality trends in a subset of Oklahoma's lakes and streams;
2) Make recommendations for future of water quality monitoring and assessment, and initiatives; and
3) Provide technical information in support of the 2012 Update of the Oklahoma Comprehensive Water Plan.

Materials and Methods

__Data Acquisition and Reduction__. Traditionally, the State of Oklahoma has utilized numerous water monitoring programs conducted by individual state and federal agencies. Although efforts are initiated to ensure that duplication of effort does not occur, each environmental agency typically designs and implements programs internally, with only necessary input from other state, municipal, or federal entities. These programs collect and/or analyze information for specific purposes that are statutorily defined, including TMDL's, water quality standards development, lake trophic status determination, non-point and point source pollution controls, or assessment of BMP's, among other activities,. Therefore, the data collected and protocols used are specific to each project's data quality objectives (DQOs) and may be limited to a defined geographic area or waterbody type, as well as a limited parametric coverage. When attempting to analyze statewide water quality trends, use of various data sources is a must and ensures that the most accurate trend analysis is performed.

To effectively determine the best path, two ad-hoc advisory committee were formed, one for lakes and one for streams. Though final decisions about the process were ultimately made by the OWRB, staff believed it highly important to discuss a litany of technical topics with a group of professional peers. Numerous water professionals from various local, state, and federal agencies as well as state universities were invited to participate in a series of conferences calls and planning meetings. The meetings addressed a broad range of topics, including which waterbodies should be examined, what parameters are most important to look at, what data is available and where is it housed, how will data reduction be implemented, what analysis methods should be employed, and how should the results be reported. In the end, various ideas were considered and it was decided to implement a limited data analysis approach for both lakes and streams.

A limited technical approach was necessitated by several factors, including limited time and funding. As discussed previously, a comprehensive, statewide trend analysis of several waterbody types is relatively unique. Regardless of time or money available, each committee reached a general consensus that limiting the extent of analysis was a wise decision, for several logistical and technical reasons. First, gathering and reduction of data into usable sets was agreed to be an enormous task. To be all inclusive, a sequence of data requests would be required, and once data were gathered, a systematic approach to verify that data were comparable would be necessary. Second, because data gaps were likely to be present and not all datasets would be of equal length, several analytical approaches would need to be developed so that end results were comparable between stations. Finally, it was determined that a coordinated method of site selection would allow for good geographical coverage of the state, while limiting the number of waterbodies to a manageable number.

Regardless of waterbody type, data acquisition and reduction followed the same generalized process, including site and parameter selection, blanket data requests, and verification of data comparability. Lakes and flowing waters are discussed with more specificity in the following paragraphs. However, as a rule, all flowing water sites and lakes were required to meet certain criteria for selection, including:

1) Be part of the BUMP;
2) Have at least a continuous, ten year period of record;
3) Have data for certain parametric types (e.g., nutrients); and
4) Have recent data gaps of no greater than 10 years.

Additionally, streams were required to have continuous stage data tied to a discharge rating curve. Sites chosen for analysis are in Table 1. In all, sixty-five (65) lakes and sixty (60) streams were chosen.

Parameters chosen for analysis were limited to widely collected analytes that represent a broad suite of potential water quality problems, including nutrients, minerals, and in-situ variables. A complete list of parameters is included in table 2. In order to have as complete of a dataset as possible, data requests were sent to a variety of agencies including the USGS, USACE, Bureau of Reclamation (USBoR), OCC, ODEQ, the Oklahoma Department of Wildlife Conservation (ODWC), the University of Oklahoma (OU), Oklahoma State University (OSU), the Indian Nations Council of Governments (INCOG), the Association of Central Oklahoma Governments (ACOG), and the municipalities of Oklahoma City and Tulsa. Each agency was asked to send all data associated with any chosen lake/site parameter pair, and to include all pertinent metadata such as sampling location, collection and quality assurance protocols, and status of monitoring. Finally, the provided data were vetted to determine compatibility with OWRB data and joined as contiguous datasets, ready for analysis.

Table 1. Lake and flowing water stations included in trends analysis.

Lake	County	River_Stream	County
Altus-Lugert	Greer	Arkansas River near Bixby	Tulsa
Arbuckle	Murray	Arkansas River near Haskell	Muskogee
Arcadia	Oklahoma	Arkansas River near Ralston	Pawnee
Atoka	Atoka	Barren Fork River near Eldon	Cherokee
Birch	Osage	Beaver River near Beaver	Beaver
Bluestem	Osage	Big Cabin Creek near Big Cabin	Craig
Broken Bow	McCurtain	Bird Creek near Port of Catoosa	Tulsa
Canton	Blaine	Black Bear Creek near Pawnee	Pawnee
Carl Blackwell	Payne	Blue River near Durant	Bryan
Chandler	Lincoln	Canadian River near Bridgeport	Blaine
Chickasha	Caddo	Canadian River near Calvin	Hughes
Claremore	Rogers	Canadian River near Purcell	McClain
Clinton	Washita	Canadian River near Whitefield	Haskell
Copan	Washington	Caney Creek near Barber	Cherokee
Dripping Springs	Okmulgee	Caney River near Ramona	Washington
Ellsworth	Comanche	Chikaskia River near Blackewell	Kay
Eucha	Delaware	Cimarron River near Buffalo	Woods
Eufaula	Haskell	Cimarron River near Dover	Kingfisher
Fairfax	Osage	Cimarron River near Guthrie	Logan
Fort Cobb	Caddo	Cimarron River near Mocane	Beaver
Fort Gibson	Cherokee	Cimarron River near Ripley	Payne
Foss	Custer	Deep Fork River near Beggs	Okmulgee
Fuqua	Stephens	East Cache Creek near Walters	Cotton
Grand Lake	Mayes	Flint Creek near Kansas	Delaware

