2021

LTWA

LAKE THUNDERBIRD WATERSHED ALLIANCE

INTEGRATED WATERSHED MANAGEMENT PLAN

Contents

1. Introduction 4
1.1 Overview & Context 4
1.2 Background on Lake Thunderbird 5
2.0 Integrated Watershed Management Plan (IWMP) 8
2.1 Purpose 8
2.2 General Approach and Methods 8
2.3 Development 8
3.0 Lake Thunderbird Watershed Alliance 10
Mission of the LTWA 10
3.1 LTWA Structure 10
3.2 LTWA Partners 10
4.0 Watershed overview 11
4.1 Boundaries and land use 11
Overview of Land Use 11
4.2 Climate, topography, geology and soils 14
Climate 14
Topography 16
Geology 17
Soils 19
4.3 Streamflow 24
5.0 Watershed features 25
6.0 Watershed uses and users 30
7.0 Public Education and Outreach Plan 31
7.1 Public Input 31
7.2 Ongoing Efforts 33
8.0 Current desktop condition assessment 35
8.1 Problem areas and priority issues 35
8.2 Management Strategies to meet goals and objectives 37
9.0 Implementation 40
10.0 Funding Sources 41
11.0 Resources 41
12.0 References 42

List of Tables

Table 1 Lake Thunderbird Morphometric Features 6
Table 2 Lake Thunderbird TMDL MS4 Permit - Waste Load Allocations 6
Table 3 Lake Thunderbird Watershed Waterbodies and ODEQ Impairment 7
Table 4 *Lake Thunderbird Watershed 2016 Land Use Percentages* 12
Table 5 Potential Watershed Stormwater Pollutants 13
Table 6 Climate Summary by County in the Lake Thunderbird Watershed 15
Table 7 Rainfall and Evaporation at Lake Thunderbird as Reported by the USACE 15
Table 8 Predominant soils in the Lake Thunderbird Watershed 20
Table 9 Lake Thunderbird Watershed EPA Toxic Release Inventory Locations 27
Table 10 Lake Thunderbird Watershed Current MSGP Permits 28
Table 11 Lake Thunderbird Uses and Users 30
Table 12 Priority Issues for LTWA to Address in the IWMP 36
Table 13 Priority Issues for Further Research to Address in the IWMP 37
Table 14 Lake Thunderbird Parameters Monitored for TMDL and Impairment 38
Table 15 Parameters for monitoring and effectiveness of management strategies 38
Table 16 Top 5 Structural and nonstructural management strategies for issue type 39

List of Figures

Figure 1. IWMP Process 8
Figure 2 Lake Thunderbird Watershed Boundaries 11
Figure 3 Lake Thunderbird Watershed 2016 Land Use 12
Figure 4 Lake Thunderbird Watershed Elevation Map 17
Figure 5 Lake Thunderbird Watershed Bedrock 18
Figure 6 Extent of the Central Oklahoma Aquifer 19
Figure 7 Lake Thunderbird Watershed Predominant Soils 21
Figure 8 Lake Thunderbird Watershed Hydraulic Conductivity 22
Figure 9 Lake Thunderbird Watershed Septic Tank Leach Field Limited Areas 23
Figure 10 Lake Thunderbird Watershed Wetlands 24
Figure 11 Lake Thunderbird Watershed Features 26
Figure 12 Lake Thunderbird Watershed Toxic Release Inventory and Permit Locations 29

1. Introduction

1.1 Overview & Context

National, state and local efforts to establish water quality baselines for conservation and improvement have increased. In the last decade, awareness of stormwater quality, potential water scarcity, and public involvement in drinking water alternatives have been recurrent in the Lake Thunderbird Watershed. In 2012, The Lake Thunderbird Efficient Use Act allowed for the storage of non-watershed water within Lake Thunderbird. It opened the door for the Central Oklahoma Master Conservancy District (COMCD) to explore other sources of water to augment the available supply from the watershed during times of drought. The Oklahoma Comprehensive Water Plan, introduced in the same year, also placed a focal point on the need to quantify water supply across the state and determine future water supply needs for each region. Alongside that study, in 2012, House Bill 3055 – The Water for 2060 Act introduced Oklahoma's goal of limiting its freshwater consumption levels in 2060 to that of 2010. Then, in 2013, ODEQ completed the Total Maximum Daily Load Study for Lake Thunderbird after it was classified as impaired and listed in the state's 303(d) list three years earlier. This evaluation placed waste load allocations upon the Municipal Separate Storm Sewer Systems (MS4s) within the watershed – the Cities of Norman, Oklahoma City and Moore. Since then, each city has developed a compliance and monitoring plan to meet the goals presented in the study to attain the water quality standards as required by the state. Four years later, in 2017, the Lake Thunderbird Watershed Partnership was established between Norman, Oklahoma City, and Moore to educate the public on the watershed, Norman's major water supply lake, and how to collaboratively protect it.

Through various drivers, including the regulatory requirements discussed above, the Lake Thunderbird Watershed now encompasses multiple ongoing efforts to establish a path towards water quality improvement of all its streams and lakes as well as Lake Thunderbird's conservation as a reliable drinking water supply source. Regional organizations that are involved with lake management education and community activities include The Oklahoma Clean Lakes and Watersheds Association (OCLWA) and Keep Oklahoma Beautiful. State agencies are also involved with tracking the water quality of the streams and lakes. The Oklahoma Water Resources Board (OWRB) publishes annual reports on nutrient levels and other water quality variables within the lake, and the Oklahoma Department of Environmental Quality (ODEQ) annually classifies each water body based on its designated beneficial uses and their impairment status. The cities within the watershed, Norman, Oklahoma City, and Moore, work continuously to fund and support efforts to improve stormwater quality through education, community events, and municipal initiatives and regulations. Finally, research by agencies and local universities on topics including stream erosion, ecological diversity, changes in streamflow and many others, also take place within the Lake Thunderbird Watershed.

Collaboration will grow in importance as the population within and near the watershed grows, and as greater pressure is placed on the conservation of water resources. The following are examples of future considerations and opportunities for local cooperation:

- The watershed's east side includes Absentee-Shawnee jurisdictional tribal land. How will tribal water management issues be addressed within existing and developing efforts within the watershed?
- The United States Congress has introduced bills to establish funding for water recycling projects in western states. Since before 2014, the City of Norman has explored water reclamation alternatives for Lake Thunderbird augmentation through Norman's Water Reclamation Facility. How will legislation like this affect Oklahoma and what direction will the state take?

- The Oklahoma Conservation Commission (OCC) has partnered with other state agencies and academic institutions to redefine wetland mapping, management, and conservation in Oklahoma. What effect will this have on municipal and state efforts to establish stormwater quality mitigation banks in the Lake Thunderbird Watershed?

1.2 Background on Lake Thunderbird

The Lake Thunderbird watershed drains 256 square miles including areas within the municipalities of Norman, Oklahoma City, and Moore, as well as small parts of unincorporated Oklahoma and Cleveland Counties (HUC11090203). The basin to which the area drains is Lake Thunderbird, created by the Bureau of Reclamation (BOR) in 1965 (OWRB, 2021). The primary purpose of Lake Thunderbird is to serve as the drinking water source for the Cities of Norman, Del City, and Midwest City, and serves as a flood control structure, a place of recreation, and a fish and wildlife habitat. The beneficial uses designated for Lake Thunderbird are (OWRB, 2018):

- Fish & Wildlife Propagation (Warm Water Aquatic Community)
- Aesthetics
- Agriculture
- Primary Body Contact Recreation
- Public & Private Water Supply

Table 1 provides Oklahoma Water Resources Board (OWRB) morphometric features at normal pool elevation for Lake Thunderbird (OWRB, 2001).

Table 1

Lake Thunderbird Morphometric Features

Feature	Data
Normal Elevation	1,039 feet
Current Elevation (as of 3/24/2021)[1]	1040.1 feet
Mean Depth	15.4 feet
Maximum Depth	58.0 feet
Surface Area	5,439 acres
Shoreline Length	154 miles
Capacity	105,838 acre-feet

In August 2010, Lake Thunderbird was placed on ODEQ's 303(d) List of Impaired Waterbodies for impaired beneficial uses of public/private water supply due to excessive chlorophyll-a levels and warm water aquatic community (WWAC) due to low dissolved oxygen and high turbidity (ODEQ, 2016). It is also listed in the Oklahoma Water Quality Standards (OAC 785:45-5-25(c)(4)) as a Sensitive Water Supply (SWS) and OAC 785:45-5-29(b) as a Nutrient-Limited Watershed (NLW) due to low dissolved oxygen, high chlorophyll-a, and high turbidity levels. These classifications led to the establishment of a Total Maximum Daily Load (TMDL) by ODEQ in 2013 for total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). Table 2 lists the waste load allocations (WLA) that were placed on Moore, Norman, and Oklahoma City (OWRB, 2013).

Table 2

Lake Thunderbird TMDL MS4 Permit - Waste Load Allocations

Water Quality Constituent	Moore (kg/day)	Norman (kg/day)	Oklahoma City (kg/day)
TN	205.1	319.4	261.8
TP	44.5	60.1	49.4
TSS	16,236.0	31,596.1	27,049.9

In addition, Lake Thunderbird is not the sole impaired water body within the watershed. The streams, shown in Table 3, have been identified by ODEQ as being impaired. Those in red were listed in the 2020 303(d) list as impaired due to one or more reasons. See the Watershed Health section of this report for more detail.

[1] Flood Control Status (USACE, 2021)

Table 3

Lake Thunderbird Watershed Waterbodies and ODEQ Impairment

Waterbody ID	Site Name
OK520810000030_00	**Hog Creek**
OK520810000040_00	**West Hog Creek**
OK520810000050_00	Clear Creek
OK520810000060_00	Dave Blue Creek
OK520810000070_00	Jim Blue Creek
OK520810000080_00	**Little River**
OK520810000090_00	**Rock Creek**
OK520810000100_00	**Elm Creek**
OK520810000110_00	East Elm Creek
OK520810000140_00	**West Elm Creek**
OK520810000150_00	Kitchen Creek
OK520810000170_00	North Fork Little River
OK520810000175_00	**Moore Creek**
OK520810000180_00	Mussel Shoals Lake Creek

Figure 1.

IWMP Process

Source: Nottawasaga Valley Integrated Watershed Management Plan

2.0 Integrated Watershed Management Plan (IWMP)

2.1 Purpose

Although there are many studies on water quality and quantity in the watershed, as well as state and local agencies and organizations that have monitored different areas over many years, a unified grassroots movement involving the watershed's stakeholders has not taken place.

The purpose of this plan is to approach water quality improvements of the Lake Thunderbird Watershed by coordinating a focused and integrated local effort supported by multiple local and state entities. The IWMP is a dynamic document for improving the state of the watershed through planned proactive conservation strategies, continuous interdisciplinary stakeholder input, established strategies for making multi-objective decisions, a timeline for goals, methods for measuring success, and adaptive management as needs change. The IWMP achieves the following:

- Introduces the foundation of the Lake Thunderbird Watershed Alliance mission and goals
- Presents the context of the watershed in terms of boundaries, land use, climate, topography, geology, soils, and streamflow
- Identifies important watershed features and how watershed users and uses interact
- Evaluates current watershed health to determine problem areas and priority issues
- Identifies management strategies to address the priority issues
- Enhances the existing public education and outreach plan
- Identifies next steps for the LTWA and watershed stakeholders

2.2 General Approach and Methods

The IWMP process involves five main steps and requires collaboration from multiple parties and/or agencies as watersheds typically extend beyond political boundaries. The initial step requires the key stakeholders to get to know the watershed via background document review. Once the watershed characteristics, uses, users, etc. are understood, the key watershed issues are identified and prioritized by the watershed stakeholders and local technical experts. Next, the local technical experts help to develop management plans to address the prioritized issues. The final steps require implementation of the management actions and continuous monitoring, reporting and updating of the management plan. In addition, public comments are collected throughout the IWMP process for further input on the watershed issues and implementation strategies.

2.3 Development

The funding for this project was provided by the Bureau of Reclamation BOR-DO-19-F010 WaterSMART: Cooperative Watershed Management Program FY 2019 Phase I Grant. The City of Norman filed an application and was granted the funding.

A technical advisory group (TAG) of academics, city officials, regulators, and volunteers advised the consultant team, Guernsey and Dragonfly Consulting, working with the City of Norman, on the following tasks:

- Identify existing studies and/or data on the watershed
- Identify problem areas in the watershed
- Define priorities and scope of the watershed issues
- Identify appropriate management and implementation strategies for each issue

Public input was sought through the following methods:

- Online and paper surveys at watershed clean up events hosted by the cities
- A Guernsey Interactive site, hosted by Esri, in which any member of the public could respond to a survey on best management practices
- An online survey developed by Dragonfly Consulting, hosted by Poll Everywhere, on general action associated with stormwater quality in the watershed
- An interactive map developed by Guernsey, hosted by Esri, on which specific locations could be identified with an issue (e.g., erosion, degraded water quality, stream obstructions)

In addition, LTWA partners (see next section) Blue Thumb, Oklahoma State University Cooperative Extension Services, COMCD, and the City of Norman were consulted on the development of a logo and website for the LTWA as well as an education and outreach plan.

3.0 Lake Thunderbird Watershed Alliance

Mission of the LTWA

The Lake Thunderbird Watershed Alliance (LTWA) was formed in 2020 to work collaboratively with residents, communities and other stakeholders to protect the water quality and quantity of Lake Thunderbird. The Lake Thunderbird Watershed Alliance will also serve as a clearinghouse for information about Lake Thunderbird including implementation projects, research and outreach material.

