2015 Oklahoma Streams Report

Beneficial Use Monitoring Program

OWRB
the water agency

EXECUTIVE SUMMARY

It is the intent of this Oklahoma Water Resources Board (OWRB) report to advance concepts and principles of the Oklahoma Comprehensive Water Plan (OCWP). Consistent with a primary OCWP initiative, this and other OWRB technical studies provide invaluable data crucial to the ongoing management of Oklahoma's water supplies as well as the future use and protection of the state's water resources. Oklahoma's decision-makers rely upon this information to address specific water supply, quality, infrastructure, and related concerns. Maintained by the OWRB and updated every 10 years, the OCWP serves as Oklahoma's official long-term water planning strategy. Recognizing the essential connection between sound science and effective public policy, incorporated in the Water Plan are a broad range of water resource development and protection strategies substantiated by hard data – such as that contained in this report – and supported by Oklahoma citizens.

Beneficial Use Monitoring Program Goal

The goal of the Beneficial Use Monitoring Program is to document beneficial use impairments, identify impairment sources (if possible), detect water quality trends, provide needed information for the OWQS and facilitate the prioritization of pollution control activities.

The Beneficial Use Monitoring Program exists as a result of the vital economic and social importance of Oklahoma's lakes, streams, wetlands, and aquifers and the associated need for their protection and management. The data contained in this report is scientifically defensible and has been collected and analyzed following procedures outlined in Use Support Assessment Protocols (USAP), developed by Oklahoma's environmental agencies. Specifically, USAPs establish a consistent method to determine if beneficial uses assigned for individual waters through Oklahoma Water Quality Standards (OWQS) are being supported. (Legitimacy of data analyzed following protocols other than those outlined in the USAP must be defended.) If the BUMP report indicates that a designated beneficial use is impaired, threatened, or otherwise compromised, measures must be taken to mitigate or restore the water quality.

Traditionally, the State of Oklahoma has utilized numerous water monitoring programs conducted by individual state and federal agencies. In general, each environmental agency designs and implements its own program with only limited participation from with other state, municipal, or federal entities. These programs collect information for a specific purpose or project (e.g., development of Total Maximum Daily Loads, OWQS process, lake trophic status determination, water quality impact assessments from nonpoint and point source pollution, stream flow measurement, assessment of best management practices, etc.). Therefore, the information is specific to each project's data quality objectives (DQOs) and is often limited to a very small geographic area.

To synchronize Oklahoma's monitoring efforts related to water quality, the State Legislature appropriated funds in 1998 to create the Beneficial Use Monitoring Program under the direction of the Oklahoma Water Resources Board, who maintains Oklahoma's Water Quality Standards. The BUMP brings the OWRB's overall water quality management program full circle. From the promulgation of OWQS, to permitting and enforcement of permits stemming from OWQS-established criteria, to non-point source controls—all agency water quality management

activities are intended to work in concert to restore, protect, and maintain designated beneficial uses.

The specific objectives of the BUMP are to detect and quantify water quality trends, document and quantify impairments of assigned beneficial uses, and identify pollution problems before they become a pollution crisis. This report interprets current Oklahoma lake and stream data collected as part of the comprehensive, long-term program. As the program matures, the BUMP report is sure to become one of the most important documents published annually in Oklahoma.

Beneficial Use Monitoring Program Components

- **Monitoring Rivers & Streams** - The OWRB is currently monitoring approximately eighty-four (84) stations on a 6-week rotation. Fixed station monitoring is based largely upon the eighty-four (84) planning basins as outlined in the Oklahoma Comprehensive Water Plan (OCWP). In general, at least one (1) sample station was located at the terminal end of each of the planning basins. The OWRB also conducts on-going special studies as well as 25-30 probabilistic monitoring stations annually.

- **Fixed Station Load Monitoring** – The OWRB is currently working with several partners including the USGS, US Army Corp of Engineers, Grand River Dam Authority, and National Weather Service to conduct flow monitoring on all of our fixed station sites that are not part of the Oklahoma/USGS Cooperative Gaging Network. This cooperative effort will allow for loadings to be calculated, trends to be assessed statewide, and provide much needed data for the Use Support Assessment process.

- **Fixed Station Lakes Monitoring** - As part of the Beneficial Use Monitoring Program, the Oklahoma Water Resources Board (OWRB) conducts sampling on lakes and reservoirs across the State of Oklahoma. To accomplish this task, the OWRB has taken a probabilistic survey approach for the lakes monitoring program. This survey design allows the state's objectives to be met as well as ensure various sized waterbodies are represented adequately. The survey population includes all lakes above 50 surface acres, which encompasses approximately 206 different waterbodies. The population is then stratified into two groups – lakes greater than 500 surface acres and those below 500 surface acres. The greater than 500 surface acres group includes 68 lakes, of which approximately one-fifth are monitored annually (quarterly samples) on a randomized draw. They are then monitored again during a subsequent year in the 5-year rotation, so that each lake greater than 50 surface acres is sampled 2 non-consecutive years during each 5 year rotation. The lakes managed by our Federal partners, the USACE and Bureau of Reclamation (BoR) are included in the 68 large lakes. Additionally, ten randomly drawn lakes of less than 500 surface acres are sampled annually (quarterly samples) over the 5 year sample frame. Many of these smaller lakes have not been sampled historically through the BUMP program and include small municipal water supplies.

  The OWRB works with other agencies, such as the US Army Corps of Engineers (USACE), for inclusion of additional information on waterbodies managed by the Corps. Data collected consists primarily of water chemistry, nutrients, and chlorophyll-a information. In general, a minimum of three to five stations per reservoir is sampled depending on the size of the reservoir. Stations are located such that they represent the lacustrine, transitional, and riverine zones of the lake. On many reservoirs, additional sites are monitored, including

major arms of the reservoir as appropriate. Water quality parameters have been added to the lakes sampling effort over the years to enhance program ability to make use support determinations.

Groundwater Monitoring and Assessment Program (GMAP) – This new program was made possible as result of the increase in funding received from the Oklahoma Legislature for water quality/quantity monitoring based on recommendations of the 2012 Update of the Oklahoma Comprehensive Water Plan. These additional monies were utilized to restore funding levels of the Beneficial Use Monitoring Program as well as to implement the new groundwater program. The new groundwater program prioritizes efforts on Oklahoma's 21 major groundwater aquifers and will continue to be phased in over the next 3 years. This baseline period will focus on 4-6 aquifers per year and will assess concentrations of nutrients, metals and major ion species. Sample size was predicated upon and proportional to the surface area of the aquifer with a general goal of 30 wells per aquifer. Some of the state's larger aquifers exceeded the goal and some of the smaller aquifers were represented by fewer wells Table 1. Sample Networks Based on Aquifer Areal Extent.

Areal Extent Category	Sample Site Well Density	Sample Sizes Generated
> 5000 km^2	1 well per 150 km^2 (6 aquifers)	37 – 89
3001 – 5000 km^2	1 well per 100 km^2 (5 aquifers)	33 – 48
1501 – 3000 km^2	1 well per 75 km^2 (6 aquifers)	25 – 33
751 – 1500 km^2	1 well per 50 km^2 (2 aquifers)	16 – 19
≤ 750 km^2	2 aquifers	6 – 10

When fully implemented, there will be 750 wells in the statewide groundwater quality network statewide. In addition, the OWRB's annual groundwater level measurement program will be doubled in capacity from around 530 to 1100 wells and will be spatially redistributed. Also over the 5-year baseline period, the OWRB plans to install 30-50 continuous water level recorders to obtain daily or hourly measurements that are more sensitive to detecting seasonal changes (brought on by drought or variable climate conditions) than can be obtained by annual measurements.