Lake	County	River_Stream	County
Guthrie	Logan	Fourche-Maline Creek near Red Oak	Latimer
Hefner	Oklahoma	Glover River near Glover	McCurtain
Heyburn	Creek	Illinois River near Tahlequah	Cherokee
Holdenville	Hughes	Illinois River near Watts	Adair
Hugo	Choctaw	Kiamichi River near Antlers	Pushmataha
Hulah	Osage	Kiamichi River near Big Cedar	LeFlore
Kaw	Osage	Lee Creek near Short	Sequoyah
Kerr, Robert S.	Sequoyah	Little River near Sasakwa	Seminole
Keystone	Tulsa	Mountain Fork River near Eagletown	McCurtain
Langston	Logan	Mountain Fork River near Smithville	McCurtain
Lawtonka	Comanche	Mud Creek near Courtney	Love
McAlester	Pittsburg	Muddy Boggy Creek near Unger	Choctaw
McGee Creek	Atoka	Neosho River near Chouteau	Mayes
McMurtry	Noble	Neosho River near Commerce	Ottawa
Meeker	Lincoln	Neosho River near Langley	Mayes
Murray	Love	North Canadian River near El Reno	Canadian
Okemah	Okfuskee	North Canadian River near Seiling	Major
Okmulgee	Okmulgee	North Canadian River near Shawnee	Pottawatomie
Oologah	Rogers	North Canadian River near Wetumka	Hughes
Overholser	Oklahoma	North Canadian River near Woodward	Woodward
Pauls Valley	Garvin	North FOrk of the Red River near Carter	Beckham
Pawnee	Pawnee	North Fork of the Red River near Headrick	Tillman
Perry	Noble	Poteau River near Heavener	LeFlore
Pine Creek	McCurtain	Red River near Hugo	Choctaw
Rocky (Hobart)	Washita	Red River near Terral	Jefferson
Sardis	Pushmataha	Sager Creek near West Siloam Springs	Delaware
Shawnee Twin No. 1	Pottawatomie	Salt Fork of the Arkansas River near Ingersol	Alfalfa
Shawnee Twin No. 2	Pottawatomie	Salt Fork of the Arkansas River near Tonkawa	Kay
Skiatook	Osage	Salt Fork of the Red River near Elmer	Jackson
Spavinaw	Mayes	Spring River near Quapaw	Ottawa
Spiro, New	LeFlore	Verdigris River near Keetonville	Rogers
Stanley Draper	Cleveland	Verdigris River near Lenepah	Nowata
Stroud	Creek	Washita River near Anadarko	Caddo
Tenkiller	Sequoyah	Washita River near Durwood	Carter
Texoma	Bryan	Washita River near McClure	Custer
Thunderbird	Cleveland	Washita River near Pauls Valley	Garvin
Tom Steed	Kiowa		
Walters (Dave Boyer)	Cotton		
Waurika	Jefferson		
Wewoka	Seminole		
Wister	LeFlore		

Table 2. Parameters included in trends analysis. (L = Lake, FW = Flowing Water)

Parameter	Waterbody Type	Parameter	Waterbody Type
Total Phosphorus	Lakes and Flowing Waters	Secchi Depth	Lakes
Total Nitrogen	Lakes and Flowing Waters	Chlorophyll-a	Lakes
Turbidity	Lakes and Flowing Waters	Chloride	Flowing Waters
Water Temperature	Lakes and Flowing Waters	Sulfate	Flowing Waters
Conductivity	Lakes and Flowing Waters	Dissolved Oxygen	Flowing Waters
pH	Lakes and Flowing Waters		

For lakes, the bulk of the data utilized for this project was collected by the OWRB. However, additional data were provided by other sources. The city of Tulsa provided long-term annual datasets for Lakes Eucha and Spavinaw, which are two of their water supply lakes, and OU provided a long-term dataset for Lake Texoma. Additionally, the USACE sent data for many of their reservoirs, including Arcadia, Birch, Broken Bow, Canton, Copan, Eufaula, Ft. Gibson, Heyburn, Hugo, Hulah, Kaw, Keystone, Texoma, Oologah, Pine Creek, Robert S. Kerr, Skiatook, Tenkiller, and Wister. To ensure data compatibility, location information from outside data sources was compared to BUMP collection sites. Outside data were not used if the location was outside the normal reservoir pool or in a stilling basin, outside the general vicinity of a comparable OWRB site, or unsubstantiated GPS coordinates were provided. The data collection methods were also reviewed to determine if they were analogous to the BUMP collection methodology. For analysis, each lake was subdivided into several datasets, including whole lake, waterbody segments (if differentiated in the OWQS), and site.

For streams, data sets were divided into historical and recent datasets, and analyzed separately and as a whole. The majority of historical data were provided by the USGS and ODEQ, while nearly all recent data were collected by the OWRB. The recent data set is typically represented by data collected since the inception of BUMP, and normally is from 1999-2009. For some sites, recent data were available from the USGS and were included in the analysis. Although some historical datasets go through 1996-1998, data collections typically ended in 1991-1993, which for most sites is the end year for historical data. The beginning point of the historical dataset is more inconsistent. Depending upon the parameter in question, data collections began as recently as the mid-1970's for nutrients and as early as the 1940's for some *in situ* parameters, like pH and conductivity. Once data were grouped, some reduction was performed. Total nitrogen was calculated as a combination of Kjeldahl nitrogen, nitrate, and nitrite. If only one or two of the analytes were present, data were excluded from the analysis. Also, on rare occasions, data were collected by separate parties on the same day and were averaged to create a single data point. Additionally, from the mid-1970s through the late 1980s, the ODEQ dataset included what appeared to be duplicate data from the USGS data collection program. Data sets were compared and where identical data occurred for the same parameter on the same day, the ODEQ datum was excluded. Finally, as an artifact of quality control procedures, multiple daily data values were provided by the

USGS for some *in situ* parameters. In these instances, the final collected data point was used for analysis.

Data Analysis. All data analyses were performed using either Minitab or WQStats statistical software. For both lakes and streams, non-parametric Mann-Kendall and Seasonal Kendall tests were used to determine trend, with a flow-weighted optional analysis also utilized for streams. Additionally, for streams, a parametric multiple linear regression was performed using flow, time, and seasonality as explanatory variables in the model. For each test, magnitude of trend was considered at an 80, 90, and 95 percent confidence level. Ultimately, all test results were considered in determining the final trend and magnitude of trend for each parameter at each site. A weight of evidence was used that considered the unique results of each trend analysis. For example, if seasonality was a significant term in the regression model, the Seasonal Kendall was given more weight in assigning the final trend.