3.1 LTWA Structure

The LTWA's eleven founding Board Members are listed below:

- Carrie Evenson – City of Norman, President
- Amanda Nairn – COMCD, Vice President
- Michele Loudenback – City of Norman, Secretary
- Lance Phillips – Oklahoma Water Resources Board, Treasurer
- Courtney DeKalb-Myers – Oklahoma State University Cooperative Extension Services, Communications Officer
- Mike Cantrell – City of Del City
- Sarah Copeland – City of Moore
- Paul Streets – City of Midwest City
- Lynne Miller – Resident
- Phil Moershel – Thunderbird Sailing Club

As per the Bylaws, each of the five cities that reside within the watershed or use Lake Thunderbird as a drinking water source (City of Norman, Midwest City, Del City, Moore, and Oklahoma City) and COMCD have one permanent position on the Board of Directors. The remaining five positions are held by a recreational interest representative and four at large members voted on by the LTWA's general membership.

Membership is open to residents and landowners in the Lake Thunderbird watershed; educators, scientists, and others who work in the watershed; individuals and/or entities which have an interest in the purpose, goals, mission, and outcomes of the Corporation. Initial members were recruited by the Board of Directors. Additional members will be recruited through public meetings, watershed events and through press releases and other media outlets, including social media outlets.

Simultaneous to the establishment of the Board, additional members were recruited to form the LTWA's TAG.

3.2 LTWA Partners

The LTWA has worked alongside the following entities in its establishment and through the development of this IWMP:

- Blue Thumb
- Center for Restoration of Ecosystems and Watersheds (CREW)
- City of Norman
- City of Midwest City
- City of Del City
- City of Moore
- Cleveland County Cooperative Extension
- COMCD
- Lake Thunderbird Sailing Club
- OCC
- ODEQ
- OWRB
- Oklahoma Water Survey (OWS)

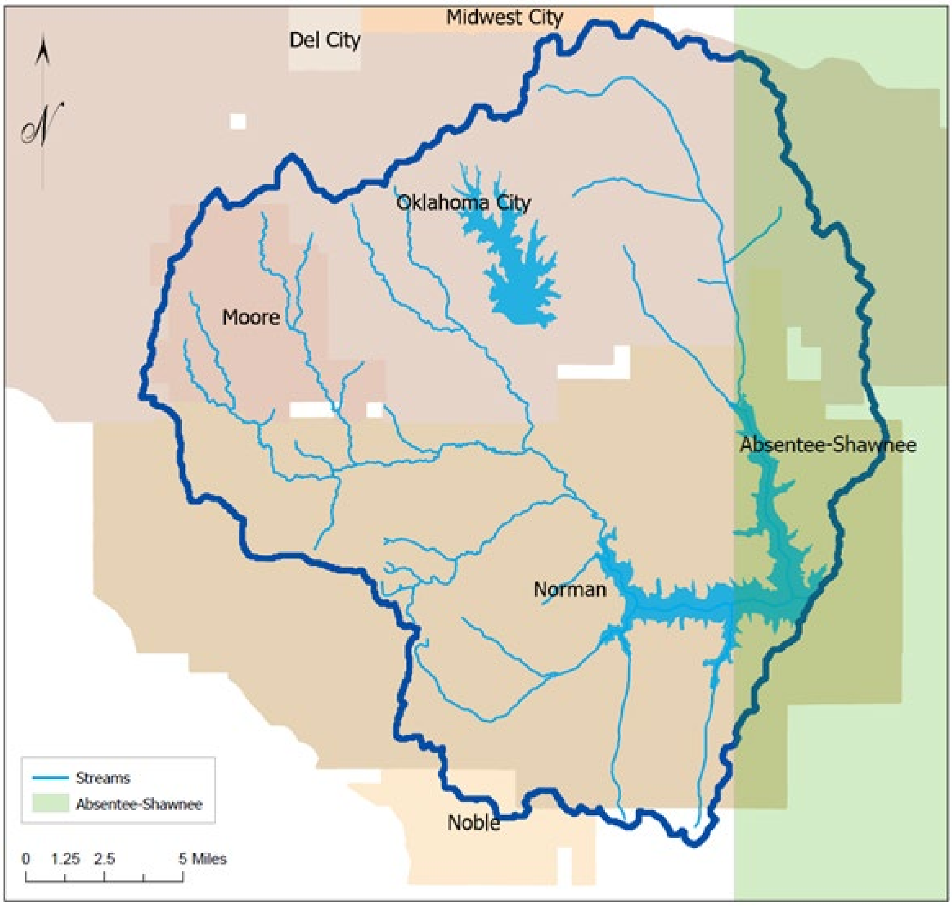
4.0 Watershed overview

4.1 Boundaries and land use

The Lake Thunderbird watershed has an area of 256 square miles of residential, commercial, and agricultural lands. It encompasses 16.1% of Oklahoma City, 69.8 % of Norman, and 94.8% of Moore. Midwest City and Noble have small sections within the central and southern portion of the boundary, respectively. In addition, the Absentee-Shawnee Tribe's boundary extends into the eastern part of the watershed (see Figure 2).

Figure 2

Lake Thunderbird Watershed Boundaries



Overview of Land Use

Based on the 2016 National Land Cover Database (NLCD) summarized in Figure 3 and Table 4, the land use within the watershed is mostly attributed to deciduous forest and grassland/herbaceous vegetation at 37% and 34%, respectively. Open water within the watershed accounts for 5% of the land use. Developed (urban) areas make up a total of 19% of the watershed area. Four percent of the watershed area is used for cultivated crops (1%) and hay/pasture (3%). Comparing 2016 land use to 2011 land use there was a small increase in developed land of 2%, from 17% in 2011 to 19% in 2016 (see rows 2-5 in Table 4). Most of the developed high and medium intensity areas are occurring in Moore and Norman on the westernmost portion of the watershed. The majority of the cultivated crops and hay/pasture areas are situated along or near the streams.

Figure 3

Lake Thunderbird Watershed 2016 Land Use

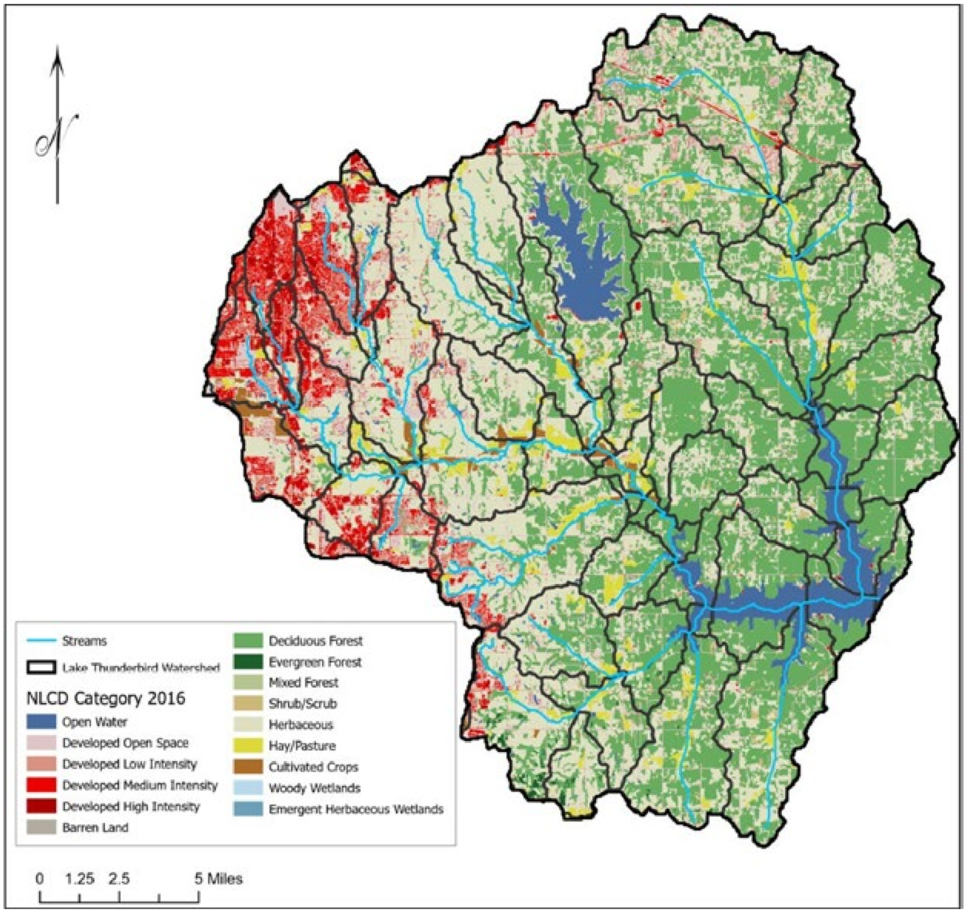


Table 4

Lake Thunderbird Watershed 2016 Land Use Percentages

Category	2011 % of Watershed Area	2016 % of Watershed Area
Open Water	4	5
Developed, Open Space	8	8
Developed, Low Intensity	5	6
Developed, Medium Intensity	3	4
Developed, High Intensity	1	1
Barren Land	0	0
Deciduous Forest	37	37
Evergreen Forest	0	0
Mixed Forest	0	0
Shrub/Scrub	1	2
Herbaceous	36	34
Hay/Pasture	3	3
Cultivated Crops	1	1
Woody Wetlands	0	0
Emergent Herbaceous Wetlands	1	0

Urbanized areas in the west produce increased runoff from impervious areas, carrying pollutants characteristic of residential and business districts such as car wash water or oil and grease, litter, fertilizers, pet and yard waste, road salt, and some metals, to municipal stormwater drainage systems and eventually the streams. The quantity of runoff also affects transport of sediment as the geomorphology of the streams change due to higher velocities of incoming water and as the channel widens with time. This increased runoff impacts stream banks and increases erosion and sediment transport.

The pasture/ranchland and less dense areas in the central and east areas also produce polluted runoff due to sediment from gravel roads, septic system or livestock waste disposal, road salt, decaying foliage, boat wash water or oil and grease.

Table 5 below summarizes the pollutants associated with each source and its impacts on the watershed.

Table 5[2]

Potential Watershed Stormwater Pollutants

Pollutant	Sources	Impacts
Nitrogen, phosphorus	Atmospheric deposition, sediment, fertilizers, pet waste, sewage, yard waste, fallen foliage	Algae growth contributing to eutrophication in lake
Suspended sediment	Impervious surfaces, gravel roads, bare soil, construction sites, stockpiles	Carries nutrients and organic matter that may lead to low dissolved oxygen levels, increased turbidity affecting the warm water aquatic community
Chlorides	De-icing or water softening chemicals	Toxic to plants, impact corrosivity of drinking water, can create leaching conditions in the distribution system as the chloride to sulfate ratio changes
Pathogens	Animal waste, insects, waste management, sewage	Human health risk and impact on recreation, impacts water treatment
Metals	Vehicle exhaust, roofing materials, industrial stormwater runoff	Toxic to plants, impacts water treatment
Organic Chemicals (pesticides, industrial chemicals or solvents, petroleum derived chemicals)	Golf courses, city maintained vegetated areas, residential lawns, industrial stormwater runoff	Toxic to plants, humans and animals. Impacts water treatment

[2] Adapted from *Typical stormwater pollutants, summary of sources and potential concerns for harvest and use.* Minnesota Stormwater Manual. (2020, April 16).

Although Lake Thunderbird is within the City of Norman, the watershed area boundary primarily contains the cities of Moore, Norman, and Oklahoma City with 19% of the watershed area being urban development and 4% attributed to agricultural use (71 % is undeveloped and 5% is open water). The high and medium intensity areas occur primarily in the western portions of the watershed within Moore and Norman while the agricultural lands are primarily along or near streams. Per the ODEQ 2013 TMDL report, Oklahoma City, Norman, and Moore contribute significant levels of nutrients and sediment (TN, TP, TSS) from urban nonpoint source runoff to Lake Thunderbird. Furthermore, build-out model scenarios performed within these municipalities resulted in an increased nutrient load from urban area stormwater compared to baseline conditions. In addition, OWRB water quality monitoring within the lake up to 2019 indicates the Lake has remained eutrophic. Therefore, the effort to improve the water quality of Lake Thunderbird must include the three major cities within the watershed, along with urban and agricultural communities within the watershed boundary.

4.2 Climate, topography, geology and soils

The holistic picture of land use, climate, topography, geology, and soils provides an understanding of the fate of precipitation in the watershed. The portion of precipitation that does not evaporate nor is captured by vegetation can infiltrate the surface and move downhill laterally within the soil as interflow. This interflow portion can percolate deeper into groundwater, or it can travel on the surface of the watershed and runoff as overland flow.

Climate

Climate is an extremely crucial factor on water resources and biological processes in a watershed (Heathcote, 2009). According to the Köppen climate classification system, the Lake Thunderbird watershed is within the humid subtropical climate (Cfa). Summers are hot and humid with mild to cold winters with periods of extreme cold being infrequent and typically not lasting more than a few days (OCS, 2021). Table 6 provides temperature, precipitation, wind speed, and sunshine observation data for Oklahoma and Cleveland counties. Air temperature influences evaporation, transpiration, and vegetation growth while wind conditions affect evapotranspiration and wind erosion. Precipitation, such as rain, snow, and dew, provides the water within the watershed (Heathcote, 2009). Prevailing winds are from the south to southeast throughout most of the state from the spring through autumn months while winter wind is equally split between northerly and southerly winds. Additionally, evaporation and percolation into the soil expend about 80% of Oklahoma’s precipitation (OCS, 2021).