- **Intensive Investigations** - If beneficial use impairment is identified or suspected, then all appropriate state agencies will be alerted and an investigation will be initiated to confirm if beneficial use impairment is occurring. If routine monitoring cannot definitively identify impairments, then an intensive study will be undertaken and if impairment is present, the source of the impairment will be identified if possible. One potential use for the intensive studies envisioned was identified during the data analysis phase of this reporting process. For example, monies could be spent to identify if high turbidity readings in rivers and streams are due to natural processes or do to human activities in the watershed of concern. Some potential causes of beneficial use impairment are; improper beneficial use or criteria (Oklahoma Water Resources Board jurisdiction), point source problems (Oklahoma Department of Environmental Quality or Oklahoma Department of Agriculture), non-point source problems (Oklahoma Conservation Commission, Oklahoma Department of Agriculture, Oklahoma Corporation Commission, or Oklahoma Department of Environmental Quality), oil and gas contamination (Oklahoma Corporation Commission), agricultural activities (Oklahoma Department of Agriculture), or mining activities (Oklahoma Department of Mines). All monitoring activities will be cooperative in nature with the agency with statutory authority assuming the lead role for intensive monitoring. If water bodies are not identified for intensive study as part of this task, then monies will be reallocated for routine monitoring of beneficial use attainment. Other entities (i.e. tribal or governmental units

outside of Oklahoma) will be involved as appropriate. All intensive-monitoring activities will be consistent with the OWQS and the USAP. If no protocols exist, then best professional judgment or State/Environmental Protection Agency guidance is used as appropriate.

Program History/Overview

Sampling of the numerous lakes, streams, and rivers across this state was initiated in the summer and fall of 1998. Lake sampling in connection with the Beneficial Use Monitoring Program began in July of 1998. Sampling on numerous streams and rivers began in earnest in November of the same year. The two sampling programs, one for lakes and one for streams had separate starting dates for a number of reasons. First, the OWRB has been conducting a lake-sampling program during the warmer summer months since 1990 as part of the Federal Clean Lakes Program. This historical lake sampling program was funded through federal dollars with the express purpose of determining lake trophic status. The trophic status of a reservoir can range from oligotrophic (low biological productivity) to hyper-eutrophic (excessive biological productivity). In general, the more productive a reservoir, the more water quality problems it is likely to experience. Federal dollars to fund this trophic state assessment of our state's lakes were discontinued in 1994. At that time, the OWRB searched for other funding sources, and through working with the Secretary of the Environment and the Oklahoma Conservation Commission, the Water Board was able to obtain a onetime federal 319 nonpoint source grant to continue the lake trophic state assessment program. The OWRB subsequently initiated a quarterly lake sampling program in the spring of 1998 and was able to roll the existing lake program into the BUMP.

For streams, no such comprehensive, statewide sampling effort was ongoing at the time the BUMP was funded. Because of this, the OWRB required a number of months to re-allocate staff and implement a monitoring regime on streams. In addition, OWRB staff greatly desired input from the other environmental agencies on the placement of stream monitoring stations. The existence of a previous statewide stream-monitoring network greatly aided in sample site selection. This historical ambient trend stream-monitoring network existed from 1975 until 1993 and was implemented by the Oklahoma State Health Department. Although this program did not evaluate sample results through comparison with the OWQS criteria or determine use support, it did provide a framework upon which to build. The historical sampling network sampled streams on a monthly basis from 1975-1986 and on a semi-annual basis from 1987-1993. Based upon the historical program and input from other agencies, the OWRB has established an ambient monitoring network of 100 active permanent stations with numerous rotational sites. Both the permanent and rotational networks are evaluated annually to determine if any stations should be dropped and others added. The Water Resources Board relies heavily on the other state and federal agencies for input into this process. In addition, monitoring personnel with the OWRB work closely with the other state environmental agencies to avoid duplication of sampling effort (i.e. the Oklahoma Conservation Commission rotating and data gaps sampling initiatives), except on a very limited basis for quality assurance purposes. A very small number of sites that are duplicative in nature do allow for the comparison of results between sampling programs to ensure that sampling protocols and the Use Support Assessment Protocols (USAP - described below) are working effectively and that decisions on support status are being made in a consistent manner.

The OWRB has developed Use Support Assessment Protocols (USAP) for lakes and streams, which are essential if the state is to be consistent in identifying waters that are not meeting their assigned beneficial uses or are threatened. The Water Resources Board has incorporated the

USAP into Oklahoma Administrative Code (OAC) 785:46 to ensure that consistent determinations for impairments are made by all of the monitoring agencies.

The state must follow consistent procedures for listing waters as impaired. Using the OWRB Use Support Assessment Protocols, it was possible for OWRB staff to assess whether threats or impairments are present in our waterways. With continued funding, identification of impaired waters will be accomplished on additional waters.

Results of Sampling Efforts

It is essential that Oklahoma quantify impacts in a comprehensive and scientific manner and look for trends in water quality to identify waters that are not meeting their assigned beneficial uses. As a state, we must manage our water resources effectively and direct money to areas in most need of protection or remediation to ensure that we continue to have good quality and sufficient quantity of water to meet our needs well into the 21st century. Comprehensive statewide data sets on rivers, streams and lakes for accurately assessing beneficial use impairments have not existed since 1993. With the implementation of monitoring on a large scale in October of 1998, this is no longer the case. With the availability of data, it is the desire of the Oklahoma Water Resources Board to provide the legislature and professional water managers with a comprehensive and up-to-date document for their review and approval. Administrative and Technical staff at the OWRB look forward to conducting the Beneficial Use Monitoring Program far into the future and providing the state of Oklahoma with the information it needs to make informed decisions that allow us to effectively manage our precious water resources.

Every two years, the OWRB analyzes data collected by BUMP and that data are used to identify if the waters of the state are meeting their assigned beneficial uses. If the stream/river segment is not meeting its beneficial use it is submitted for inclusion on the EPA's 303d list. The latest EPA approved 303d list of impaired waters can be found on the Oklahoma Department of Environmental Quality's website. Oklahoma's 303d list

INTRODUCTION

It is the intent of this Oklahoma Water Resources Board (OWRB) report to advance concepts and principles of the Oklahoma Comprehensive Water Plan (OCWP). Consistent with a primary OCWP initiative, this and other OWRB technical studies provide invaluable data crucial to the ongoing management of Oklahoma's water supplies as well as the future use and protection of the state's water resources. Oklahoma's decision-makers rely upon this information to address specific water supply, quality, infrastructure, and related concerns. Maintained by the OWRB and updated every 10 years, the OCWP serves as Oklahoma's official long-term water planning strategy. Recognizing the essential connection between sound science and effective public policy, incorporated in the Water Plan are a broad range of water resource development and protection strategies substantiated by hard data – such as that contained in this report – and supported by Oklahoma citizens.

Protecting Oklahoma's valuable water resources is essential to maintaining the quality of life for all Oklahomans. Used for a myriad of purposes—such as irrigation, hydropower, public/private water supply, navigation, and a variety of recreational activities—the state's surface and groundwater provides enormous benefits to Oklahoma from both an economic and recreational standpoint.