In all, over 200,000 data points were considered in the lakes analysis and over 15,000 individual tests were performed. For streams, over 350,000 data points were used in performing greater than 24,000 tests. All test results are available upon request.

Results and Recommendations

Because of the enormity of dataset and subsequent analyses, individual lake and flowing water site results are not presented in this summary document but can be found on the OWRB website or provided upon request. Statewide results are presented for both lakes and streams in the following graphs (Figures 1-11). Graphics for each waterbody type are subdivided into parameter categories. Streams data are further subdivided into three periods of record— all data, historical data, and recent data. For each parameter, simple bar graphs show the number of waterbodies, statewide, that either indicate an increasing trend, decreasing trend or no trend. The abbreviation “ND” represents sites that had “no data” for a particular parameter.

Diagnostically, the direction of a trend may have different meanings for different parameters. For the most part, an increasing trend is typically indicative of water quality degradation. This is true for total nitrogen, turbidity, chlorophyll-a, water temperature, conductivity, chloride, and sulfate. However, a decreasing trend in Secchi depth and dissolved oxygen may also be indicative of water quality degradation. Trends in pH are much more site specific and follow no general rule. However, an upward or downward trend in pH would generally infer a more alkaline or acidic condition, respectively. Each direction could also demonstrate a move towards a more neutral condition. It should be noted that bar color should not be used to infer an either good or poor condition, but is done for display consistency. Although some inferences may be made from the statewide dataset, the trends for individual lakes and streams/rivers are much more indicative of a gain or loss in condition, especially when interpreted with the slope of a significant trend. These interpretative results will be provided for each station on the BUMP website.

This first iteration of a statewide trend analysis has successfully laid the groundwork for ongoing analysis. Future reports should include other waterbodies, such as smaller streams, and some examination of biological trends. In order to accommodate other information, some rules from this report will need to be relaxed, including period of record, continuous discharge records, and frequency of data collection. A two or three-tiered study would allow for their inclusion, with different levels of certainty and confidence applied at each tier. A more inclusive, but qualified, report should allow for a more complete review of state water quality trends, while still defining the limitations of datasets and subsequent results.

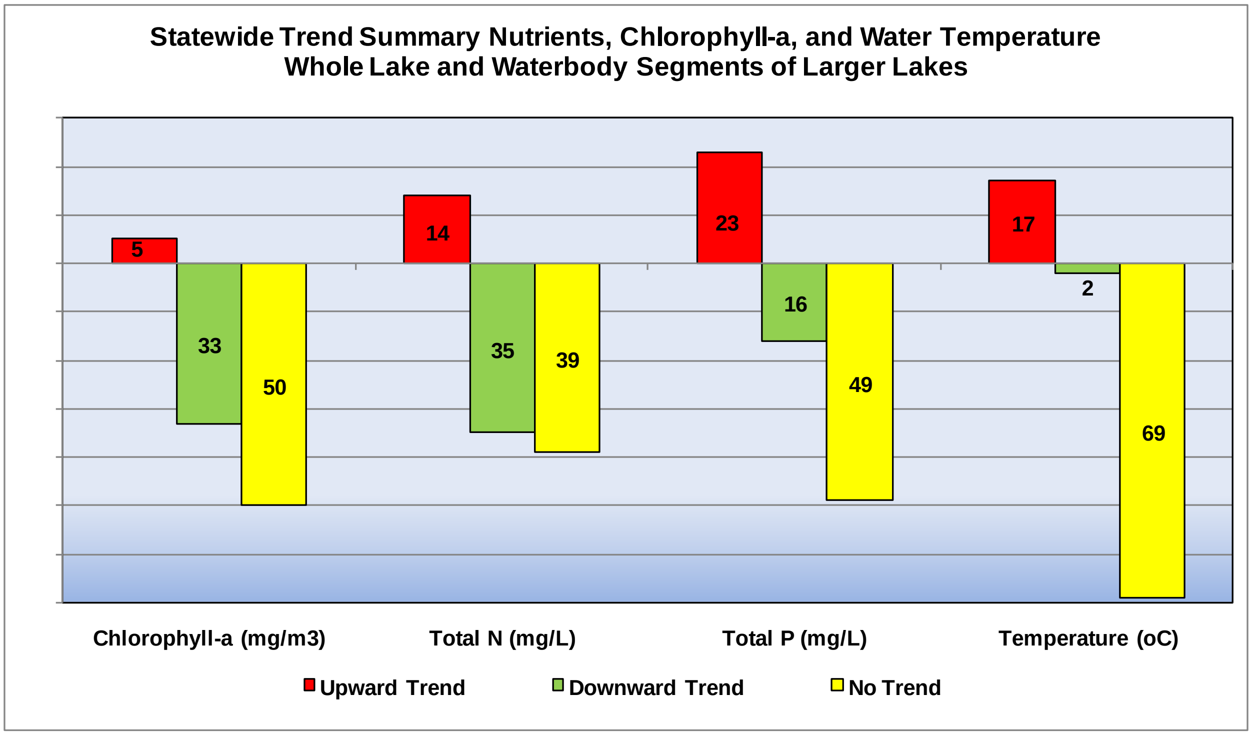

Figure 1. Statewide trend summary for whole lake and waterbody segments of larger lakes represented for total phosphorus and nitrogen, chlorophyll-a, and water temperature.