Table 6

Climate Summary by County in the Lake Thunderbird Watershed

County	Temperature (deg F)			Precipitation (in)		Avg	Avg	Annual
	Avg Annual	Avg Max	Avg Min	Avg Annual Rainfall	Avg Annual Snowfall	Humidity (%)	Wind Speed (mph)	Fraction of Sunshine Observed (%)
Oklahoma	61.5	72.2	50.8	36.52	7.0	67	7	55-80
Cleveland	60.2	71.3	49.2	38.88	6.8	68	10	55-80

(OCS, 2021)

At Lake Thunderbird, the USACE monitors and calculates daily evaporation rates based on solar radiation, wind speed, relative humidity, and average air temperature. The reports from 2015-2019 are summarized in Table 7. The average rainfall for the time period was 18,973 acre-feet per year, and the average evaporation was 32,021 acre-feet per year. As discussed above, in a typical year, evaporation exceeds rainfall. From 2015 to 2019, the average ratio of evaporation to rainfall was 1.7.

Table 7

Rainfall and Evaporation at Lake Thunderbird as Reported by the USACE

	2019		2018		2017		2016		2015	
	Rain	**Evap.**	**Rain**	**Evap.**	**Rain**	**Evap.**	**Rain**	**Evap.**	**Rain**	**Evap.**
Jan	503	1,233	98	1,691	573	1,471	141	1,198	359	**1,363**
Feb	250	1,138	1,731	1,405	586	1,942	494	2,296	279	**1,434**
Mar	2,029	2,135	161	2,924	944	2,898	705	2,619	835	**1,936**
Apr	1,775	3,254	1,500	3,606	3,067	2,966	3,090	2,912	1,738	**2,477**
May	3,854	3,213	2,140	4,413	2,354	3,746	1,478	2,834	14,096	**2,638**
Jun	2,700	4,461	2,565	3,975	60	4,186	1,233	3,601	4,911	**4,752**
Jul	-	5,062	1,806	3,905	506	4,374	4,145	4,367	3,356	**4,772**
Aug	2,029	4,188	1,558	4,023	3,360	3,490	145	3,122	374	**3,269**
Sep	780	3,526	2,634	2,450	1,340	2,874	1,231	2,527	900	**3,497**
Oct	2,203	2,397	1,508	1,538	1,275	2,700	180	1,998	1,089	**2,185**
Nov	944	1,332	468	1,397	59	1,658	221	1,386	2,194	**1,259**
Dec	374	1,459	1,704	1,178	431	1,126	196	1,010	1,607	**1,319**
Total	**17,441**	**33,398**	**17,873**	**32,505**	**14,555**	**33,431**	**13,259**	**29,870**	**31,738**	**30,901**

Topography

The quality of groundwater, lakes, and streams of a watershed depends on the pollutants present and the movement of water through soils, deeper rock formations, man-made structures, and the bodies of water themselves. The topography, geology, soils, and land use of a specific point and its surrounding area are what influence the movement of water and determine where pollutants accumulate and interact with existing conditions to cause impairment.

The topography of a watershed is what defines its boundaries, but it also influences spatial distributions of temperature, local slopes, subcatchment areas, and vegetation. Soils interact with these factors and their own individual characteristics to play a major role in the transport and storage of water through the landscape. Therefore, topography helps define soil moisture through four main factors as described below. One thing to note is that these factors represent general relationships that affect and may also be affected by other characteristics of the soil including the hydraulic conductivity, its parent material, and soil conservation and management practices (Florinsky, 2012).

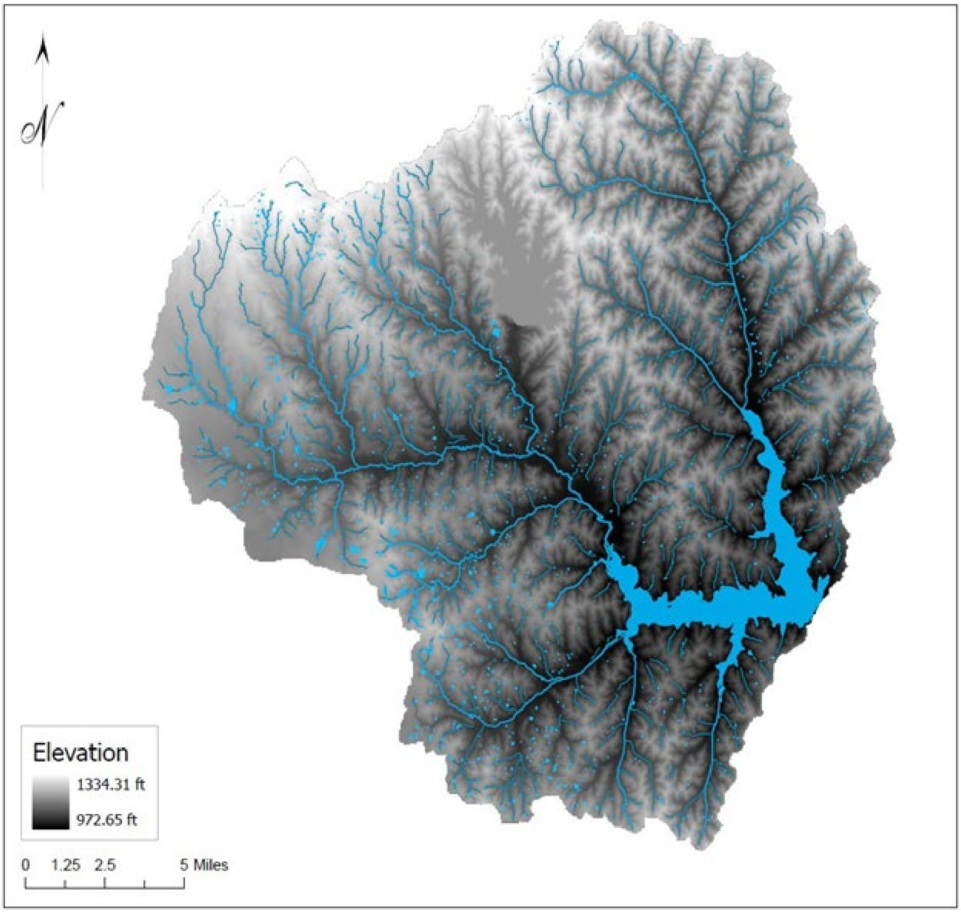
1. Slope gradient – As slope gradient increases, the velocity of water increases and moisture decreases, thus increasing runoff and transport of water out of the area.
2. Slope aspect – Slope aspect is the orientation of a slope as it relates to cardinal direction. Areas with differing degrees of exposure to direct sunshine impact the redistribution of snow over land and rates of freezing or melting, hence contributing to soil moisture. Increased soil moisture can indicate areas more likely to pond or saturate leading to increased surface runoff.
3. Horizontal and vertical curvatures – The curvature in topography is the “slope of the slope” and determines whether a surface is linear, convex, or concave in varying directions (Kimerling et. Al, 2011). These values help estimate overland and intrasoil water flow through where it is likely to converge or diverge as well as accelerate or decelerate. For example, saturated zones are observed in areas of convergence and deceleration (Florinsky, 2012).
4. Location of a point in a catchment area – Slope gradient and the location of an area within a catchment area helps define the topographic index, which is one measure of flow accumulation and high soil moisture.

These four factors impact soil moisture, which in turn impacts water quality. For example, areas more likely to saturate and pond can accumulate pollutants that are washed off through surface runoff in a larger storm. A low spot in a small ranchette storing manure in an uncovered area nearby can receive stormwater mixed with nutrients and contribute to polluted runoff once it is saturated and overflows.

Figure 4 below shows only elevation within the Lake Thunderbird watershed, ranging from approximately 973 – 1334 ft. The watershed is within the relatively flat geographical region, the Red Bed Plains, consisting of flat plains and gently rolling hills.

Figure 4

Lake Thunderbird Watershed Elevation Map

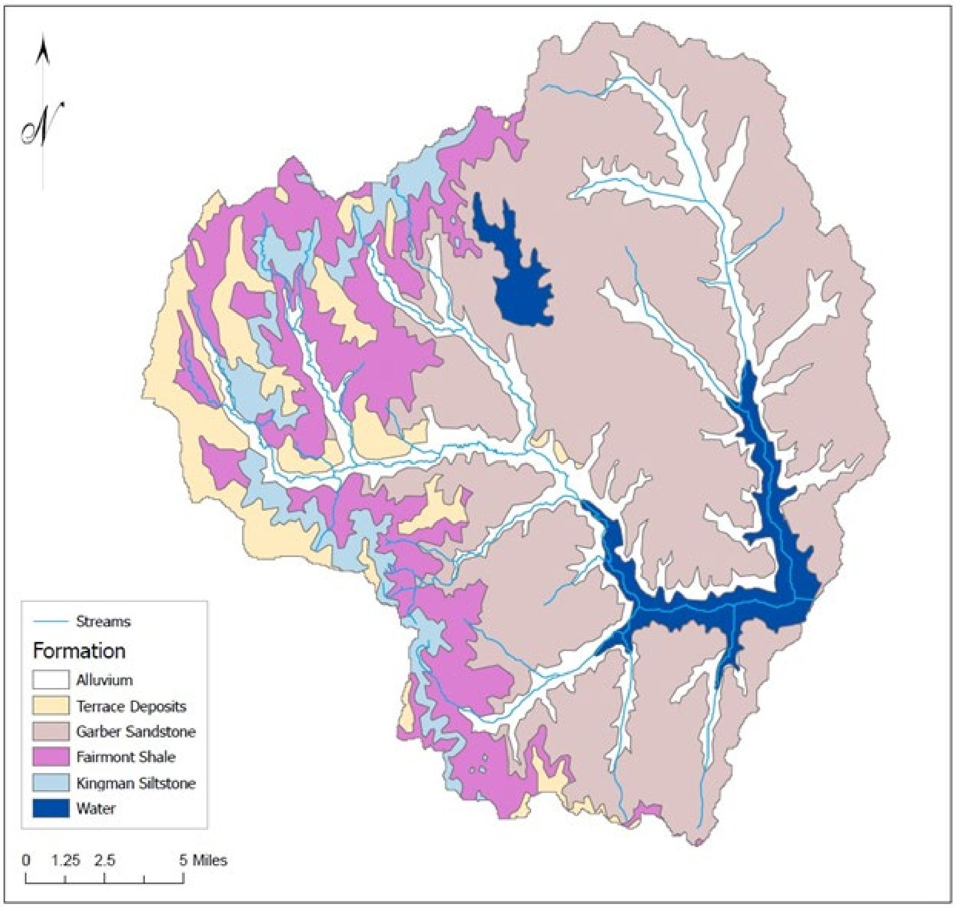


Geology

Figure 5 shows a definitive north to south partition of the bedrock underlying the watershed. The eastern side encompasses a section of the area's Garber Wellington Formation which is primarily cross-bedded, fine-grained sandstone with some floodplain deposits or mudstones (Smith, 2004). To the west, the Permian-age Hennessey Group formations encompass interbedded red shale, clay, and some siltstone. The terrace and alluvium deposits located along the major streams are lenticular beds of unconsolidated or loosely consolidated clays, silts, sand, and gravel (USGS & OWRB, 2019).

Figure 5

Lake Thunderbird Watershed Bedrock



The geology of the area defines the availability of fresh ground water and the dynamics of its flow through the formation of aquifers. The Central Oklahoma Aquifer lies beneath the Lake Thunderbird watershed and has the vertical extent shown in Figure 6 below (USGS & OWRB, 2019). The aquifer is known as the Garber Wellington Aquifer because most of the groundwater yield available exists within that formation, compared to the bedrock areas of shale, siltstone and the shallower terrace deposits. The predominant clay and lower hydraulic conductivity of the Hennessey Group acts as a confining layer, and the terrace and alluvial deposits hold a comparatively lower fraction of the total available water. The first water depth of the aquifer within the watershed begins at approximately 57-107 ft.[3] The maximum annual yield (MAY) of the Garber Wellington was tentatively determined to be 2.0-acre feet per acre per year by OWRB in August 2019.[4]

The aquifer can also be divided into confined areas, bordering the Hennessey Group, and both shallow and deep unconfined areas in the central

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[3] Average of watershed elevation and does not reflect average value of wells in the area

[4] From OWRB's Maximum Annual Yield (MAY) Fact Sheet, the MAY of a groundwater basin is "used to describe thetotal amount of fresh groundwater that can be withdrawn while allowing a minimum 20-year life of the basin"

region. Brine lays at deeper depths and is not available as fresh water. The relationship between the aquifer and the watershed is twofold. First, the availability of groundwater reduces the reliance on Lake Thunderbird as the sole source of drinking water. Second, unconfined aquifer areas and streams in the watershed are hydrologically connected, meaning that precipitation that recharges groundwater is witnessed as the baseflow of streams. Activities such as pumping from shallow wells can alter that recharge and flow relationship if overused. The confined aquifer is not readily recharged by precipitation and chemical processes differ from those in shallower areas. In the watershed, the City of Norman has faced levels of arsenic beyond those acceptable by the Environmental Protection Agency's (EPA) water quality standards in its deep wells and has participated in pilot studies and research to determine the best course of action for removal/treatment.