The National Recreation Lakes Study Commission (NRLSC) estimates that 32,100 people in Oklahoma are employed in support of activities related to our numerous man-made lakes. Also according to the NRLSC, 18,718,000 visitor days are spent on Oklahoma lakes each year and recreation in and around these lakes contributes approximately $2.2 billion each year to Oklahoma's economy. Of additional value are the recreational benefits associated with our smaller municipal/watershed projects, Oklahoma Department of Wildlife lakes, and rivers and streams throughout the state, which infuse millions into state coffers through fishing, hunting, camping and related activities. (In 1987, the Oklahoma Comprehensive Outdoor Recreation Plan estimated that approximately $10.7 million was realized through camping and $15.2 million through hunting/fishing.[1]) According to a 2001 federal study, fishing activities alone contribute $476,019 dollars to Oklahoma's economy, not including the substantial ancillary costs associated with that extremely popular sport.[2]

In addition to surface waters, abundant groundwater also fuels the state's economy serving as supply for thousands municipalities, rural water districts, industrial facilities, and agricultural operations. According to the 2012 update of the Oklahoma Comprehensive Water Plan (OCWP), groundwater represents the primary water supply for approximately 300 cities and towns and comprises 43 percent of the total water used in the state each year.[3] Groundwater resources also supply approximately 90 percent of the state's irrigation needs, and around 8% of Oklahoma's citizens obtain their drinking water from private wells.

Oklahoma works to protect and manage its water resources through a number of initiatives, with the Oklahoma Water Quality Standards (OWQS) serving as the cornerstone of the state's water quality management programs. The Oklahoma Water Resources Board (OWRB) is designated

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[1] Oklahoma Statewide Comprehensive Outdoor Recreation Plan (SCORP), 1987.
[2] U.S. Department of Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. *2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.*
[3] Oklahoma Water Resources Board, *Update of the Oklahoma Comprehensive Water Plan, 1995*.

by state statute as the agency responsible for promulgating water quality standards and developing or assisting the other environmental agencies with implementation framework. State agencies are responsible for implementing the OWQS as outlined by the OWRB through development of Implementation plans. Protecting our waters is a cooperative effort between many state agencies and because the OWQS are utilized by all agencies and represent a melding of both science and policy, they are an ideal mechanism to assess the effectiveness of our diverse water quality management activities.

The OWQS are housed in OAC 785:45 and consist of three main components: beneficial uses, criteria to protect beneficial uses, and anti-degradation policy. An additional component, which is not directly part of the OWQS but necessary to water resource protection, is a monitoring program. A monitoring program is required in order to ensure that beneficial uses are maintained and protected. If uses are not being maintained, the cause of that impairment must be identified and restoration activities should be implemented to improve water quality such that it can meet its assigned beneficial uses.

All state agencies are currently required to implement Oklahoma's Water Quality Standards within the scope of their jurisdiction through the development of an Implementation Plan specific for their agency. This process, called OWQS Implementation, allows the OWQS to be utilized by other state agencies in the performance of their regulatory (statutory) responsibilities to manage water quality or to facilitate best management practice initiatives.

In the late 1990's, the need for a protocol to determine beneficial use impairment was identified, which would facilitate state agencies in directing their time and money to the areas in most need of protection or remediation. The OWRB, working in close concert with other state environmental agencies and other concerned parties developed Use Support Assessment Protocols (USAP) to be used by all parties for assessing if a water body was meeting its assigned beneficial uses. In addition, protocols were developed which could be coupled with a trend monitoring system to detect threatened waters before they become seriously impaired. Data collection efforts connected with protocol development and/or implementation also serves a vital purpose in refining numerical criteria currently included in the OWQS and in developing appropriate numerical and narrative criteria for future OWQS documents. It is essential that our waters meet assigned uses and that OWQS implementation protocols are appropriate. Please see the OWRB website for the applicable Oklahoma Administrative Code OAC 785:46 related to the USAP. Final approval of the USAP occurred in 2000 and the OWRB has constantly worked to refine the existing protocols and pursue the addition or modification of USAP protocols to further enhance its utility and effectiveness.

Work to be performed towards development and implementation of the critical fourth component of the OWQS program, monitoring, is the subject of this report. All sampling activities described and conducted as part of this program were consistent with the Oklahoma USAP. It is also important to note that they are consistent with Environmental Protection Agency (EPA) reporting requirements for the "*Integrated Water Quality Monitoring and Assessment Report*", §319 Nonpoint Source (NPS) Assessment, and the §314 Lake Water Quality Assessment (LWQA).

Background & Problem Definition

The State of Oklahoma has historically had numerous monitoring programs conducted by several state and federal agencies. In general, each environmental agency conducts their monitoring programs with some degree of integration and coordination with other state,

municipal, or federal programs. Most water quality monitoring programs in Oklahoma are designed and implemented by each agency to collect information for one specific purpose or project (i.e. development of Total Maximum Daily Loads, OWQS process, lake trophic status determination, water quality impacts from point source dischargers, stream flow measurements, document success of best management practices, etc.). Information of this type is very specific to each individual project's data quality objectives (DQOs) and is often limited to a very small geographic area. This document describes sampling activities the OWRB has historically conducted on lakes and efforts that are currently on going on lakes and streams across Oklahoma as part of a comprehensive, long-term, statewide Beneficial Use Monitoring Program (BUMP). The goal of the BUMP is to detect and quantify water quality trends, document and quantify impairments of assigned beneficial uses, and identify pollution problems before they become a pollution crisis.

The state is taking a major step towards coordinating sampling activities with the creation of a "Water Quality Monitoring Council" comprised of representatives from state, local, and federal agencies as well as universities, industries, volunteer groups, Indian tribes, and environmental organizations. This Council as envisioned would serve a useful purpose in providing an avenue for communication between the various groups and will allow the state to coordinate water quality monitoring in a more effective manner. The Council will focus on coordinating agency activities and help the state avoid duplication of effort. Coordination between all concerned parties is obviously essential, but a comprehensive basic monitoring initiative to support the OWQS implementation process must be pursued to identify waters which are not meeting their assigned beneficial uses and thus ensure that Oklahoma's water resources are protected from water quality degradation. The Council will also be pivotal in ensuring consistency between data collection efforts. The Monitoring Council will function in a coordinating capacity, which will maximize monitoring efforts.

Beneficial Use and Monitoring Program Overview

The overall goal of the Beneficial Use Monitoring Program is to document beneficial use impairments, identify impairment sources (if possible), detect water quality trends, provide needed information for the OWQS, and facilitate the prioritization of pollution control activities.

Beneficial Use Monitoring Program Components

- **Monitoring Rivers & Streams** - The OWRB is currently monitoring approximately eighty-four (84) stations on a 6-week rotation. Fixed station monitoring is based largely upon the eighty-four (84) planning basins as outlined in the Oklahoma Comprehensive Water Plan (OCWP). In general, at least one (1) sample station was located at the terminal end of each of the planning basins. The OWRB also conducts on-going special studies as well as 25-30 probabilistic monitoring stations annually.
- **Fixed Station Load Monitoring** - The OWRB is currently working with several partners including the the USGS, US Army Corp of Engineers, Grand River Dam Authority, and National Weather Service to conduct flow monitoring on all of our fixed station sites that are not part of the Oklahoma/USGS Cooperative Gaging Network. This cooperative effort will allow for loadings to be calculated, trends to be assessed statewide, and provide much needed data for the Use Support Assessment process. Along with the USGS cost share program, Oklahoma's 319 program, Oklahoma's 314 program and the 303(d)-process will drive sample site locations associated with this task.

- **Fixed Station Lakes Monitoring** - As part of the Beneficial Use Monitoring Program, the Oklahoma Water Resources Board (OWRB) conducts sampling on lakes and reservoirs across the State of Oklahoma. To accomplish this task, the OWRB has taken a probabilistic survey approach for the lakes monitoring program. This survey design allows the state's objectives to be met as well as ensure various sized water bodies are represented adequately. The survey population includes all lakes above 50 surface acres, which encompasses approximately 206 different water bodies. The population is then stratified into two groups – lakes greater than 500 surface acres and those below 500 surface acres. The greater than 500 surface acres group includes 68 lakes, of which approximately one-fifth are monitored annually (quarterly samples) on a randomized draw. They are then monitored again during a subsequent year in the 5-year rotation, so that each lake greater than 50 surface acres is sampled 2 non-consecutive years during each 5 year rotation. The lakes managed by our Federal partners, the USACE and Bureau of Reclamation (BoR) are included in the 68 large lakes. Additionally, ten randomly drawn lakes of less than 500 surface acres are sampled annually (quarterly samples) over the 5 year sample frame. Many of these smaller lakes have not been sampled historically through the BUMP program and include small municipal water supplies.