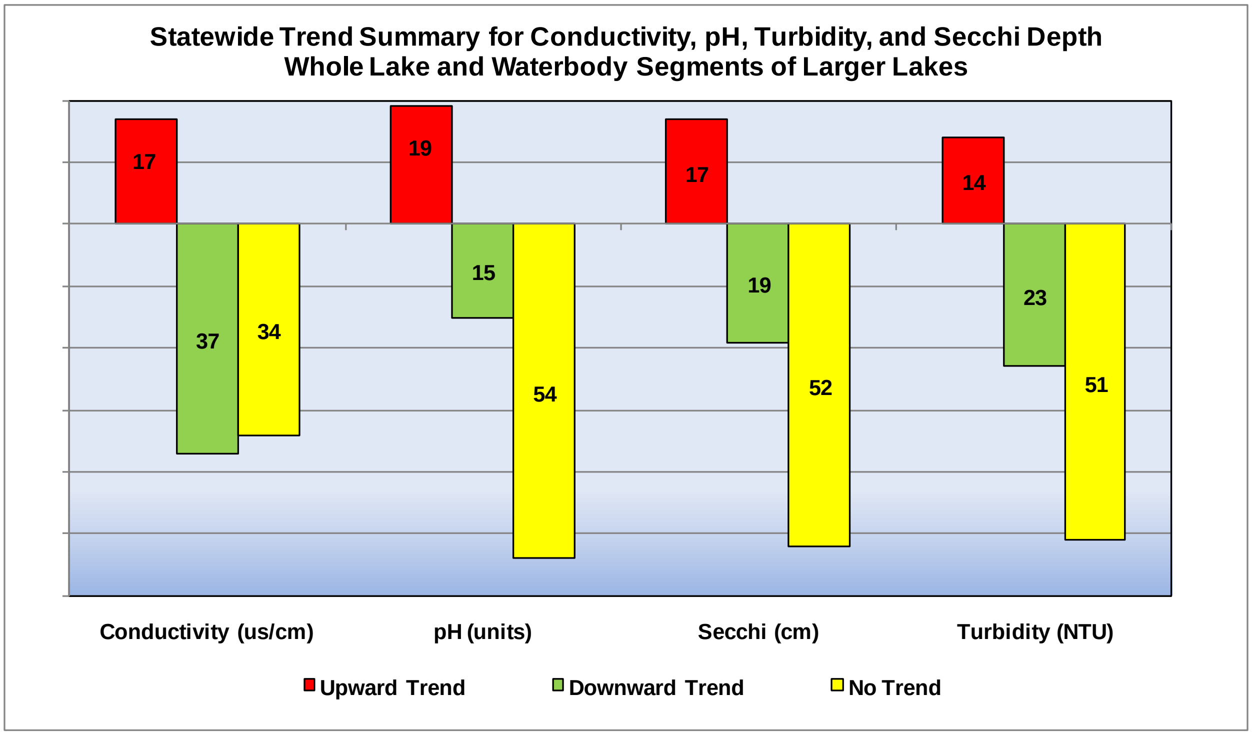

Figure 2. Statewide trend summary for whole lake and waterbody segments of larger lakes represented for conductivity, pH, Secchi depth, and turbidity.

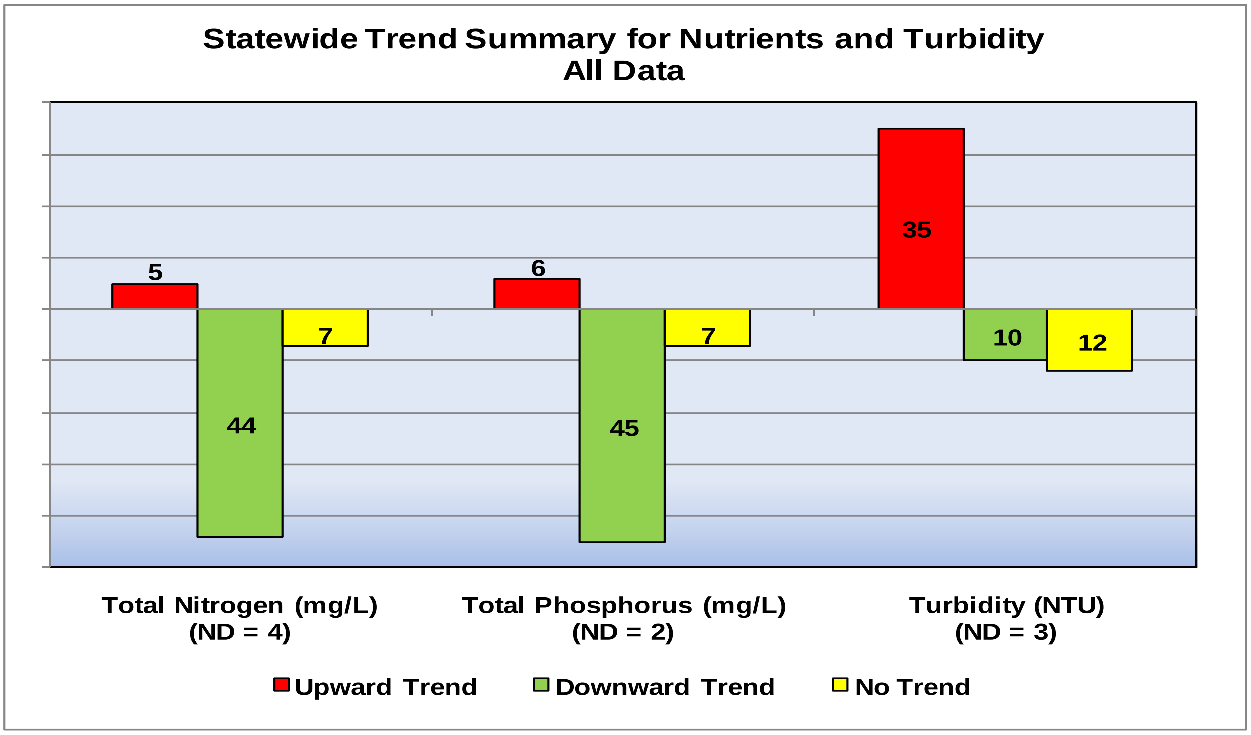

Figure 3. Statewide trend summary of all data for flowing waters represented for total phosphorus and nitrogen, and turbidity.