Figure 6

Extent of the Central Oklahoma Aquifer

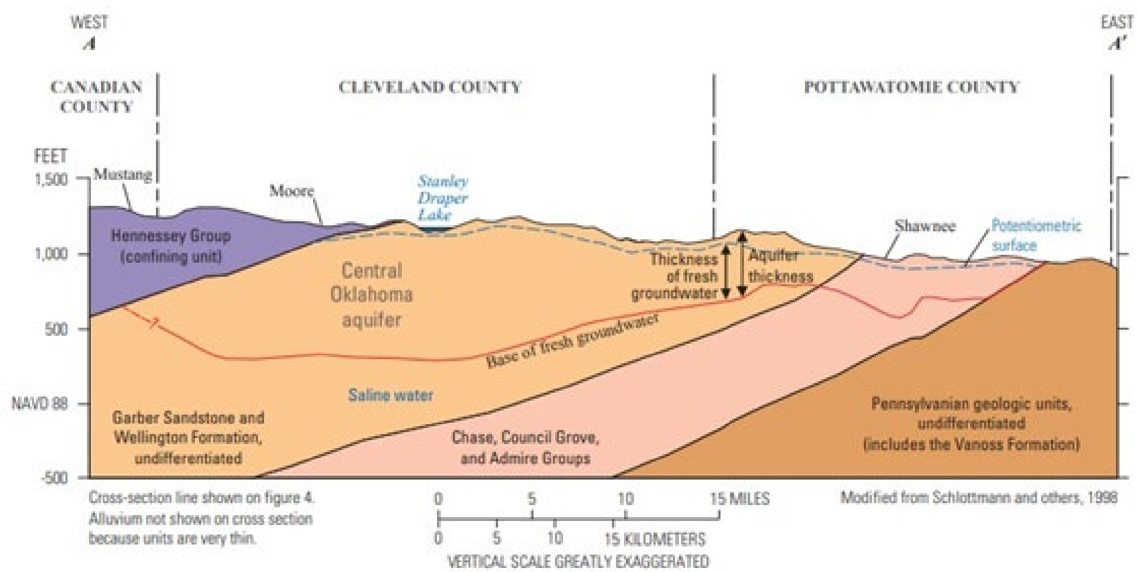


Figure 5. Cross-section *A–A′* diagram (shown on figure 4) showing bedrock geologic units of the Central Oklahoma aquifer.

The components of the rock also contribute to the composition of soils on the surface. Although soils overlaying bedrock are composed of the same material, older formed soils are affected by climate and chemical and physical processes that can alter their characteristics. [5]

Soils

Soil taxonomy consists of 6 levels, with the *series* being the lowest category (highest specificity). This is also the name typically used to name soil map units as provided by the United States Department of Agriculture (USDA) Web Soil Survey. In the Lake Thunderbird Watershed, the

[5] This figure is reprinted from publicly available data from the OWRB and USGS in their 2019 study *Hydrogeologyand simulation of groundwater flow in the Central Oklahoma (Garber-Wellington) Aquifer, Oklahoma, 1987 to 2009, and simulation of available water in storage*

soil series that make up approximately 50% of all soils are Newalla (22%), Darsil (10%), Pulaski (9%), Renfrow (6%) and Stephenville (6%).[6] Table 8 includes a description of each and Figure 7 shows their distribution.

Table 8

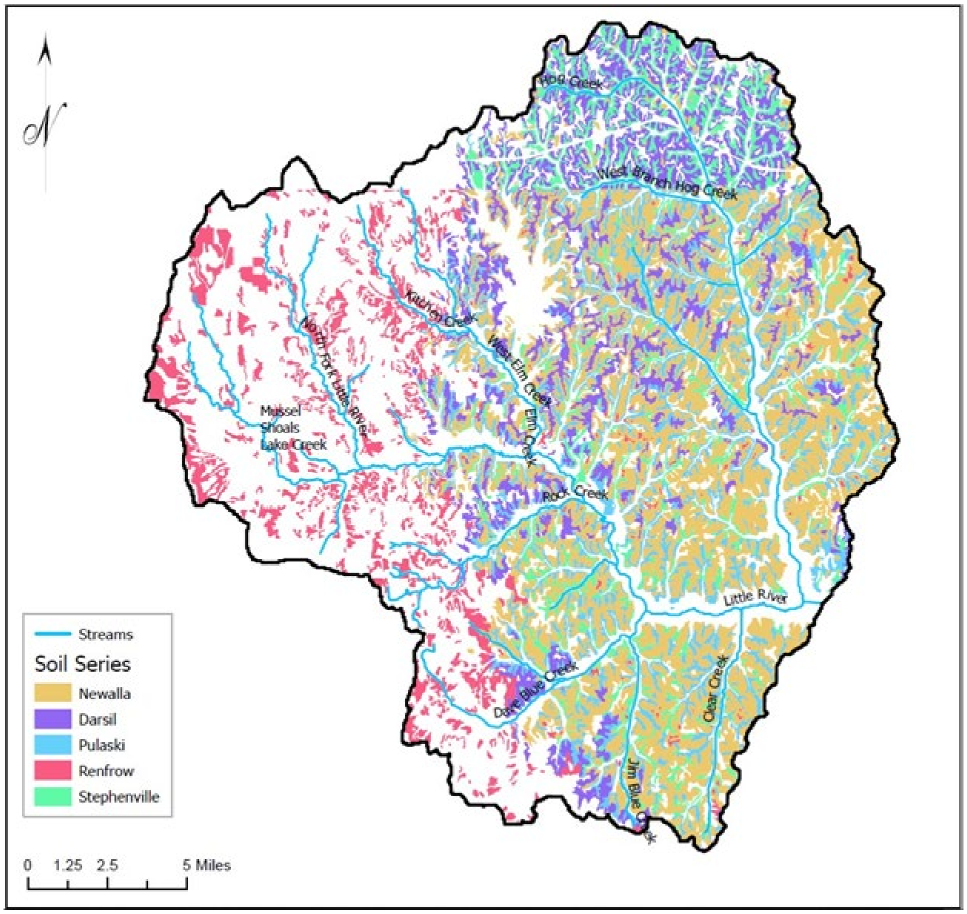
Predominant soils in the Lake Thunderbird Watershed

Soil Series	Description
Newalla	Deep, moderately well drained, very slowly permeable soils. The upper part formed in material weathered from sandstone and the lower part formed in material weathered from shale of Permian age.
Darsil	Shallow, excessively drained, soils that formed in material weathered from weakly cemented sandstone of Permian age. These soils occur on convex ridge crests of low hills.
Pulaski	Very deep, well drained, moderately rapidly permeable flood plain soils that formed in loamy alluvial sediments of Holocene age. These nearly level to very gently sloping flood plain soils are on small tributaries.
Renfrow	Very deep well drained soils that formed in material weathered from clayey shale of Permian age. These soils are on summits and backslopes of low hills.
Stephenville	Moderately deep, well drained, soils formed in material weathered from sandstone of Permian age. These soils are on very gently sloping to moderately steep side slopes of hills.

[6] These are approximate percentages since there is a discrepancy between soil map unit identification at theCleveland & Oklahoma County border in the NRCS Soil Survey

Figure 7

Lake Thunderbird Watershed Predominant Soils



Specific soil types vary widely within a watershed as categorized by not just their soil series, but the various components in each area and their slope, erosion status and other properties. However, when looking at only one attribute, clearer patterns emerge. The following discussion is an overview of a few soil properties relevant to the water quality of the watershed.

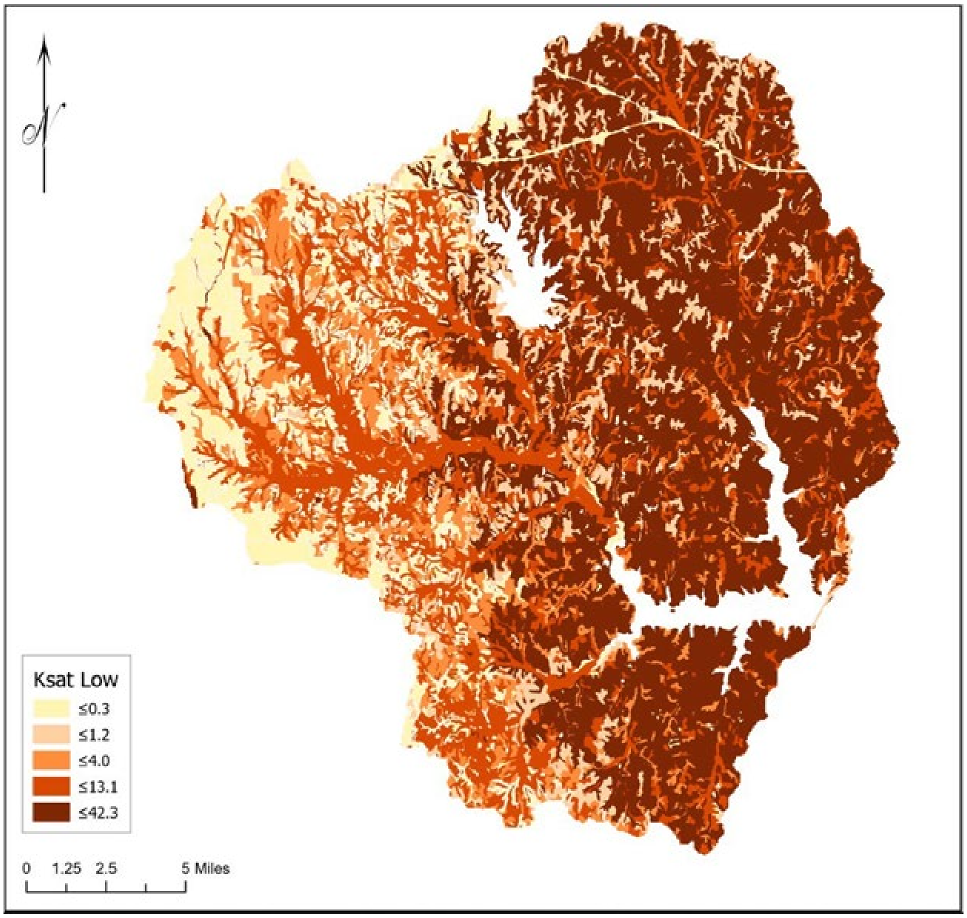
In Figure 8, the hydraulic conductivity of each soil unit area is mapped for the watershed.[7] Saturated hydraulic conductivity (Ksat) is the rate at which water moves through soil and represents the ease with which it flows through the pores and fractures of soil. The porosity or types and sizes of those pathways represent the permeability of the soil and depend on available organic matter, aggregation and other factors.

As in the geological map above, there is a dividing line between the hydraulic conductivity of the soils on the east versus west side of the watershed. The latter, overlaying shale and siltstone formations, have a lower hydraulic conductivity limit than the sandier (greater percentage of sand components in each soil map unit area) soils of the east.

[7] "Hydraulic conductivity of the material can be defined as the ability of the fluid to pass through the pores andfractured rocks" (Saravanan, 2019)

Figure 8

Lake Thunderbird Watershed Hydraulic Conductivity



The runoff class assigned to soils is based on Ksat and percent slope, and is divided into 6 categories of potential runoff: negligible, very low, low, medium, high, or very high. Hydrologic soil group classifications (A through D) are also intertwined with runoff potential. Group D soils have lower Ksat values and the highest runoff potential. Hydrologic groups are also based on depth to a seasonal high-water table, infiltration rate, permeability after prolonged wetting, and depth to a very slowly permeable layer. As discussed previously, stormwater runoff carries pollutants from different land uses into nearby streams and lakes. Therefore, areas with soils falling into high or very high runoff classes and classified as Group C or D are more likely to contribute to stormwater runoff.

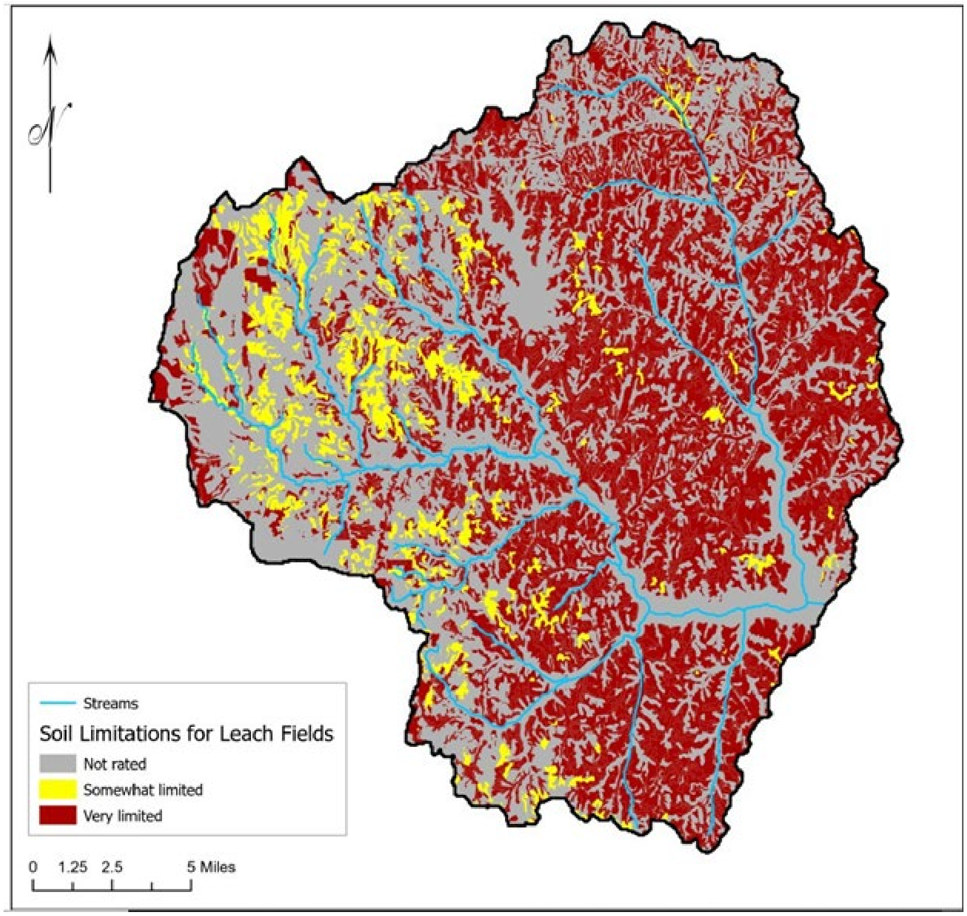
These characteristics also define the adequacy of soils or a soil area to different applications. Limits to the adequacy of soils for septic tank leach fields, for example, are based on seepage, water movement rate, slope, depth to bedrock, flooding and depth to the saturated zone. In Figure 9 below, the rating class "very limited" indicates that the soil has one or more features that are unfavorable for septic tank leach field application.[8] Malfunctioning septic tanks or leach fields are one of many known possible contributors of nutrients and bacteria to nearby streams and lakes. However, few studies have

[8] The eastern part of the watershed has sandier soils with higher Ksat values. However, for septic tank leach field installation, the dominant soils in this region -Newalla and Darsil - limit their use due to slope/ depth to bed rock and slow percolation, respectively.

been completed in the watershed for a comprehensive analysis of current septic tank influence.