  The OWRB works with other agencies, such as the US Army Corps of Engineers (USACE), for inclusion of additional information on water bodies managed by the Corps. Data collected consists primarily of water chemistry, nutrients, and chlorophyll-a information. In general, a minimum of three to five stations per reservoir is sampled depending on the size of the reservoir. Stations are located such that they represent the lacustrine, transitional, and riverine zones of the lake. On many reservoirs, additional sites are monitored, including major arms of the reservoir as appropriate. Water quality parameters have been added to the lakes sampling effort over the years to enhance program ability to make use support determinations.

- **Groundwater Monitoring and Assessment Program (GMAP)** – This new program was made possible as result of a $1,500,000 increase in funding received from the Oklahoma Legislature for water quality/quantity monitoring based on recommendations of the 2012 Update of the Oklahoma Comprehensive Water Plan. These additional monies were utilized to restore funding levels of the Beneficial Use Monitoring Program as well as to implement the new groundwater program. The new groundwater program prioritizes efforts on Oklahoma's 21 major groundwater aquifers and will continue to be phased in over the next 3 years. This baseline period will focus on 4-6 aquifers per year and will assess concentrations of nutrients, metals and major ion species. Water quality data will be collected from networks of wells on the basis of an aquifer's areal extent. This design feature generated sample populations of at least 30 wells for each of Oklahoma's 15 largest aquifers. Smaller aquifers are represented by fewer wells but proportionally have more sites per areal extent (Table 1).

Table 1. Sample Networks Based on Aquifer Areal Extent.

Areal Extent Category	Sample Site Well Density	Sample Sizes Generated
> 5000 km^2	1 well per 150 km^2 (6 Aquifers)	37 – 89
3001 – 5000 km^2	1 well per 100 km^2 (5 aquifers)	33 – 48
1501 – 3000 km^2	1 well per 75 km^2 (6 aquifers)	25 – 33
751 – 1500 km^2	1 well per 50 km^2 (2 aquifers)	16 – 19
≤ 750 km^2	2 aquifers	6 – 10

In the first year of sampling, 203 wells in 6 major aquifers were sampled for water quality and 299 wells for water level. When fully implemented, there will be 750 wells in the statewide groundwater quality network statewide. In addition, the OWRB's annual groundwater level measurement program will be doubled in capacity (from around 530 to 1100 wells) and will be spatially redistributed. Work began on expanding the groundwater level measurement program in January 2014 with the addition of 87 new wells to the program. For one-half of the water level network, manual measurements will become tri-annual events. In January 2014, 110 wells were added to the tri-annual measurement network. Additionally, over the 4-year baseline period, the OWRB plans to install 30-50 continuous water level recorders to obtain daily or hourly measurements that are more sensitive to detecting seasonal changes (brought on by drought or variable climate conditions) than can be obtained by annual measurements. Sixteen continuous water level recorders were installed in 8 aquifers across the state for this purpose in the first year of sampling.

- **Intensive Investigations** - If beneficial use impairment is identified or suspected, then all appropriate state agencies will be alerted and an investigation will be initiated to confirm if beneficial use impairment is occurring. If routine monitoring cannot definitively identify impairments, then an intensive study will be undertaken and if impairment is present, the source of the impairment will be identified, if possible. For example, monies could be spent to identify if high turbidity readings in rivers and streams are due to natural processes or do to human activities in the watershed of concern. Some potential causes of beneficial use impairment are; improper beneficial use or criteria (Oklahoma Water Resources Board jurisdiction), point source problems (Oklahoma Department of Environmental Quality or Oklahoma Department of Agriculture), non-point source problems (Oklahoma Conservation Commission, Oklahoma Department of Agriculture, Oklahoma Corporation Commission, or Oklahoma Department of Environmental Quality), oil and gas contamination (Oklahoma Corporation Commission), agricultural activities (Oklahoma Department of Agriculture), or mining activities (Oklahoma Department of Mines). All monitoring activities will be cooperative in nature with the agency with statutory authority assuming the lead role for intensive monitoring. If water bodies are not identified for intensive study as part of this task, then monies will be reallocated for routine monitoring of beneficial use attainment. Other entities (i.e. tribal or governmental units outside of Oklahoma) will be involved as appropriate. All intensive-monitoring activities will be consistent with the OWQS and the USAP. If no protocols exist, then best professional judgment or State/Environmental Protection Agency guidance is used as appropriate.

STREAM MONITORING PROGRAM

The Stream Beneficial Use Monitoring Program (BUMP) was initiated in November of 1998. BUMP streams staff began collecting monthly data in November of 1998 and throughout the years has changed from monthly sampling to bi-monthly sampling depending on program needs. Beginning in 2013, a six-week sampling cycle was implemented. Each stream station is described individually with information outlining the site location and other pertinent information followed by a brief synopsis of data results. All of the sites are listed at this hyperlink, current permanent monitoring sites.

River and Stream Monitoring HISTORIC Overview

Historically, the collection of data on rivers and streams across the state has been inconsistent. Over the years, various local, tribal, state, and federal agencies managed a number of sampling programs for different purposes. These programs have varied in nature ranging from site-specific, short-term monitoring to broad, statewide sampling, such as the one conducted by the former Oklahoma State Department of Health (OSDH). When OSDH stopped their monthly sampling program in 1989 it created a void in the dataset and the need for a new, comprehensive, statewide ambient trend monitoring program. In addition, Oklahoma lacked a program with the specific capability of documenting statewide beneficial use impairments on a long-term basis. The Beneficial Use Monitoring Program (BUMP) was created to fulfill these goals. By establishing a monitoring network that evaluates general water quality through the use of an existing framework like the Oklahoma Water Quality Standards (OWQS), the state of Oklahoma initiated a progressive phase in the long-term assessment of the overall health of our state's streams and rivers.

Materials & Methods

The Monitoring Network: The BUMP rivers and streams network consists of three major station classifications — permanent ambient trend, rotating, and statistical survey sites. Permanent ambient trend monitoring stations are relatively static within the program. In general, they do not change from year to year and were chosen to allow for long-term assessment of beneficial uses and water quality trends. Since program inception, a small number of sites have been dropped and new sites have been added to more effectively assess the water quality of our major stream basins. Statistical survey stations are selected at random every two years and visited once or twice during biological index periods. Rotating stations are selected for specific purposes and typically have a finite lifespan.

With the creation of the permanent monitoring network, OWRB staff established three overarching objectives for the program.

First, the network must encompass the entire state. To accomplish this, a commitment was made to locate at least one site in each of the 8-digit USGS hydrologic units (HUC; Table 1) (Map).

Table 1. Eight Digit United States Geological Survey HUC Watersheds.