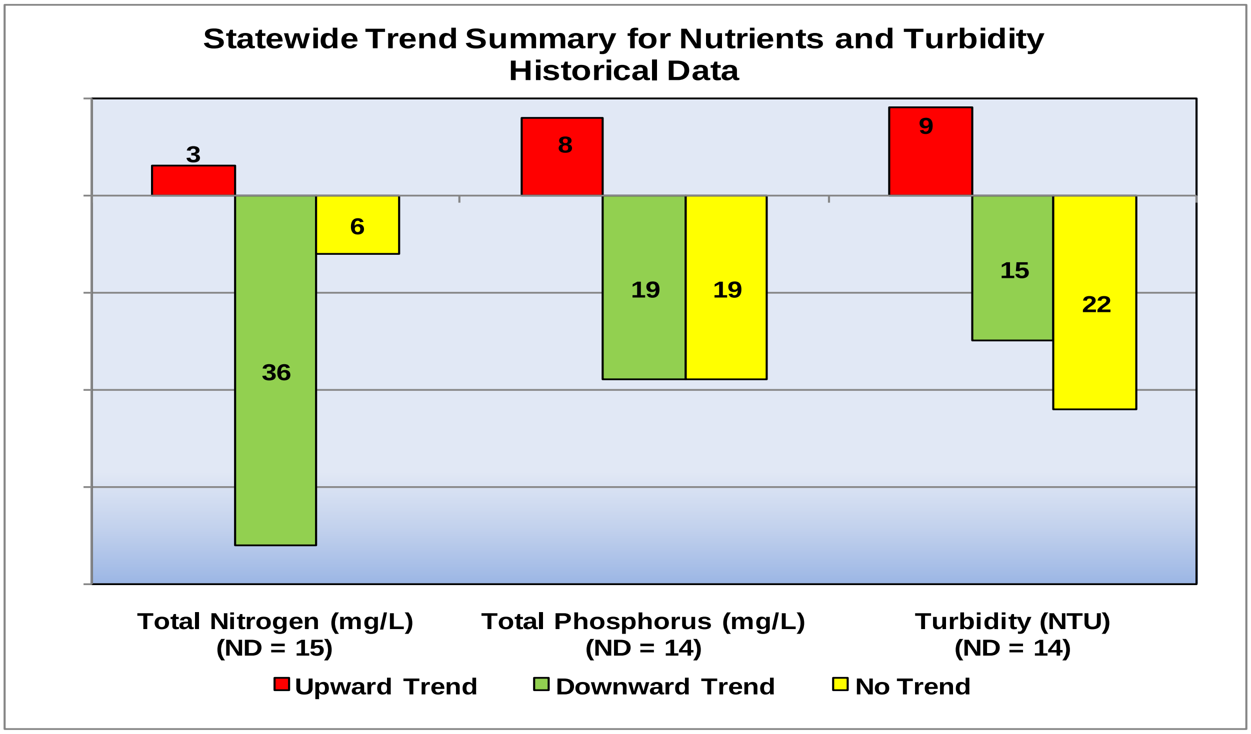

Figure 4. Statewide trend summary of historical data for flowing waters represented for total phosphorus and nitrogen, and turbidity.

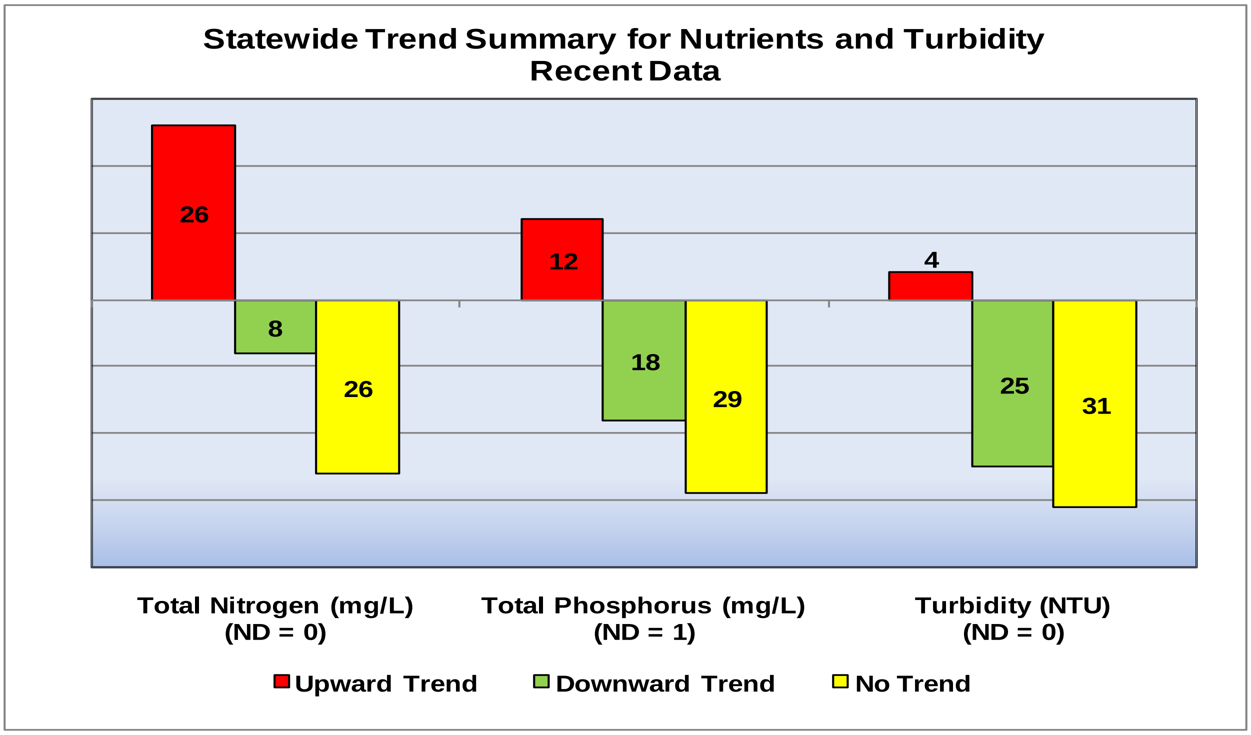

Figure 5. Statewide trend summary of recent data for flowing waters represented for total phosphorus and nitrogen, and turbidity.