Figure 9

Lake Thunderbird Watershed Septic Tank Leach Field Limited Areas

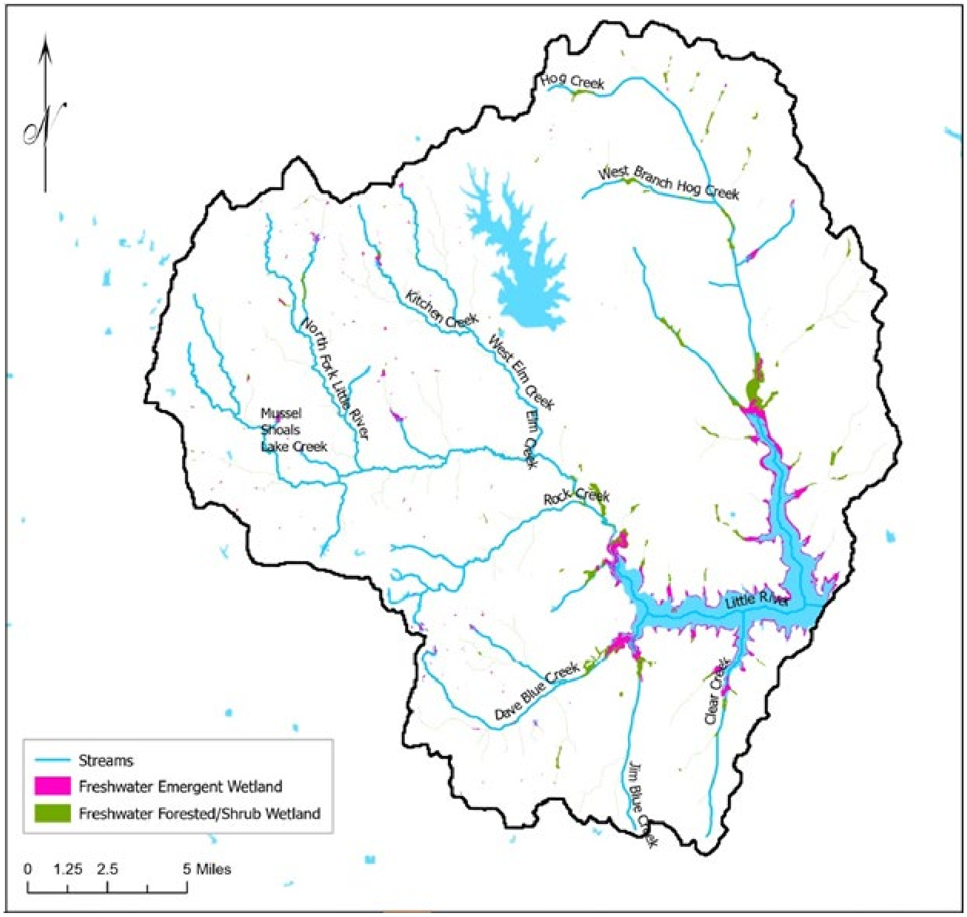


Soils can also present clues on how to use the natural environment for water quality improvement in the watershed. One aspect to note is that none of the soils in the watershed have a hydric rating ("Under natural conditions, these soils [hydric soils] are either saturated or inundated long enough during the growing season to support the growth and reproduction of hydrophytic vegetation") (USDA, 2016). The lack of hydric soils indicates that wetlands were not a historically prevalent land cover category in the area, and likely could be seen only as narrow riparian wetlands. The 1981 National Wetland Inventory mapping (see Figure 10) shows an increase in wetland land cover, compared to historical data, suggesting that the creation of the Lake Thunderbird reservoir helped establish freshwater emergent and freshwater forested/shrub wetlands along the downstream areas of its tributaries. These wetlands are helpful in capturing nutrients, sediment and other pollutants as water slows down and enters pooled areas where storage and biological processes by organisms and vegetation can capture and transform pollutants into biologically beneficial versions. Considering existing and potential new constructed wetlands, the 2011 Oklahoma Conservation

Commission (OCC) study on wetland feasibility found that both small- and large- scale wetland construction would be applicable to improving Lake Thunderbird water quality (OCC, 2011)

Figure 10

Lake Thunderbird Watershed Wetlands



4.3 Streamflow

Models developed for nonpoint source pollutant runoff to streams and lakes in the watershed depend highly on streamflow data for load calculations and for calibration to ensure the model reflects local watershed dynamics. However, the only USGS gauging stations in the watershed are at the Lake Stanley Draper dam and the Lake Thunderbird dam. The ODEQ 2013 TMDL model estimated flow using the HSPF watershed model and did not use existing measured flows.

In recent years, the availability of data has expanded. Each municipality has monitoring stations for both water quality and discharge in the streams within their boundaries (refer to section "Watershed features") as part of compliance with TMDL guidelines. Therefore, as that data is analyzed and reviewed for quality control, there will be an opportunity for watershed-wide analysis of pollutant loads, flooding and low flow patterns, and a seasonal and long-term evaluation of streamflow relationships to impairment, both within the streams and at the lake. To date, the data has not been fully analyzed.

5.0 Watershed features

As discussed, Lake Thunderbird is a reservoir, whose dam is on the southeastern side of the lake. Called the Norman Dam, COMCD describes it as "a zoned earthfill embankment with a volume of about 3 million cubic yards. The crest of the dam is 30 feet wide, 7,263 feet long, and about 144 feet high. The spillway is located in the left abutment and has a morning-glory inlet with an ungated crest of 22-feet 4-inch diameter" (COMCD, 2021). Lake Stanley Draper is another reservoir in the watershed from which Oklahoma City sources a portion of its drinking water. However, there is minimal discharge downstream of the lake into East Elm Creek and so is typically excluded from stormwater modeling of the Lake Thunderbird Watershed. This report does not evaluate Lake Stanley Draper as a water source for the watershed.

Other watershed features are highlighted in Figure 11 below. Historic sites include the Little Doctor Homestead, a historic Absentee Shawnee homestead in what is now called the Post Oak Campground (Bureau of Reclamation, 2009). Nature-oriented areas include the Little River State Park and a few Land Conservation Easements in Norman.[9] There are no designated wildlife management areas in the watershed per the Oklahoma Department of Wildlife Conservation's (ODWC) online maps. However, there are designated fishing areas and daily limits within the lake. In addition, COMCD has authority from the BOR to control feral hog populations as necessary. In recent months, there has not been much activity on that front.

Figure 11 below shows these features spatially.

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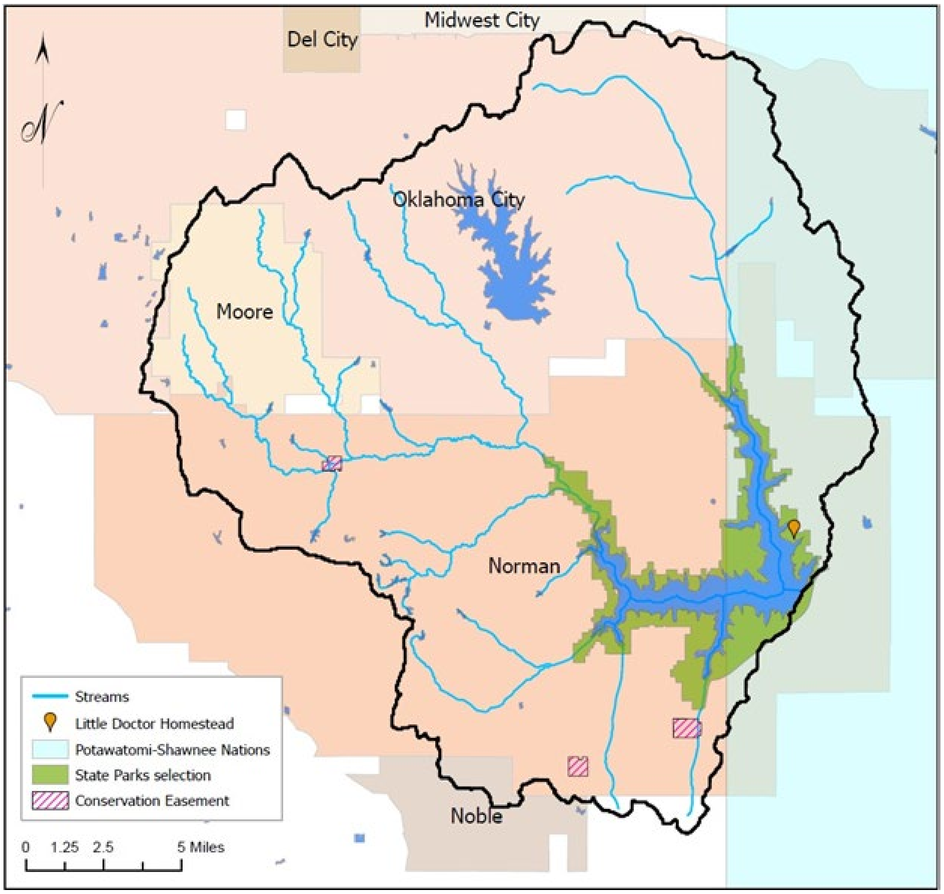
[9] Note: these areas were estimated from City of Norman GIS data available online but not downloadable

Figure 11

Lake Thunderbird Watershed Features



There are no point sources in the watershed from which pollutants are discharged directly into a body of water from wastewater or industrial activities[10]. However, there are a few other locations of note when documenting the current state of industrial/construction practices in the area and their potential contribution to water quality impairment. The following discussion identifies locations as monitored by the EPA or the state. Figure 12 below presents them spatially.

The EPA publishes Toxic Release Inventory (TRI) data every year on those facilities that release any of the listed 770 chemicals that can cause significant chronic or adverse human health effects or significant adverse environmental effects. Not all industrial facilities must participate in the program but those that are, report on any release to water, air, or land. The watershed has four TRI locations as listed in Table 9 below:[11]

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[10] There are no municipal wastewater facilities, industrial wastewater facilities, or concentrated animal feeding operations (CAFO) within the Lake Thunderbird watershed.

[11]. Environmental Protection Agency. (2019). *2019 TRI Factsheet: State*-Oklahoma.

Table 9

Lake Thunderbird Watershed EPA Toxic Release Inventory Locations

Facility Name	Chemical	Fugitive Air (lbs)	Water (lbs)	On-site release total (lbs)
SOUTHWESTERN WIRE INC	Nickel	0	0	0
	Zinc compounds	383	0	383
	Lead and lead compounds	0.2	0	0.2
JOHNSON CONTROLS INC-NORMAN	Copper	79.2	24.7	103.9
MOORE BATCH PLANT	Lead and lead compounds	0	0	0
	Nitrate compounds (reportable only when in aqueous solution)	0	0	0
BIO-CIDE INTERNATIONAL INC	Chlorine dioxide	0	0	0

The National Pollutant Discharge Elimination System (NPDES) was established to regulate point source pollutant discharges. The program includes both stormwater and industrial and municipal wastewater discharges. In Oklahoma, ODEQ issues the permits in most areas. The EPA issues permits for activities in areas where ODEQ is not the permitting authority.[12]

As stated previously, there are no point source industrial or wastewater discharges within the watershed. However, there are stormwater discharge sites. The Lake Thunderbird Watershed encompasses 15 OKR05 Multi-Sector General Permit (MSGP) stormwater discharge sites as listed in Table 10. These sites are allowed to discharge stormwater from their property into nearby bodies of water but are required to sample and monitor it. The site that released copper to water in 2019 according to the TRI, Johnson Controls, Inc., reported the total as 100% stormwater-sourced and estimated the total quantity through sampling. Its MSGP Permit allows for stormwater discharge into the Little River.

The NPDES program also requires stormwater permits for construction sites (OKR10 permits). The active OKR10 permits are included here because runoff from disturbed land can contribute sediment loads to streams. The three municipalities with TMDL limits designated by ODEQ are required to include any potential contribution from sites with authorized Industrial or Construction Stormwater permits within their waste load allocations.[13]

Also included in the map are total retention facilities, or wastewater treatment sites managed by small entities that do not discharge into a stream or lake. However, the potential exists for some contribution of pollutants from these sites if they overflow or if the collection system connected to the lagoons malfunctions.