8 Digit HUC Number	Description	8 Digit HUC Number	Description
11040001	Cimarron Headwaters	**11100301**	Middle North Canadian
11040002	Upper Cimarron	**11100302**	Lower North Canadian
11040006	Upper Cimarron – Liberal	**11100303**	Deep Fork
11040007	Crooked	**11110101**	Polecat – Snake
11040008	Upper Cimarron – Bluff	**11110102**	Dirty – Greenleaf
11050001	Lower Cimarron – Eagle Chief	**11110103**	Illinois
11050002	Lower Cimarron – Skeleton	**11110104**	Robert S. Kerr Reservoir
11050003	Lower Cimarron	**11110105**	Poteau
11060001	Kaw Lake	**11120105**	Lower Prairie Dog Town Fk., Red
11060002	Upper Salt Fork – Arkansas	**11120202**	Lower Salt Fork – Red
11060003	Medicine Lodge	**11120302**	Middle North Fork – Red
11060004	Lower Salt Fork – Arkansas	**11120303**	Lower North Fork – Red
11060005	Chickaskia	**11120304**	Elm Fork – Red
11060006	Black Bear – Red Rock	**11130101**	Groesbeck – Sandy
11070103	Middle Verdigris	**11130102**	Blue – China
11070105	Lower Verdigris	**11130201**	Farmers – Mud
11070106	Caney	**11130202**	Cache
11070107	Bird	**11130203**	West Cache
11070205	Middle Neosho	**11130208**	Northern Beaver
11070206	Grand Lake	**11130210**	Lake Texoma
11070207	Spring	**11130301**	Washita Headwaters
11070208	Elk	**11130302**	Upper Washita
11070209	Lower Neosho	**11130303**	Middle Washita
11090103	Rita Blanca	**11130304**	Lower Washita
11090201	Lower Canadian – Deer	**11140101**	Bois D'Arc – Island
11090202	Lower Canadian – Walnut	**11140102**	Blue
11090203	Little	**11140103**	Muddy Boggy
11090204	Lower Canadian	**11140104**	Clear Boggy
11100101	Upper Beaver	**11140105**	Kiamichi
11100102	Middle Beaver	**11140106**	Pecan – Waterhole
11100103	Coldwater	**11140107**	Upper Little
11100104	Palo Duro	**11140108**	Mountain Fork
11100201	Lower Beaver	**11140109**	Lower Little
11100203	Lower Wolf		

Second, the foundation of the monitoring network should focus on the state's largest rivers, the Arkansas River and the Red River, and their major tributaries, such as the Canadian River and the Washita River. Consideration was given to the major tributaries of rivers such as the Canadian River and the Little River. Further consideration was also given to areas of the state (e.g., the Panhandle) that were underrepresented as well as rivers and streams (e.g., the Deep Fork River) that were conspicuously missing from the network.

Third, the advice and input of other state environmental agencies and professionals was sought before making a final determination of permanent monitoring station locations. In particular, the Oklahoma Department of Environmental Quality (ODEQ) and the Oklahoma Conservation Commission (OCC) have been, and continue to be very helpful in assisting with locating permanent stations.

Operating within these overarching objectives, the staff of the OWRB selected and performed monitoring on 130 permanent ambient trend monitoring sites since September of 1998. Beginning in January 2013, the OWRB adjusted the monitoring network to more closely align with the needs of the Oklahoma Comprehensive Water Plan. The goal was to put a permanent station at the outflow of all 82 water planning basins (Map), while maintaining a small network of reference condition sites. Along with the redesigned network, the frequency of sampling was increased from 6 samples per year to 8 samples per year.

The placement of a site location necessitates several considerations. First, a site must be accessible by vehicle and be safe for sampling personnel and other motorists. Second, the site must be located in an area where representative data can be acquired. The OWQS Use Support Assessment Protocols (USAP) sets spatial limitations on the data that is collected. Essentially, a site can only represent twenty-five stream miles for non-wadeable streams and ten stream miles for wadeable streams (with some exceptions). Furthermore, a site can only be representative of the water body identification number (12-digit HUC number) in which it is located and the site cannot be located within a regulatory mixing zone. This requires monitoring sites be selected in a way which represents as long a stream reach as possible while still maintaining the spatial integrity outlined in USAP. Thirdly, it is important that historical data be considered. Many of the BUMP permanent monitoring sites were selected from a set of historical stations which were previously used in the OSDH statewide monitoring program (when OSDH dissolved it became part of the ODEQ Ambient Trend Monitoring Program). Before initial sampling began in 1998, OWRB staff worked closely with the ODEQ to integrate many of the historical sites into BUMP. Although the historical data from these sites cannot be used to assess beneficial uses (USAP sets a temporal limitation of five years), the historical data set benefits the state in assessing long-term water quality trends. Lastly, it is imperative that rivers and streams which have been designated in the OWQS as Outstanding Resource Waters (ORW), High Quality Waters (HQW), or Sensitive Water Supplies (SWS) be given unique consideration even if they do not meet the objectives as outlined. The water quality status of each site is discussed in more detail in the individual site pages.

The goal of the rotating portion of the program is to provide short-term assessments on priority waters as identified by a state agency or other party. Two general objectives were identified to aid in the determination of what would qualify as a rotating site. First, it should be determined that data collection at a particular site should be short-term in nature and not extend past one sampling year, although some stations do remain in the network for up to two years. Data collected within that year should allow water quality managers to make the appropriate decisions regarding the segment being monitored. For instance, if a stream reach is listed as impaired on the 303(d) list due to pH, measuring pH throughout one year should allow the requesting agency or entity to either de-list the segment or determine what other monitoring efforts are necessary. Secondly, the monitoring should fall within the framework of the USAP. Since the inception of the program, the staff of OWRB have met individually with representatives of other state agencies to identify their priority short-term monitoring needs. Once the OWRB receives a list of waters for monitoring from the interested agencies, staff evaluates the nominations and notifies the nominating agency of which waters would be monitored (to date, all of the waters requested for monitoring have been accommodated). In all, over 220 monitoring stations have been or are currently being monitored. In most instances, the segments were listed for one or more variables on the state's 303(d) list. For a comprehensive list of historic and/or current rotational monitoring stations, please contact the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800.

Statistical survey monitoring is a unique study design for which monitoring stations across the state are selected at random. The OWRB has been actively involved in this type of monitoring since 2004. The latest probabilistic data report is titled "Statewide Stream/River Probabilistic Monitoring Network for the State of Oklahoma from 2008-2011" and can be found under "Water Quality Monitoring" on the reports page of the OWRB website at www.owrb.ok.gov/reports.

Stream Monitoring Variables: The variables being monitored were chosen to reflect both objectives of the programs — assessment of beneficial uses within the framework of USAP as well as the assessment of general water quality. Even though a variable may not be listed in the OWQS with a specific criterion (e.g., hardness), the variable is an important constituent in analyzing and understanding the general water quality of a particular segment. See ~~Table~~ 2 for a list of monitoring variables.

Data for general water quality, nutrient, metals, organics, chlorophyll-a, and bacteriological variables are collected in one of two ways. Some variables are monitored in-situ utilizing a YSI or EXO multi-probe instrument. The data are uploaded from the instrument to a data logger, transferred manually to a field log sheet, and downloaded to the OWRB monitoring database. These variables include dissolved oxygen (D.O.), %D.O. saturation, water temperature, pH, salinity, total dissolved solids, and specific conductance. Data for all other variables are gathered from water quality samples collected at the station. When the flow of a channel is approximately 1.5 ft/s or greater, samples are collected using a depth-integrated method. Samples at non-wadeable sites are collected by lowering a depth-integrated sampler (DH-95 with polyethylene collection bottle) from a bridge, through the water column at equal width increments across the channel. Samples at wadeable sites are collected with a DH-81 wadeable depth-integrated sampler (polyethylene collection bottle) through the water column at equal width increments. When the flow of the channel is less than 1.5 ft/s, a grab composite sample is collected. Non-wadeable sites are collected by lowering a weighted bottle sampler with a 1-L bottle under the surface of the channel. Wadeable sites are collected using a whirl-pak inside of a 1-L collection bottle and submerging the bottle under the water. Equal width increments are used in both wadeable and non-wadeable sites to get an accurate representation of the channel. Grab samples are conducted if the channel is a series of