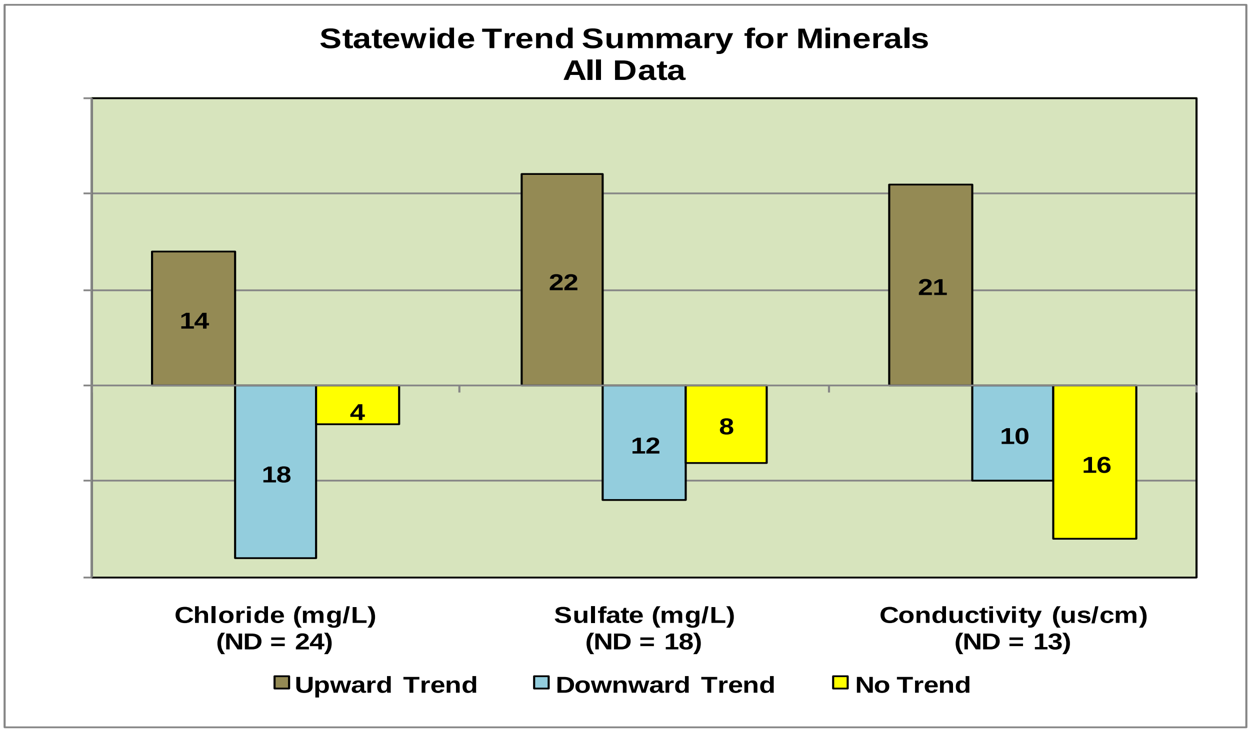

Figure 6. Statewide trend summary of all data for flowing waters represented for chloride, sulfate, and conductivity.

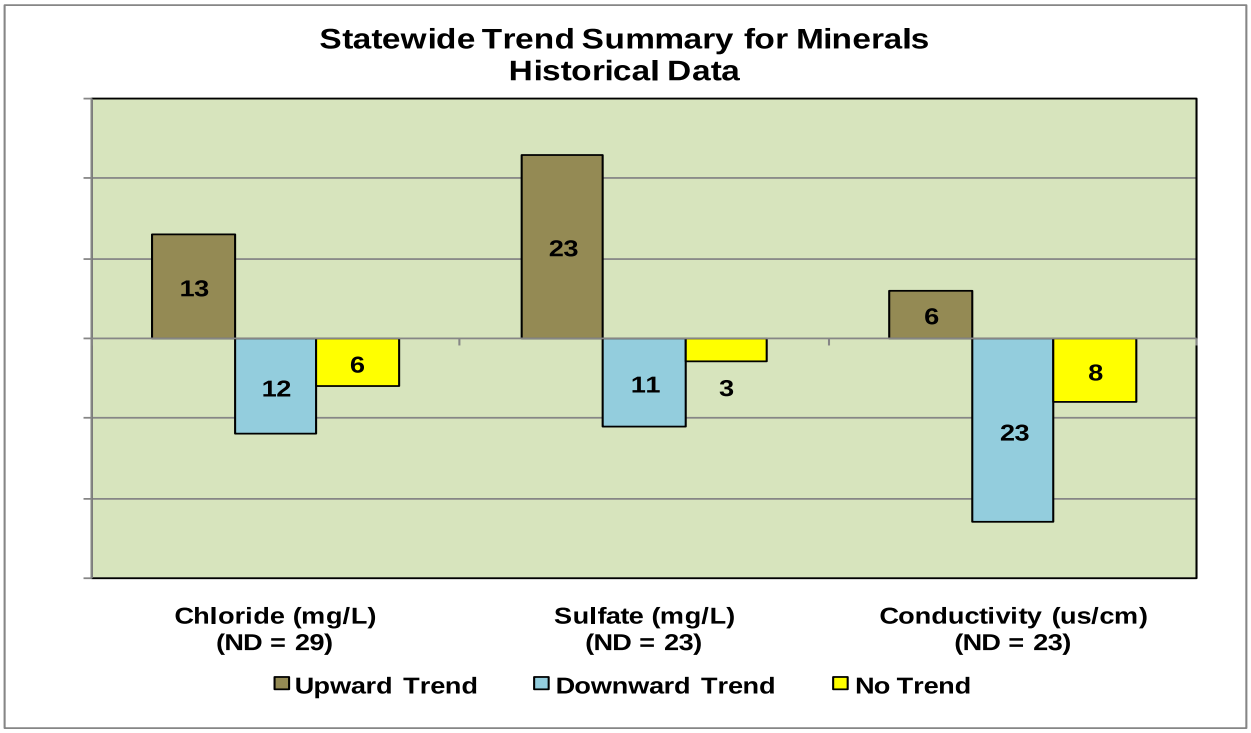

Figure 7. Statewide trend summary of historical data for flowing waters represented for chloride, sulfate, and conductivity.