[12] Note that the sites discussed in this section are all permitted sites. There is the potential for additional unpermitted sites to exist within the watershed and contribute to pollutant loads.

[13] Stated on Page 3 of The Lake Thunderbird report prepared by ODEQ in 2013.

Note that in most past models produced by ODEQ and other agencies in the area, the discharging and potentially discharging locations discussed are not emphasized in the analysis, since the contamination likelihood is considered to be minimal and dynamic compared to that of nonpoint source runoff.

Finally, the map includes monitoring station locations managed by each of the three cities. These stations are on important streams that feed Lake Thunderbird, and the data collected are used to establish baseline conditions and to identify progress towards TMDL compliance. Due to their spatial distribution, they are also likely to capture changes in water quality from permit location discharges.

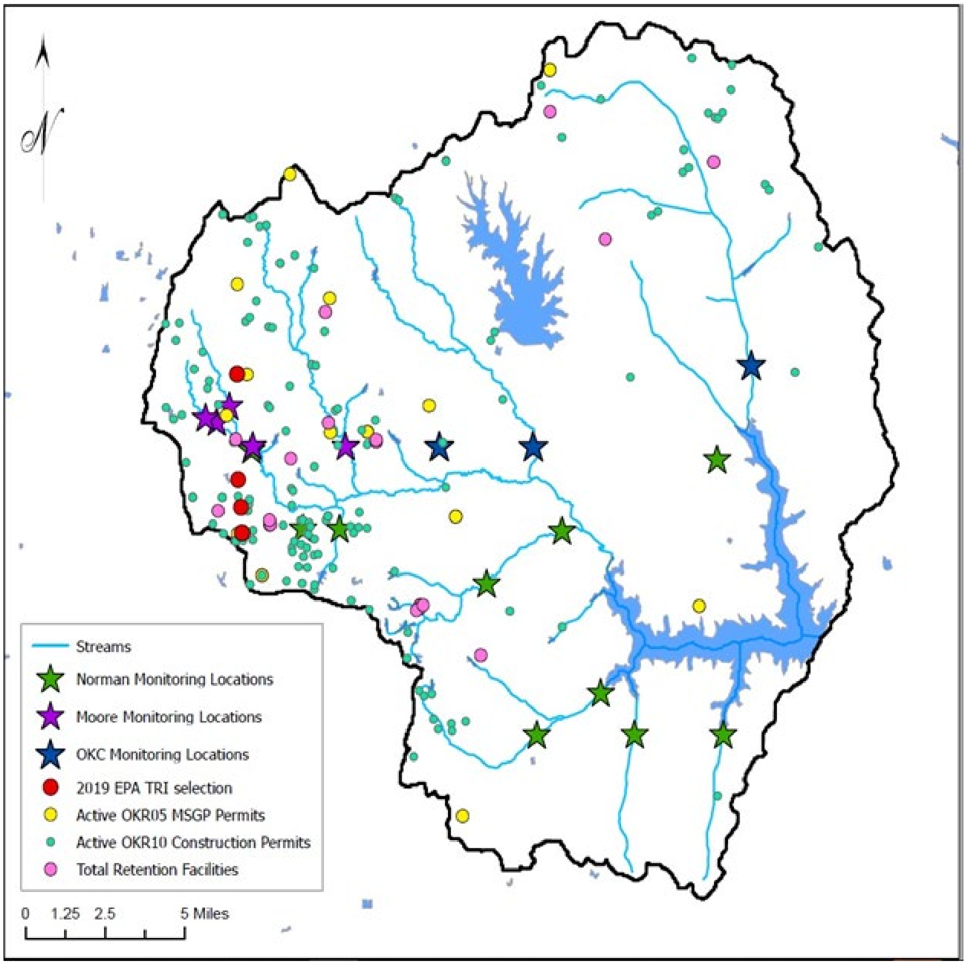
Table 10

Lake Thunderbird Watershed Current MSGP Permits

	Facility	City	Permit	Effective Date	Standard Industrial Classification (SIC) Description	Sensitive Waters
1	SOUTHEAST OKC LANDFILL	OKC	OKR050 488	4/01/19	Refuse Systems	No
2	WILLIAMS LAND	OKC	OKR052 553	6/25/19	Miscellaneous Nonmetallic Minerals	No
3	Vickers S&G $4	Noble	OKR053 128	1/14/19	Miscellaneous Nonmetallic Minerals	No
4	Butler Yard	OKC	OKR052 700	4/01/19	Crushed and Broken Stone	No
5	SPAULDING AUTO SALVAGE	Norman	OKR051 422	5/16/18	Motor Vehicle Parts, Used	No
6	Derichbourgh Recycling USA	Norman	OKR053 695	9/01/19	Motor Vehicle Parts, Used	No
7	E & S EQUIPMENT, INC.	Norman	OKR051 761	9/01/19	Industrial Valves	No
8	Norris Rods Inc - 12500 S Sunnylane Rd	Moore	OKR053 758	12/05/19	Oil and Gas Field Services	No
9	FEDEX FREIGHT EAST INC- OKLAHOMA CUSTOMER CENTER	OKC	OKR051 530	5/10/18	Trucking, Except Local	No
10	Max Wesheimer Airport	Norman	OKR050 565	2/05/19	Airports, Flying Fields, & Services	Yes
11	Silver Star - PMI	Moore	OKR050 570	6/14/19	Asphalt Paving Mixtures and Blocks	No
12	Johnson Controls Inc - Norman	Norman	OKR050 347	4/30/19	Refrigeration and Heating Equipment	No
13	SOUTHWESTERN WIRE CO	Norman	OKR051 014	10/01/19	Miscellaneous Fabricated Wire Products	No
14	Del Real Foods LLC	Moore	OKR053 627	5/01/19	Frozen Specialties	No
15	RUPPERT ENTERPRISES INC	Moore	OKR050 252	12/30/19	Motor Vehicle Parts, Used	No

Figure 12

Lake Thunderbird Watershed Toxic Release Inventory and Permit Locations



6.0 Watershed uses and users

Watershed stakeholders encompass a wide variety of groups, and all are impacted by water quality and quantity issues. For example, recreation clubs benefit from healthy streams where swimming, camping, and a healthy ecosystem are key to maximizing benefits from being and experiencing the outdoors. Many residents both within and outside the watershed get their drinking water from the lake after it is treated by their municipalities. The cities and local businesses benefit from tourism to the area, and the lake itself offers many opportunities for recreation.

The 2019 population estimate for the cities within the watershed is provided in Table 11.

Table 11

Lake Thunderbird Uses and Users

City	Estimated 2019 Population
Del City	21,712
Midwest City	57,407
Moore	62,055
Noble	7,053
Norman	124,880
Oklahoma	655,057

The watershed's largest water consumption comes from the residents of Norman, Del City, and Midwest City who source a part of their drinking water from Lake Thunderbird.[14] COMCD holds the water rights for supply from the lake. The proportion allocated to each city (based on a maximum total supply per year of 21,600 acre-feet) is as follows: Norman is permitted to use up to 43.8% of the annual total available to COMCD. Del City can use up to 15.8% and Midwest City can use up to 40.4%. The actual volumes differ per year based on available supply. Midwest City's water treatment plant is designed to treat 13 MGD and Del City's plant is designed for 5 MGD.

With the growing demand for water and statewide plans that have indicated potential signs of scarcity in the future, all three cities have supplemental groundwater sources. In addition, the City of Norman has the ability to purchase water from Oklahoma City.

[14] Water Supply from Lake Stanley Draper is not included in this report.

LTWA Open House

7.0 Public Education and Outreach Plan

The LTWA established an Education and Outreach Committee at the start of the organization. The goal was to develop a dynamic and proactive education and outreach plan to disseminate information gathered by the LTWA and to guide the organization in how best to reach watershed stakeholders. The Committee also supported the development of the IWMP through preliminary efforts to gather input from the public through the development of a logo, an LTWA website and an interactive site hosted by Guernsey.

7.1 Public Input

The LTWA surveyed watershed residents to find out what they know and what they think are the main issues in the watershed. Some of these methods were used during watershed clean up events in 2020 and 2021, others were only available virtually. The first LTWA Open House was held in person on June 15, 2021 at The Station in Moore. This event featured poster boards with content available on the LTWA website (See Appendix B for digital versions of the boards).

Public input on watershed health and potential management strategies was sought through three methods:

- Online survey on management practices: The question asked was "If funding was available to help you implement a Best Management Practice on your property, which of the following Best Management Practices would you be most likely to implement?"

  The management practices available for ranking were a structural BMP subgroup of those developed by the TAG, since residential/commercial/landowners would not be responsible for most catchment scale BMPs. The results showed that the top five choices were:

1) Rainwater harvesting
2) Nutrient management
3) Reduced tillage cropping systems, terraces, contour stripping
4) Conservation Easements
5) Bioretention/filtration cells or raingardens

- Survey on areas of concern: Visitors to the LTWA Interactive Site were able to attach a comment to a specific location on the watershed map. The instructions were: "let us know your thoughts on the project, any local knowledge you may have about the watershed, conservation tips, questions, or concerns."

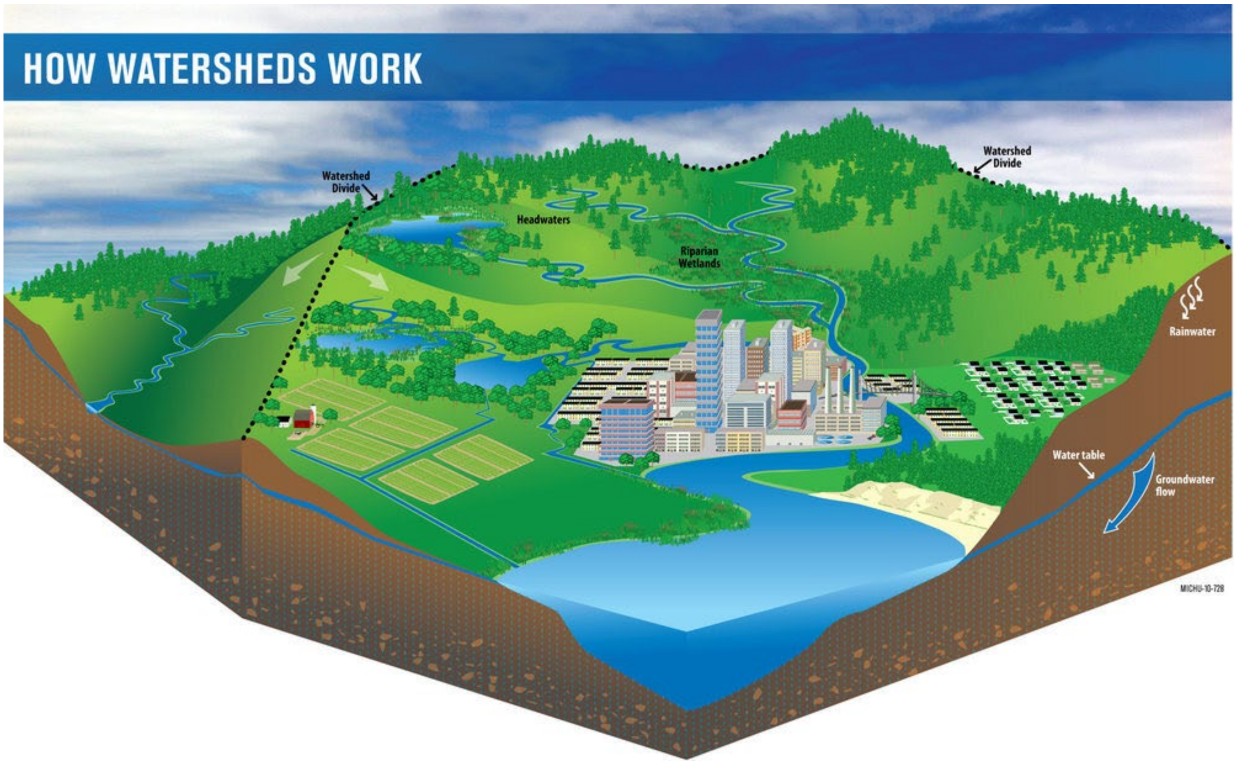
  There were eight comments left on the interactive map (only seven pertaining to the watershed):

1) "Soil erosion is occurring on both sides of Sooner Road between SE 134th and approximately S Osborne Way"
2) "The construction project on the southwest side of south 34th and Broadway around Central Park Drive, which I believe may be part of The Apples subdivision, has silt fences knocked over, dirt tracking, and erosion off the site"
3) "The construction project (maybe a new subdivision?) on the west side of the Bryant Broadway intersection has silt fences knocked over, and dirt track off the site"
4) "The unincorporated area east of Belmar Golf Club experiences frequent gavel and dirt washout from the businesses and homes into the roadways and surrounding areas each time it rains"
5) "The hillsides along both Tecumseh Road and 12th Ave NE are eroding. It is not uncommon to find dirt washing into the road after rain"
6) "There is a lot of soil erosion taking place in Northeast Lions Park in Norman, especially around the pond area"
7) "Creekside Bike Park is experiencing a significant amount of trash and tire dumping" (this park is just outside the watershed)

- Survey on stakeholder perception of stormwater quality and the watershed

  The majority of responses reflected the following: (Please see Appendix C for the full results)

1) The water quality in Lake Thunderbird is getting much worse or is the same
2) Agreement that the quality of water in the streams near their homes affects Lake Thunderbird
3) Trash and stormwater runoff have the biggest impact on Lake Thunderbird
4) Agreement that the things individuals do in their yard, driveway and other areas have impact on water quality of streams
5) Local government, state government, and individuals are the top three responsible entities for protecting water quality in the watershed
6) Social media is the preferred way to communicate information about the watershed to its stakeholders



Source: Mississippi Watershed Management Organization

The purpose of the public input was to identify challenges and strengths in implementation of the management strategies. For example, the TAG did not choose rainwater harvesting as one of the forefront recommended strategies. The discrepancy between the TAG and public response may be due to widespread knowledge of rainwater harvesting as an environmentally conscious individual action, versus its lower efficiency at improving stormwater quality. The comments on the interactive map showed that erosion from construction projects and along roads are highly visible items that are easily identifiable as problem areas to address.