disconnected pools. If sampling occurs from a bridge, the sampling typically is done on the down-stream side of the bridge. The sampling methods used are described in detail in the Collecting Water Quality Samples SOP. From this water sample, water quality variables are monitored in several ways. For laboratory analysis of general water quality variables and nutrients, water is aliquoted, as outlined in the SOP, into two, 1L bottles (one for sulfuric acid/ice preservation and one for ice preservation). If a metals analysis is necessary, water is collected at the thalwag of the channel into a 250mL bottle and preserved with nitric acid for a total recoverable metals panel, or filtered and preserved with nitric acid for a dissolved metals panel, as per standard operating procedures guidelines. Sample water for the determination of nephelometric turbidity, total hardness, and total alkalinity is also aliquoted from the remainder of the general chemistry sample water. Nephelometric turbidity is determined through use of a HACH portable turbidimeter. Total hardness and alkalinity are determined using HACH test kits. All instruments and test kits are calibrated and used according to manufacturer's instructions. Sestonic chlorophyll-a samples are also collected from the composited water sample and are filtered through a glass fiber filter with subsequent chemical/physical extraction and preservation in a 12mL glass vial with buffered acetone. Organics have an increased affinity for polypropylene, and allowing sample water to contact polypropylene bottles or other collection equipment may cause concentrations to be significantly underestimated. Therefore, when organics analyses are required, water is collected using a 1-Liter Teflon bottle and composited into a 2-gallon glass bottle. The laboratory sample is aliquoted by inverting the glass bottle 10 times and dispensing to one-quart or one-pint clear or amber glass jars depending on the type of organic analysis. The samples are placed on ice for preservation. Bacteriological samples are collected using a composite grab sample method and are aliquoted to two 100mL bacteria bottles for laboratory analysis.

Biological data are collected using a variety of methods. Typically, fish are collected using electrofishing methods.Alternatively, a seine net is used to collect fish when conductivity is not conducive to electrofishing. Benthic macroinvertebrates are collected by targeting the richest habitats in the water body, which includes riffles, streamside vegetation, and woody debris. Collections are then shipped to an outside lab where a subsample is taken for taxonomic analysis. Various habitat measures are also included during each biological sampling event. During fish collections, staff conduct habitat assessments derived from standard EPA methods and collect both quantitative and qualitative measurements on in-stream and riparian characteristics. During macroinvertebrate collections, habitat assessment is focused on determining target habitat type and substrate composition. Benthic chlorophyll-a samples are gathered from the characteristic substrates of the stream.

Table 2. Variables Monitored by the BUMP Stream Sampling Program.

SAMPLE VARIABLES		
General Water Quality Variables – Sampled 6 times annually		
Dissolved Oxygen (D. O.)	pH	Specific Conductance
Temperature	Total Dissolved Solids	% D. O. Saturation
Salinity	Total Alkalinity	Total Hardness
Chloride	Nephelometric Turbidity	Sulfate
Nutrients – Sampled 6 times annually		
*Kjeldahl Nitrogen	Ammonia Nitrogen	Total Phosphorus

SAMPLE VARIABLES		
*Nitrate Nitrogen	*Nitrite Nitrogen	
Metals – Sampled as needed		
Arsenic	Cadmium	Chromium
Copper	Lead	Mercury
Nickel	Selenium	Silver
Zinc	Thallium	
Organics – Site specific sampling as needed		
Analysis of Pesticides, Herbicides, Fungicides, and other organics		
Bacteriological Communities – Sampled 5-10 times annually (during recreational season)		
Enterococci	*Escherichia coli*	
Biological Communities – Sampled as described below		
Sestonic Chlorophyll-a (8 times annually	Benthic Chlorophyll-a (as needed during summer)	Fish (once every 4-5 years)
Benthic Macroinvertebrates (1 collection in the summer annually)	Habitat (sampled with fish and macroinvertebrate sampling)	

*Total nitrogen is calculated by OWRB staff, based upon concentrations for these compounds

For a more detailed discussion of water quality sampling procedures, please contact the OWRB for copy of the BUMP Standard Operating Procedures (SOP). The SOP document can be obtained by contacting the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800 or by accessing and downloading the document via the web at the following link. Streams SOP's

Quality Assurance/Quality Control (QA/QC): QA/QC will not be discussed in detail in this report. However, for a comprehensive description of field QA/QC methods, please contact the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800. For laboratory QA/QC methods please contact the Oklahoma Department of Environmental Quality/Customer Services Division at (405) 702-6100. Comprehensive QA/QC has been performed on all data collected and utilized for this report.

It is also imperative that the state continues to refine the minerals criteria found in OAC 45: Appendix F. The process was begun in earnest in 2005 with a major revision to Appendix F criteria, and the assessments in this report reflect these new criteria. However, some management segment values are still extrapolated from minimum data and from stations not necessarily representative of the entire management segment. By using the OWRB's methodology for the development of site-specific minerals criteria, BUMP data as well as other water quality monitoring program data may be used to refine inconsistent criteria.

Comment [s1]: Update this paragraph

RESULTS AND DISCUSSION

It is essential that Oklahoma quantify impacts in a comprehensive and scientific manner and look for trends in water quality to identify waters that are not meeting their assigned beneficial

uses. As a state, we must manage our water resources effectively and direct money to areas in most need of protection or remediation to ensure that we continue to have good quality and sufficient quantity of water to meet our needs well into the 21st century. It is the desire of the Oklahoma Water Resources Board to provide the legislature, the general public and professional water managers with a comprehensive and up-to-date document for their review and approval. Administrative and Technical staff at the OWRB look forward to conducting the Beneficial Use Monitoring Program far into the future and providing the state of Oklahoma with the information it needs to make informed decisions related to the effective management of its precious water resources.

Every two years, the OWRB analyzes data collected by BUMP and uses that data to determine if the waters of the state are meeting their assigned beneficial uses. If the stream/river segment is not meeting its beneficial use it is submitted for inclusion on the EPA's 303(d) list. The latest EPA approved 303(d) list of impaired waters can be found on the Oklahoma Department of Environmental Quality's website. Oklahoma's 303d list

Guide to Interpreting Ambient Water and Effluent Variables (ILMB, BC 1998)

The following guide defines each variable, discusses the importance of the variable to the aquatic environment and lists potential anthropogenic sources.

Temperature

Definition: This is a measurement of the intensity (not amount) of heat stored in a volume of water. Surface water temperatures naturally range from 0°C under ice cover to 40°C in hot springs. Natural sources of heat include: solar radiation, transfer from air, condensation of water vapor at the water surface, sediments, precipitation, surface runoff and groundwater. Temperature is the primary influencing factor on water density.

Importance: Temperature affects the solubility of many chemical compounds and can therefore influence the effect of pollutants on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impacts many species. Vertical stratification patterns that naturally occur in lakes affect the distribution of dissolved and suspended compounds.

Anthropogenic sources: industrial effluents, agriculture, forest harvesting, urban developments, mining.

Turbidity

Definition: This is a measurement of the suspended particulate matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, organic material, or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). Pure distilled water would have non-detectable turbidity (0 NTU). The extinction depth (for lakes), measured with a Secchi disc, is an alternative means of expressing turbidity.

Importance: High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress fish productivity. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant.

Anthropogenic sources: forest harvesting, road building, agriculture, urban developments, sewage treatment plant effluents, mining, industrial effluents.

pH

Definition: This is the measurement of the hydrogen-ion concentration in the water. A pH below 7 is acidic (the lower the number, the more acidic the water, with a decrease of one full unit representing an increase in acidity of ten times) and a pH above 7 (to a

maximum of 14) is basic (the higher the number, the more basic the water). Fresh waters have a pH range from 5.5 in southeast Oklahoma to nearly 9.0 in central Oklahoma,

Importance: Higher pH values tend to facilitate the solubilization of ammonia, heavy metals and salts. The precipitation of carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5.