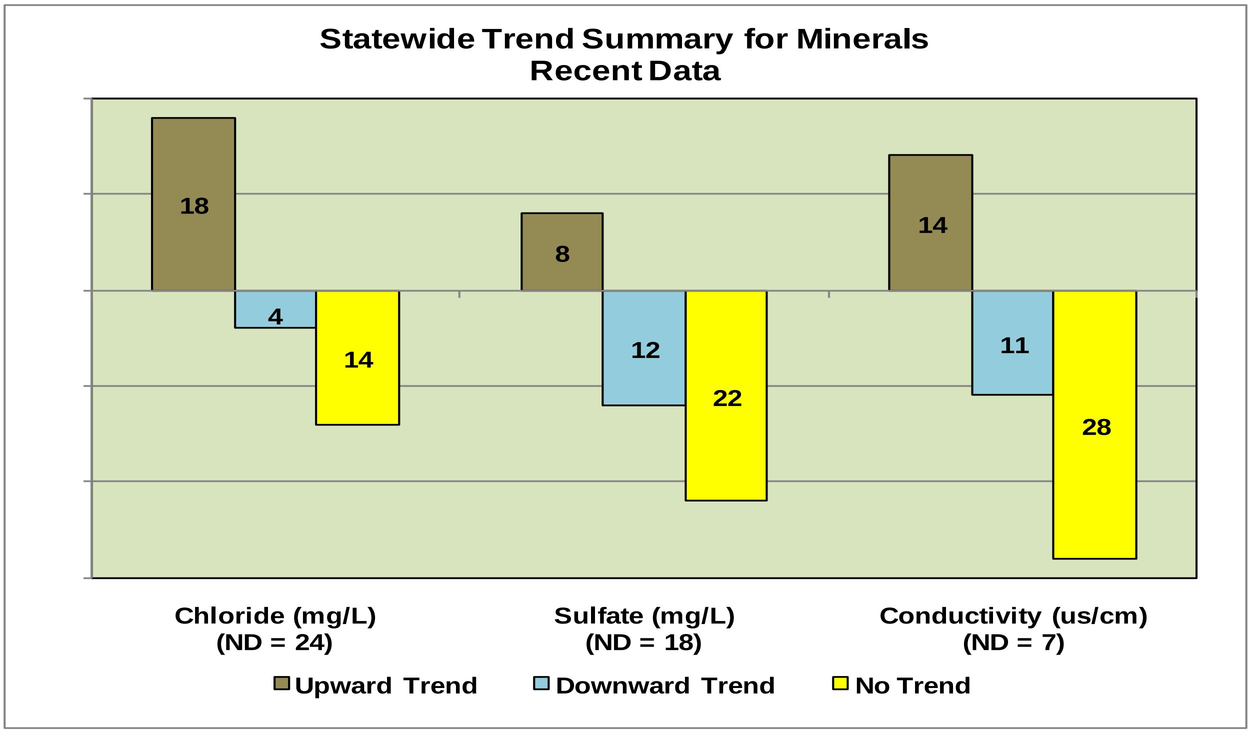

Figure 8. Statewide trend summary of recent data for flowing waters represented for chloride, sulfate, and conductivity.

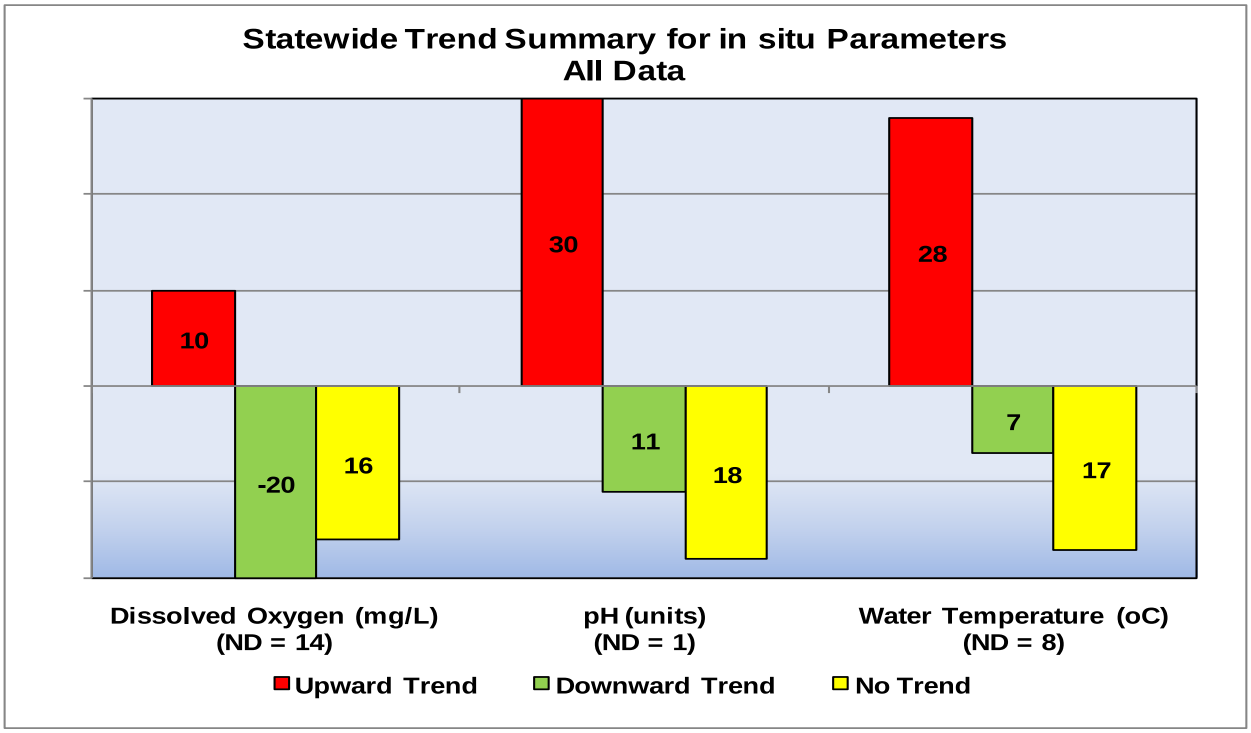

Figure 9. Statewide trend summary of all data for flowing waters represented for dissolved oxygen, pH, and water temperature.