Based on the results, the LTWA will focus its education efforts on helping residents better understand all the issues that impact water quality, how individuals can make a difference and who is responsible for protecting water quality.

7.2 Ongoing Efforts

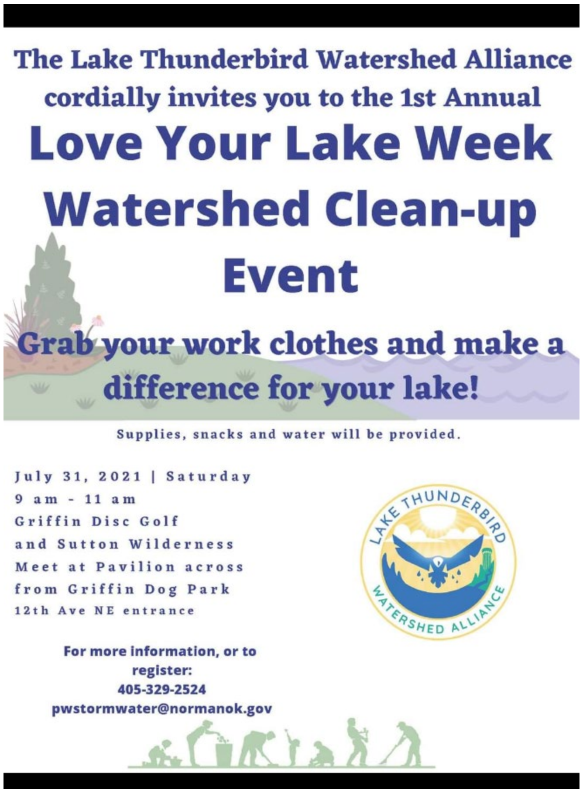
The LTWA provides continued opportunity for communication from watershed residents through the interactive site established during the planning process. The interactive site uses GIS technology to allow citizens to mark and describe issues they notice at locations throughout the watershed. Based on this input, the LTWA will identify where restoration work or best management practices will be most effective.

In addition, the interactive site and LTWA website provide general knowledge on stormwater quality and watershed dynamics. Individuals can also access a variety of items on how to take action to begin improving stormwater quality within their households and communities.

To reach a broad audience, the LTWA will partner with local organizations, watershed communities and COMCD to host a variety of educational and hands-on events. Additionally, LTWA has developed and made readily available on their website, educational materials, videos and presentations on a variety of topics.

The LTWA will continue to hold stakeholder and member meetings, coordinate youth water quality-themed summer camps based on a model used in other Oklahoma watersheds, provide watershed displays for members or local groups to check out for events, and participate in city-sponsored watershed events, county fairs and other community events. For more information on what the LTWA is doing and offers, visit their website at https://ltwaok.org.

Outreach materials are included in Appendix D of this plan.



LTWA Event Facebook Post

8.0 Current desktop condition assessment

The TAG provided research and data ranging from city stormwater management plans to annual Lake Thunderbird water quality reports to studies on best management practice (BMP) applicability. There were over 80 studies identified for the project team to review. The studies, along with discussions with the TAG, were used to develop a list of issues in the watershed, identify parameters for monitoring, and establish management strategies.

8.1 Problem areas and priority issues

Most channels within the watershed are unstable to highly unstable due to streambank and bed erosion, and the lake has several reaches of shoreline with category 5 erosion. Consequently, sediment accumulation within the lake's conservation pool is occurring at a rate of 400-acre feet per year (OWRB, 2001). Sediment results in increased turbidity and under anoxic conditions, contributes to higher level of nutrients and lower dissolved oxygen. This encourages the eutrophication of the lake, which is measured through chlorophyll-a, a proxy of algal biomass (OWRB, 2018). The major causes of streambank and bed erosion are increased velocities and flows from urban areas. Locally, livestock can damage streambanks and beds. Shoreline erosion is often due to overland runoff, obstruction of longshore currents, recreational boating activities that require high speeds, and/or loss of the littoral zone. The key areas identified by the TAG as priorities for erosion were:

- Bank erosion at the Upper Little River
- Bank erosion at the Little River
- Bank erosion at the North Fork Little River
- Shoreline erosion at Lake Thunderbird
- Bank erosion at Hog Creek
- Bank erosion at Dave Blue Creek
- Bank erosion at West Elm Creek

Nutrients (nitrogen and phosphorous) were mainly found to be from urban stormwater runoff containing fertilizers, animal waste, oil/grease, road salt although less dense areas and agricultural land can also contribute to nutrient loads (septic system or livestock waste, road salt, decaying foliage, boat wash water, or oil/grease). Increased input of nutrients into streams eventually leads to lake algae growth and an increase in oxygen demand, resulting in elevated chlorophyll-a levels and lower dissolved oxygen, as well as taste and odor complaints. The key areas identified by the TAG as priorities for nutrients were:

- Degraded water quality at the Upper Little River
- Degraded water quality at the North Fork Little River
- Degraded water quality at Dave Blue Creek
- Degraded water quality at Jim Blue Creek

The process also identified data gaps and issues that require further study and consideration to specify sources, causes and impacts. The reason for insufficient information on these items includes projects performed many years ago that were not followed up on with the recommended monitoring or additional studies, lacked priority in funding or research, involved a developing and contentious issue with high public involvement in which a solution has not been established, or required complex undertakings that would involve analyzing the entire watershed for many years. The areas to be further assessed and discussed are:

- Improved sedimentation transport modeling from streambank erosion and mitigation methods for lake shoreline erosion such as breakwaters
- Septic tank spatial influence on stream water quality within the watershed
- Internal loading/legacy loading of nutrients in Lake Thunderbird including lake bottom sediment dynamics
- Further testing and research on CECs. Seasonal testing showed there was nonylphenol, atrazine, simazine, artificial sweeteners and DEET detected in three of the four samples taken.
- Drinking water taste and odor complaints

- Bank erosion along Rock Creek
- Degraded water quality within Little River, Kitchen Creek, and Clear Creek

Table 12 and Table 13 below show the final prioritized watershed issues. The latter lists topics that require further research to identify the best path for addressing them.

Please reference Appendix A for the complete desktop assessment of the watershed to read about how the problem areas and priority issues were identified.

Table 12

Priority Issues for LTWA to Address in the IWMP

No	Issue Category	Specific Issue	Geographical Area
1	Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River
2	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Upper Little River
3	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Little River
4	Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River
5	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	North Fork Little River
6	Shoreline Erosion	High TSS	Lake Thunderbird
7	Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek
7	Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek
7	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Hog Creek
10	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Dave Blue Creek
11	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	West Elm Creek

Table 13

Priority Issues for Further Research to Address in the IWMP

No	Issue Category	Specific Issue	Geographical Area
1	Water Quality Degradation	More data /studies on septic tank potential impacts on water quality. Specific area studies on density, proximity to stream, etc.	Where developments are not connected to city wastewater systems
2	Water Quality Degradation	More data on internal loading/ legacy loading of nutrients in Lake Thunderbird	Lake Thunderbird
3	Water Supply & Capacity	More data on taste and odor complaints from each of the cities and implications for treatment. This includes evaluation of presence of CEC's, pesticides, and herbicides.	Lake Thunderbird
4	Degraded Water Quality	Bank erosion	All watershed streams where erosion has been identified
5	Degraded Water Quality	Flooding effects on water quality	Where flooding is common
6	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Rock Creek
7	Degraded Water Quality	High TDS	Little River
8	Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek
9	Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek (currently monitored)

8.2 Management Strategies to meet goals and objectives

The overarching measure of success of the work done by different groups in the watershed has been the level to which water quality standards at the lake are attained, with the goal of delisting it as an impaired water body. This would require attaining a long-term average chlorophyll a concentration of 10 µg/L at a depth of 0.5 meters, a surface dissolved oxygen concentration of more than 5.0 mg/L during the summer and fall, 6.0 mg/L in the spring and less than 50% of the total volume at a concentration of 2.0 mg/L. For turbidity, the water quality standard is 25 NTUs with less than 10% of collected samples exceeding the value in a 10-year dataset (OWRB, 2018). Table 14 summarizes the water quality standards. These efforts do not only focus on the lake itself, since, by definition, the whole watershed impacts the resulting water quality in the lake. Research on the streams and the influence of all land uses and practices continue to provide clues into the most effective ways of advancing the goal to improve water quality in the watershed.

Table 14

Lake Thunderbird Parameters Monitored for TMDL and Impairment

Parameter	Criteria	Specific Threshold	OWRB 2017-2018 BUMP Data from Lake Thunderbird	OWRB Long term 10-year average (2009-2019)	Reference
Dissolved Oxygen (DO)	Surface criteria for WWAC lakes: 10% or less of surface samples across all life stages and seasons	April 1 – June 15: < 6.0 mg/L OR June 16 – March 31: < 5.0 mg/L	N/A	N/A	**OWRB 785:46-15-5(b)(5)(A)**
	Water column criteria for WWAC lakes: less than 50% of the volume or 50% or less of the water column of all sample sites in the lake	< 2.0 mg/L	Up to 67% of water column < 2 mg/L in July	[15]	**OWRB 785: 46-15-5(b)(6)(A)**
Chlorophyll-a	Long- average (ten-year data used in ODEQ 2013 TMDL report)	< 0.010 mg/L or 10 µg/L at a depth of 0.5 meters	0.021 mg/L	26 µg/L with 82% of samples exceeding 10 µg/L	**OAC 785: 45-5-10(7)**
Turbidity	Lakes: 10% or less of the samples may exceed specific threshold	< 25 NTU	Average: 14 NTU with 4% of values > OWQS of 25 NTU	Average: 24.8 NTU with 26.4 % samples exceeding 25 NTU	**OAC 785:45-5-12(7)**

The TAG was consulted to determine reliable methods for gauging and addressing priority issues. The following tables present the parameters that received more than 50% approval and the top five management strategies for each issue.

Table 15
Parameters for monitoring and effectiveness of management strategies

Issue	Method 1	Method 2	Method 3
Nutrient/ Low DO levels in a stream	Concentration of total nitrogen (TN) and total phosphorous (TP)	Concentration of dissolved oxygen (DO)	
Bank erosion within a stream	Bank erosion hazard index (BEHI)	Channel stability index (CSI)	Near bank stress (NBS)
Shoreline erosion of Lake Thunderbird	Positive shoreline accretion	Establishment of vegetation	Measurements of bank height

[15] One violation in 2019 as 52% of lake's total volume was anoxic water. This value is for 2019 only, not the long-term average. No-long term average value was reported in the 2019 OWRB Water Quality Report for the lake

Table 16

Top 5 Structural and nonstructural management strategies for issue type

Issue	Method 1	Method 2	Method 3	Method 4	Method 5
	Structural Management Strategies				
Nutrient concentrations in a stream	Catchment scale – riparian buffer restoration	Catchment scale – streambank stabilization	Catchment Scale – retention wet pond/ wet bottom extended detention / dry extended detention	Catchment scale – constructed wetland	Local scale – bioretention/ filtration cells or rain gardens
	Nonstructural Management Strategies				
	Education – fertilizers and nutrient runoff/ soil tests	Education – riparian buffers	Administrative – construction site stormwater runoff control	Ag/ livestock – alternative water sources for livestock	Ag/ livestock – rotational grazing
	Structural Management Strategies				
Bank erosion within a stream	Catchment scale – streambank stabilization	Catchment scale – riparian buffer restoration	Catchment Scale – retention wet pond/ wet bottom extended detention / dry extended detention	Local scale – bioretention/ filtration cells or rain gardens	Catchment scale – constructed wetland
	Nonstructural Management Strategies				
	Education – riparian buffers	Ag/ livestock – conservation easements	Education – earth disturbance and importance of soil cover	Compensatory Mitigation	Further monitoring and research
	Structural and Nonstructural Management Strategies				
Shoreline erosion of Lake Thunderbird	Wetland restoration in areas where tributaries enter lake	Access control and protection in certain lake areas	Installation of breakwaters	Lake wide limitations on engine size or speed restrictions	

Additional points to consider for priority issue management:

- 5 years is an adequate period to track progress made on each issue
- Every management strategy should be site specific

9.0 Implementation

The mission of the LTWA relies on implementation of an agreed upon IWMP and its future versions. Below are short, medium, and long-term goals to identify where the majority of the effort of the LTWA and its members is currently directed towards.