Anthropogenic sources: mining, agriculture, industrial effluents, acidic precipitation (derived from emissions to the atmosphere from cars and industry).

Dissolved Oxygen (DO)

Definition: This is a measure of the amount of oxygen dissolved in water. Typically the concentration of dissolved oxygen in surface water is less than 10 mg/L. The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. The maximum solubility of oxygen (fully saturated) ranges from approximately 15 mg/L at 0°C to 8 mg/L at 25°C (at sea level). Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Natural re-aeration of streams can take place in areas of waterfalls and rapids.

Importance: Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments. Oligotrophic (low nutrient) lakes tend to have increased concentrations of dissolved oxygen in the hypolimnion (deeper waters) relative to the epilimnion (defined as orthograde oxygen profiles). Eutrophic (high nutrient) lakes tend to have decreased concentrations of dissolved oxygen in the hypolimnion relative to the epilimnion (defined as clinograde oxygen profiles).

Anthropogenic causes of decreased DO: forest harvesting, pulp mills, agriculture, sewage treatment plant effluent, industrial effluents, impoundments (dams).

Hardness, total

Definition: The hardness of water is generally due to the presence of calcium and magnesium in the water. Other metallic ions may also contribute to hardness. Hardness is reported in terms of calcium carbonate and in units of milligrams per litre (mg/L). Waters with values exceeding 120 mg/L are considered hard, while values below 60 mg/L are considered soft.

Importance: Harder water has the effect of reducing the toxicity of some metals (i.e., copper, lead, zinc, etc.). Soft water may have corrosive effect on metal plumbing, while

hard water may result in scale deposits in the pipes. If the water has a hardness of greater than 500 mg/L, then it is normally unacceptable for most domestic purposes and must be treated.

Anthropogenic sources: mining, industrial effluents

Alkalinity

Definition: This is the measurement of the water's ability to neutralize acids. It usually indicates the presence of carbonate, bicarbonates, or hydroxides. Alkalinity results are expressed in terms of an equivalent amount of calcium carbonate. Note that this does not mean that calcium carbonate was found in the sample. Natural waters rarely have levels that exceed 500 mg/L.

Importance: Waters that have high alkalinity values are considered undesirable because of excessive hardness and high concentrations of sodium salts. Waters with low alkalinity have little capacity to buffer acidic inputs and are susceptible to acidification (low pH).

Anthropogenic sources that destroy alkalinity: mining, industrial effluents, acidic precipitation.

Total Dissolved Solids (TDS)

Definition: This is a measure of the amount of dissolved material in the water column. It is reported in mg/L with values in fresh water naturally ranging from 0-1000 mg/L. Dissolved salts such as sodium, chloride, magnesium and sulphate contribute to elevated filterable residue values.

Importance: High concentrations of TDS limit the suitability of water as a drinking and livestock watering source as well as irrigation supply. High TDS waters may interfere with the clarity, color, and taste of manufactured products. High TDS naturally occurs in some parts of western Oklahoma.

Anthropogenic sources: mining, industrial effluent, sewage treatment, agriculture, road salts.

Total Suspended Solids (TSS)

Definition: This is a measure of the particulate matter that is suspended within the water column. Values are reported in mg/L.

Importance: High concentrations of TSS increase turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills. Settling suspended solids can cause impairment to spawning

habitat by smothering fish eggs. Suspended solids also interfere with water treatment processes.

Anthropogenic sources: forest harvesting, road building, industrial effluents, urban developments, placer mining, municipal sewage treatment plants.

Specific Conductivity

Definition: This is the measurement of the ability of water to conduct an electric current - the greater the content of ions in the water, the more current the water can carry. Ions are dissolved metals and other dissolved materials. Conductivity is reported in terms of microsiemens per centimeter (µS/cm). Natural waters are found to vary between 50 and 1500 µS/cm. In Oklahoma, some western rivers have specific conductivity values > 25,000 uS/cm, while many waters in the Ouachita Mountains of southeastern Oklahoma have perennial conductivities of < 25.

Importance: Specific Conductivity may be used to estimate the total ion concentration of the water, and is often used as an alternative measure of dissolved solids. It is often possible to establish a correlation between conductivity and dissolved solids for a specific body of water [dissolved solids = conductivity x 0.55 to 0.9 (the most often used is 0.65)]. Fish diversity typically is inversely proportional to conductivity.

Anthropogenic sources: mining, roads (de-icing salts), industrial & municipal effluents. High conductivity may also be naturally occurring.

Chloride

Definition: Of the halides, chloride appears in the highest concentrations in natural fresh water system, and is reported as mg/L. The average chloride concentration varies widely in Oklahoma with values of < 10 mg/L in southeastern Oklahoma to > 3000 mg/L in the Cimarron and upper Red River watersheds. .

Importance: Chloride is important in terms of metabolic processes, as it influences osmotic salinity balance and ion exchange. Higher chloride concentrations can reduce the toxicity of nitrite to aquatic life. Fish diversity typically is inversely proportional to chloride concentration.

Anthropogenic sources: municipal water supply disinfection, sewage treatment plant effluents, urban developments, industrial effluents, mining.

Sulfate

Definition: Sulfur is commonly found as a component of sedimentary and igneous rocks in the form of metallic sulfides. Sulfides are oxidized upon contact with aerated water, producing sulfate ions in solution. (Lehigh 2010)

Importance: When sulfate is less than 0.5 mg/L, algal growth will not occur. On the other hand, sulfate salts can be major contaminants in natural waters. Excessive levels in water may cause illness. The average sulfate concentration varies widely in Oklahoma with values of < 10 mg/L in southeastern Oklahoma to > 1500 mg/L in the upper Red River watersheds. (Lehigh 2010)

Anthropogenic sources: combustion of fuel, present in soils that are oxidized through natural processes, organic waste treatment, mine drainage, and evaporite sediments, such as anhydrite and gypsum.

Total phosphorus

Definition: This is a measure of both inorganic and organic forms of phosphorus. Phosphorus can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. It is rarely found in significant concentrations in surface waters, and is generally reported in µg/L or mg/L.

Importance: Since phosphorus is generally the most limiting nutrient, its input to fresh water systems can cause extreme proliferations of algal growth. Inputs of phosphorus are the prime contributing factors to eutrophication in most fresh water systems. A general guideline regarding phosphorus and lake productivity is: <10 µg/L phosphorus yields is considered oligotrophic, 10-25 µg/L P will be found in lakes considered mesotrophic, and >25 µg/L P will be found in lakes considered eutrophic.

Anthropogenic sources: sewage treatment plant effluent, agriculture, urban development (particularly from detergents), industrial effluents.

Orthophosphate (PO_4^{-3})

Definition: This is a measure of the inorganic oxidized form of soluble phosphorus. It is generally reported in µg/L or mg/L.

Importance: This form of phosphorus is the most readily available for uptake during photosynthesis. High concentrations of orthophosphate generally occur in conjunction with algal blooms.

Anthropogenic sources: sewage treatment plant effluent, agriculture, urban developments, industrial effluents.

Nitrite (NO_2^-)

Definition: This is a measure of a form of nitrogen that occurs as an intermediate in the nitrogen cycle. It is an unstable form that is either rapidly oxidized to nitrate (nitrification) or reduced to nitrogen gas (de-nitrification). This form of nitrogen can also be used as a

source of nutrients for plants. Nitrite is generally reported in either µg/L or mg/L. It is normally present in only minute quantities in surface waters (<0.001 mg/L).

Importance: Since nitrite is also a source of nutrients for plants its presence encourages plant proliferation. Nitrite is toxic to aquatic life at relatively low concentrations.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents, mining (blasting residuals).