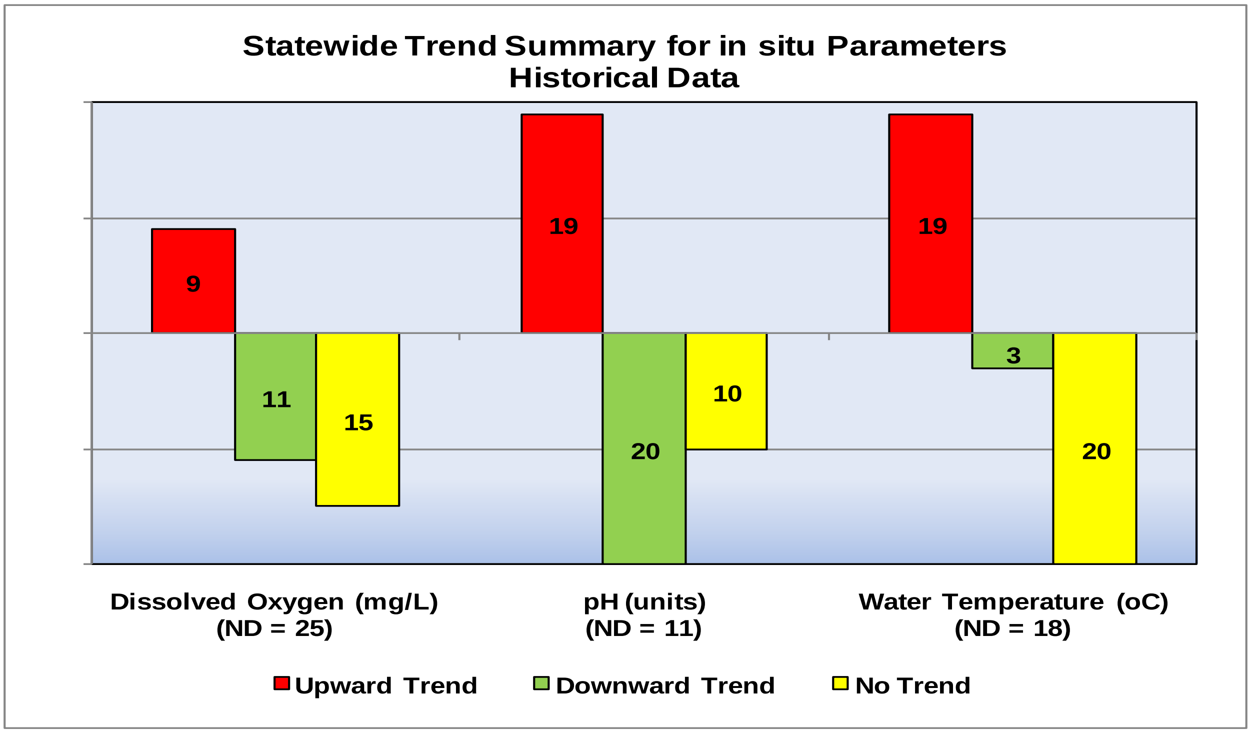

Figure 10. Statewide trend summary of historical data for flowing waters represented for dissolved oxygen, pH, and water temperature.

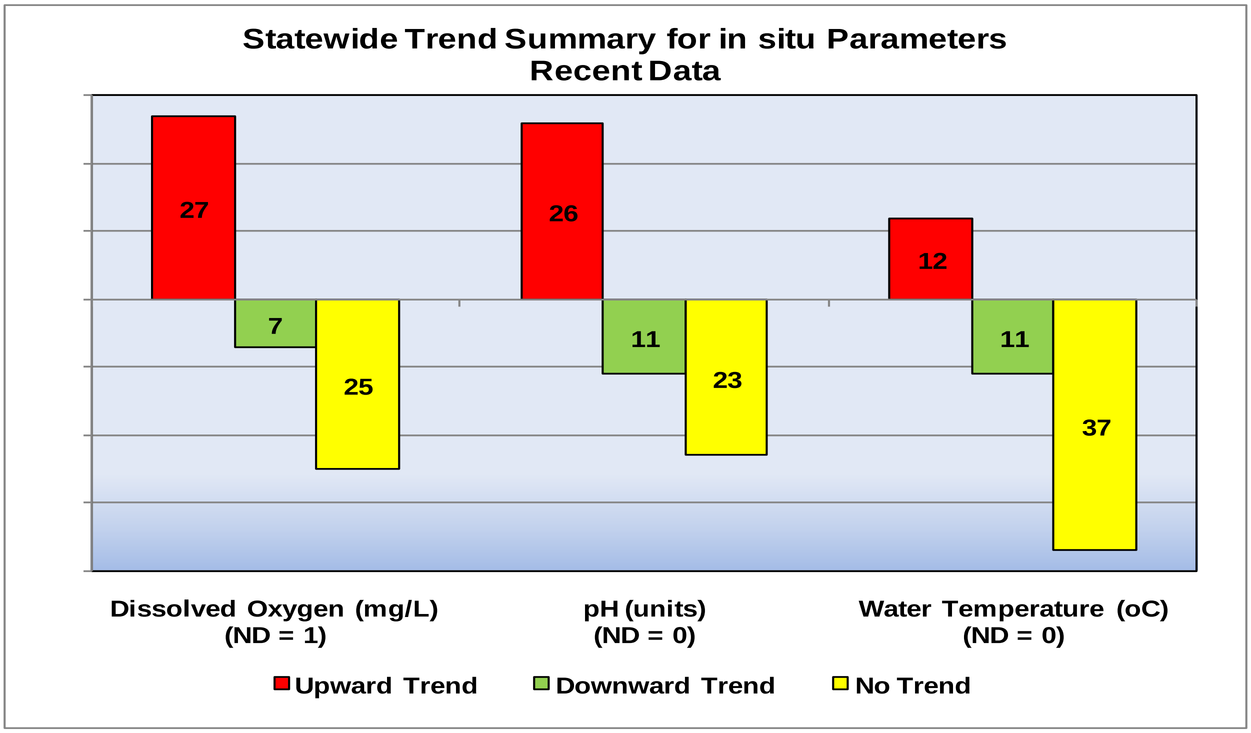

Figure 11. Statewide trend summary of recent data for flowing waters represented for dissolved oxygen, pH, and water temperature.