Nitrate (NO_3^-)

Definition: This is the measurement of the most oxidized and stable form of nitrogen in a water body. Nitrate is the principle form of combined nitrogen found in natural waters. It results from the complete oxidation of nitrogen compounds, and is generally reported in µg/L or mg/L. Without anthropogenic inputs, most surface waters have less than 0.3 mg/L of nitrate.

Importance: Nitrate is the primary form of nitrogen used by plants as a nutrient to stimulate growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations. At high levels it is toxic to infants.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents, mining (blasting residuals).

Total Ammonia (NH_3 & NH_4^+)

Definition: This is a measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4^+). Nitrogen is an essential plant nutrient and although ammonia is only a small component of the nitrogen cycle, it contributes to the trophic status of a body of water. Ammonia is generally reported in either µg/L or mg/L. Natural waters typically have ammonia concentrations less than 0.1 mg/L.

Importance: Excess ammonia contributes to eutrophication of water bodies. This results in prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies, and recreation. Ammonia at high concentrations is toxic to aquatic life.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents, mining (blasting residuals).

Kjeldahl nitrogen

Definition: This is a measure of both the total ammonia and the organic forms of nitrogen.

Importance: Excess ammonia contributes to eutrophication of water bodies. This results in prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies, and recreation. Ammonia at high concentrations is toxic to aquatic life. Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs. Kjeldahl nitrogen is a necessary value for calculating total nitrogen in a system.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, paper plants, industrial effluents, recreation, mining (blasting residuals).

Total nitrogen

Definition: This is a measure of all forms of nitrogen (organic and inorganic). Nitrogen is an essential plant element and is often the limiting nutrient in marine waters. Total nitrogen is typically calculated by summing nitrate, nitrite, and Kjeldahl nitrogen.

Importance: The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present, be it ammonia, nitrite, nitrate, or organic nitrogen (each of which are discussed in detail above).

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, paper plants, industrial effluents, recreation, mining (blasting residuals).

Chlorophyll A

Definition: Chlorophyll a is a green pigment found in plants. It absorbs sunlight and converts it to sugar during photosynthesis. Chlorophyll a concentrations are an indicator of phytoplankton abundance and biomass.

Importance: They can be an effective measure of trophic status, are potential indicators of maximum photosynthetic rate and are a commonly used measure of water quality. High levels often indicate poor water quality and low levels often suggest good conditions. However, elevated chlorophyll a concentrations are not necessarily a bad thing. It is the long-term persistence of elevated levels that is a problem.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, storm water run-off, natural occurrences.

Trophic State Index

Definition of Trophic State: Trophic state is the total weight of living biological material (biomass) in a waterbody at a specific location and depth. (Carlson, 1996)

Definition of Trophic State Index: A simple and effective management tool for tracking algae growth in lakes worldwide is to express chlorophyll-A as trophic status. Here the

concentration of chlorophyll-A is correlated to the biomass of algae in the sampled water. **Carlson's (1977)** trophic state index (TSI) is one of the most commonly used measurements to compare lake trophic status, which is based on algal biomass. Carlson's TSI uses chlorophyll-a concentrations to define level of eutrophication on a scale of 1 to 100. The trophic scale is set up so that a ten-unit increase in trophic state represents a doubling of algae biomass. The OWRB's statewide lakes sampling program assigns one of three trophic states to Oklahoma reservoirs on an annual basis. A lake is considered oligotrophic below 40, mesotrophic from 41-50, eutrophic 51-60, and hypereutrophic when greater than or equal to 61. The biological condition of the waterbody indicates the lake's level of nutrient enrichment or eutrophication. Secchi depth and total phosphorus can also be used to calculate TSI.

Importance: Trophic state is understood to be the biological response to forcing factors such as nutrient additions, but the effect of nutrients can be modified by factors such as season, grazing, mixing depth, etc. (Carlson, 1996)

Fecal Coliform

Definition: Fecal coliform bacteria are a group of bacteria that are passed through the fecal excrement of humans, livestock and wildlife. The bacteria can be found in the digestive tract of warm-blooded animals and aid in the digestion of food.

Importance: In themselves, fecal coliform bacteria do not pose a danger to people or animals; however, where fecal coliform are present, disease-causing bacteria may also be present. Fecal coliform contamination may indicate that water is polluted with human or animal waste, which can harbor other pathogens that may threaten human health.

Anthropogenic sources: agricultural runoff, animal waste, human waste, leaky sewer lines, on-site septic systems, straight pipes, stormwater runoff from developed land including roads, buildings and residential yards and surface or land application of human and/or animal waste

Enterococcus

Definition: Like fecal coliform bacteria, enterococci are passed through the fecal excrement of humans, livestock and wildlife. The bacteria can be found in the digestive tract of warm-blooded animals and aid in the digestion of food.

Importance: EPA approves the use of enterococci as an indicator of potential pathogenic contamination in recreational bathing waters.

Anthropogenic sources: agricultural runoff, animal waste, human waste, leaky sewer lines, on-site septic systems, straight pipes, stormwater runoff from developed land including roads, buildings and residential yards and surface or land application of human and/or animal waste

E. Coli

Definition: E-Coli are one type of pathogenic fecal coliform bacteria, and the most common facultative, disease-causing bacteria in the feces of warm-blooded animals.

Importance: Most *E. coli* bacteria are harmless and are found in great quantities in the intestines of people and warm-blooded animals. Some strains, however, can cause illness. EPA approves the use of enterococci as an indicator of potential pathogenic contamination in recreational bathing waters.

Anthropogenic sources: agricultural runoff, animal waste, human waste, leaky sewer lines, on-site septic systems, straight pipes, stormwater runoff from developed land including roads, buildings and residential yards and surface or land application of human and/or animal waste

Statistics

n: The number of discrete values in the population or dataset that are used in analyses.

Mean: The mean is a measure of central tendency, or location within the population. For a population or dataset, the mean is the arithmetic average of all values. If data are normally distributed, the mean is equivalent to the median.

Median: The median is a measure of central tendency. The median can also be defined as the 50th percentile. In a population or dataset, the median is the value that has just as many values above it as below it. If there is an even number of values, the median is the average of the two middle values. For normally distributed populations or datasets, the median coincides with the mean and the center of the distribution. For this reason, the median of a sample is often used as an estimator of the center of the distribution. If the distribution has heavier tails than the normal distribution, the median is usually a more precise estimator of the population distribution center than the mean.

Percentiles: In a population or dataset, the pth percentile is a value such that at least a percent of the values take on this value or less and at least (100-P) percent of the values take on this value or more. For example, the 25th (p25) and 75th (p75) percentiles represent the points that 25 and 75 percent of the population are less than. Along with the median, the p25 and p75 values are also known as the 1st, 2nd, and 3rd quartiles, respectively.

Minimum: The minimum is the smallest measured value in the population or dataset.

Maximum: The maximum is the largest measured value in the population or dataset.

Interquartile Range: The difference between the 3d and 1st quartiles are called the interquartile range (IQR). The IQR is used as a measure of population or dataset variability, or dispersion.

Sampling distribution: The probability distribution of the statistic is called the sampling distribution. When a population or dataset is measured, some summary value (called a statistic) is usually computed. For example, the population mean and variance are two statistics, and the value of the statistic changes as the population changes. The normal distribution is a probability distribution which is bell-shaped, symmetrical, and single peaked. In a normally distributed population or dataset, the mean, median and mode coincide and lie at the center of the distribution. The two tails extend indefinitely and never touch the x-axis (asymptotic to the x-axis). In non-normally distributed datasets, the mean shifts to either the right or left tail of the distribution and is not equivalent to the median.

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