Short Term

- **Raise awareness**
  - Continue with education efforts through public and community meetings
  - Distribute educational materials
  - Meet periodically with other watershed entities such as conservation districts, state agencies, landowner organizations, farm groups and HOAs to both provide and gather information
- **Targeted effort to imporove water quality**
  - Determine which BMPs will provide the most benefit and be the most implementable to target funding sources based on public input and agency/municipal experience
  - Work with local landowners to implement those practices through development of conservation plans or other mechanism

Medium Term

- **Report improvements in water quality as a result of continued monitoring**
  - Share it with members and make it easily understandable for the public
- **Track implementation of BMP locations**
- **Update plan as things change (e.g. TMDL compliance monitoring and reporting from the three MS4 permitted cities provide vital data on progress and focus areas)**
- **Continue education the public and include water quality data and effects of BMPS**
- **Develop short videos featuring local landowners that are implementing practices to gain trust and acceptance.**

Long Term

- **Show longer-term water quality trends to show improvements or identify additional areas to work in**
- **Investigate new technology and watershed management support decision tools**
- **Continue implementing most up-to-date BMPs**
- **Continue education programing and ensuring they are relevant, use latest technologies or tools and ensure they remain engaging.**

10.0 Funding Sources

The LTWA will continue to research funding sources from a variety of entities. The local conservation districts have cost-share programs to implement some BMPs within the watershed. The LTWA will meet with the local district boards to discuss opportunities where the cost-share practices they approve can help improve water quality. Other grant opportunities include the Bureau of Reclamation WaterSmart Phase II grant for plan implementation and funding through the Oklahoma Water Resources Board for septic system replacement or other nonpoint source water quality improvement practices.

The LTWA board will do periodic searches for grants available from foundations or other entities that offer grants, such as the National Environmental Education Foundation (NEEF) or locally through the Lake Thunderbird Education Foundation, to help strengthen their education and outreach program.

See Appendix E for a comprehensive list of funding opportunities. Not all of the sources have eligibility for nonprofits but all offer pathways for the LTWA to help other organizations and landowners in the watershed have the support to implement conservation practices, participate in education programs, and form partnerships to improve water quality and quantity in the watershed.

11.0 Resources

Financial resources are certainly a need for the organization and plans are in place to help identify ways to address this need. However, the best and most useful resource the LTWA has is its board, members and partners. By tapping into the vast knowledge base and expertise of these people, the LTWA can acquire further resources for education; thus, potentially accomplishing more than an individual city. They can do this because of the efforts they have made to include community voices in the planning process.

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Appendix A

September 2021

LAKE THUNDERBIRD WATERSHED DESKTOP ASSESSMENT

guernsey
ENGINEERS
ARCHITECTS
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Contents

Introduction 4
- Background 4
- Scope 6
- Method 8

Section 1A - Watershed Boundaries and Land Uses 9
- Watershed Boundaries 9
- Overview of Land Use 10

Section 1B - Watershed Climate, Topography, Geology, and Soils 14
- Climate 14
- Topography 16
- Geology 18
- Soils 21

Section 1C - Stream Flow 27

Section 2 - Watershed Features 28
- Existing Data on Physical Characteristics 38
- Existing Data on Biological/Ecosystem Characteristics 40
- Existing Data on Pollutant/Chemical Characteristics 40
- Known impaired areas 43
- Existing Information on Social and Economic Systems 44
- Existing Water Quality Management 46
- Priority Issues to Address 52
- Priority Issues for Further Research 53

Conclusions 54
- Next Steps 55

Public Input 56

Resources 57

Tables

Table 1 *Lake Thunderbird Morphometric Features* 5
Table 2 Lake Thunderbird TMDL MS4 Permit - Waste Load Allocations 5
Table 3 *Lake Thunderbird Watershed Waterbodies and ODEQ Impairment* 6
Table 4 *Lake Thunderbird Watershed 2016 Land Use Percentages* 12
Table 5 *Potential Watershed Stormwater Pollutants* 13
Table 6 *Climate Summary by County in the Lake Thunderbird Watershed* 14
Table 7 *Rainfall and Evaporation at Lake Thunderbid as Reported by the USACE* 16
Table 8 *Predominant soils in the Lake Thunderbird Watershed* 21
Table 9 *Lake Thuderbird Watershed EPA Toxic Release Inventory Locations* 30
Table 10 *Lake Thunderbird Watershed Current MSGP Permits* 31
Table 11 *Lake Thunderbird Uses and Users* 34
Table 12 *Lake Thunderbird Parameters Monitored for TMDL and Impairment* 38
Table 13 *2018 ODEQ Water Quality Report for Lake Thunderbird Watershed Streams and Lakes* 43
Table 14 *Priority Issues for LTWA to Address in the Integrated Watershed Management Plan* 52
Table 15 *Priority Issues for Further Research to Address in the Integrated Watershed Management Plan* 53

Figures

Figure 1. *Lake Thunderbird Watershed Boundaries* 9
Figure 2 *Lake Thunderbird Watershed 2016 Land Use* 11
Figure 3 *Lake Thunderbird Watershed Elevation Map* 18
Figure 4 *Lake Thunderbird Watershed Bedrock* 19
Figure 5 *Extent of the Central Oklahoma Aquifer* 20
Figure 6 *Lake Thunderbird Watershed Predominant Soils* 22
Figure 7 *Lake Thunderbird Watershed Soil Hydraulic Conductivity* 23
Figure 8 *Lake Thunderbird Watershed Septic Tank Leach Field Application Limited Areas* 25
Figure 9 *Lake Thunderbird Watershed Wetlands* 26
Figure 10 *Lake Thunderbird Watershed Features* 29
Figure 11 *Lake Thunderbird Watershed Toxic Release Inventory and Permit Locations* 33
Figure 12 *Cleveland County Water Uses 2010* 36
Figure 13 *Cleveland County Water Uses 2060* 36

Introduction

Overview

The Lake Thunderbird Alliance (LTWA) was formed on December 14, 2020. The guiding goal of the organization is to develop an Integrated Watershed Management Plan (IWMP) to address water quality issues and restore the beneficial uses of Lake Thunderbird. The IWMP is a dynamic document for improving the state of the watershed through planned proactive conservation strategies, continuous interdisciplinary stakeholder input, established strategies for making multi-objective decisions, a clear timeline for goals, methods for measuring success, and adaptive management as needs change.

As part of the plan's development, a Desktop Assessment is required to gain understanding of the Lake Thunderbird Watershed use impairments and causes, to help guide prioritization of the issues and provide a baseline for plan goals. This Desktop Assessment serves as a compilation of key characteristics and known studies regarding the Lake Thunderbird Watershed. It will be used to identify the focus of the IWMP as it provides an understanding of the current watershed condition through the evaluation of social, economic, physical, chemical, and biological features and processes.

Background

The Lake Thunderbird watershed is in central Oklahoma and drains 256 square miles in Oklahoma and Cleveland Counties including areas within the municipalities of Norman, Oklahoma City, and Moore, as well as small parts of unincorporated Oklahoma and Cleveland Counties (HUC11090203). The watershed drains into Lake Thunderbird, which was created by the Bureau of Reclamation (BOR) in 1965 (OWRB, 2021). The primary purpose of Lake Thunderbird is to serve as the drinking water source for the Cities of Norman, Del City, and Midwest City. Secondary benefits include flood control, recreation, and fish and wildlife habitat. The beneficial uses designated for Lake Thunderbird are (OWRB, 2018):

- Fish & Wildlife Propagation (Warm Water Aquatic Community)
- Aesthetics
- Agriculture
- Primary Body Contact Recreation
- Public & Private Water Supply

Table 1 provides Oklahoma Water Resources Board (OWRB) morphometric features at normal pool elevation for Lake Thunderbird (OWRB, 2001). A summary of Lake Thunderbird water quality from the Beneficial Use Monitoring Program (BUMP) sampling and assessment performed by OWRB is provided in Appendix A for reference.

Table 1

Lake Thunderbird Morphometric Features

Feature	Data
Normal Elevation	1,039 feet
Current Elevation (as of 3/24/2021)[1]	1040.1 feet
Mean Depth	15.4 feet
Maximum Depth	58.0 feet
Surface Area	5,439 acres
Shoreline Length	154 miles
Capacity	105,838 acre-feet

In August 2010, Lake Thunderbird was placed on the Oklahoma Department of Environmental Quality's (ODEQ) 303(d) List of Impaired Waterbodies for impaired beneficial uses of public/private water supply due to excessive chlorophyll-a levels and warm water aquatic community (WWAC) due to low dissolved oxygen and high turbidity (ODEQ, 2016). It is also listed in the Oklahoma Water Quality Standards (OAC 785:45-5-25(c)(4)) as a Sensitive Water Supply (SWS) and OAC 785:45-5-29(b) as a Nutrient-Limited Watershed (NLW) due to low dissolved oxygen, high chlorophyll-a, and high turbidity levels. These classifications led to the establishment of a Total Maximum Daily Load (TMDL) by ODEQ in 2013 for total nitrogen (TN), total phosphorus (TP), and suspended solids (TSS). Table 2 lists the waste load allocations (WLA) that were placed on Moore, Norman, and Oklahoma City (OWRB, 2013):

Table 2

Lake Thunderbird TMDL MS4 Permit - Waste Load Allocations

Water Quality Constituent	Moore (kg/day)	Norman (kg/day)	Oklahoma City (kg/day)
TN	205.1	319.4	261.8
TP	44.5	60.1	49.4
TSS	16,236.0	31,596.1	27,049.9

In addition, Lake Thunderbird is not the sole impaired water body within the watershed. The streams, shown in Table 3, that feed into it have been identified by ODEQ as being impaired. Those in red were listed in the 2018 303(d) list as impaired due to one or more reasons. See the Watershed Health section of this report for more detail.

[1] Flood Control Status (USACE, 2021)

Table 3

Lake Thunderbird Watershed Waterbodies and ODEQ Impairment

Waterbody ID	Site Name
OK520810000030_00	**Hog Creek**
OK520810000040_00	**West Hog Creek**
OK520810000050_00	Clear Creek
OK520810000060_00	Dave Blue Creek
OK520810000070_00	Jim Blue Creek
OK520810000080_00	**Little River**
OK520810000090_00	**Rock Creek**
OK520810000100_00	**Elm Creek**
OK520810000110_00	**East Elm Creek**
OK520810000140_00	**West Elm Creek**
OK520810000150_00	Kitchen Creek
OK520810000170_00	North Fork Little River
OK520810000175_00	**Moore Creek**
OK520810000180_00	Mussel Shoals Lake Creek

Although there are many studies on water quality and quantity in the watershed, as well as state and local agencies and organizations that have monitored different areas over many years, a unified grassroots movement involving the watershed's stakeholders has not taken place. Improved water quality could result in more efficient use of the lake, park, and resources in general. For instance, Lake Thunderbird and Lake Thunderbird State Park are recreational sites that attract tourists and provide a source of revenue. The total visitation for the state park in 2015 was 742,343 with a total revenue of $606,696 (Wu et al., 2019). Should the water quality improve, there could be more interest in recreational uses, suchas camping, fishing, and hiking, generating more revenue. In addition, Lake Thunderbird isa drinking water source for the Cities of Norman, Midwest City, and Del City. Due to the degradation in the water quality, water treatment costs will increase in order to reduce pollutant loading, specifically organic compounds. Midwest City conducted a pilot plant to reduce the presence of organic compounds, such as TOC, Geosmin/MIB, etc., in drinking water, which result in taste/odor and human health issues. Therefore, focusing capital investments on the mitigation of pollutants at the source (streams and lake) will not only help remove Lake Thunderbird from the impaired list, but also benefit all the uses associated with the lake and park. So, it is time to approach Lake Thunderbird differently by coordinatinga focused effort including multiple local and state entities.

Scope

Using existing data and published resources, the desktop assessment will identify the key characteristics of the watersheds and how they impact the current issues in the watershed to accomplish the following:

- ❖ Determine the nature and extent of use impairments in the basin.
- ❖ Identify the causes of existing use impairments.

Once incorporated in the IWMP each issue will be listed along with applicable management strategies.

The sections in the body of this report are as follows:

Section 1A Watershed Boundaries and Land Use	Geographical description of the watershed in terms of the municipal and Absentee-Shawnee Land boundaries, and the land use as reported by the National Land Cover Database (NLCD). **Purpose:** Present spatial distribution of land uses and their associated stormwater quality impacts
Section 1B Watershed Climate, Topography, Geology and Soils	Description of the watershed in terms of its predominant climate characteristics, topography, geology, and soils as they relateto water quality and quantity. **Purpose:** Present spatial distribution of watershed physical characteristics and a description of how specific combinations of thse attributes impact water quality and quantity.
Section 1C Streamflow	Description of watershed streamflow data available. **Purpose:** Note that streamflow data is currently being gathered by the threemunicipalities but that a comprehensive dataset of streamflow has not existed in the watershed for many years.
Section 2 Watershed Features	Description of other watershed landmarks and dynamic features and activities that provide insight into social, economic, and industrial characteristics. **Purpose:** Presentlandmarks not commonly included in the existing watershed studies and current EPAand state or city permitted locations. Monitoring stations of all three cities are included to identify the spatial relationshipwith permit locations.
Section 3 Water Uses & Users	Description of what the watershed offers its residents and visitors. **Purpose:** To introducethe stakeholders of the watershed and how they may be impacted by water quality and quantity issues.
Section 4 Watershed Health	Compilation and description of the most relevant studies evaluated for this report. **Purpose:** The studies are categorized by topic and a brief summary is included at the beginning of each subsection to identify their importance towards water quality or quantity issues in the watershed.
Section 5 Scoping of Issues	Description of how the main issues from the studies in Section 3 were scoped (by boundary setting and identification of the issue cause and impact). Purpose: The methodology presented describes how the issues were then prioritized with feedback from the TAG in order to establish top issues for the LTWA’s goals.

Method

A Technical Advisory Group (TAG), consisting of members from partner Cities, county agencies, academic institutions, and stateagencies, was established to provide technical feedback for the development of the desktop assessment and watershed management plan. The TAG's specific role was to help identify existing studies and/or dataon the watershed, identify problem areas in the watershed, define priorities and scope of the watershedissues, and identify appropriate management and implementation strategies for each issue.

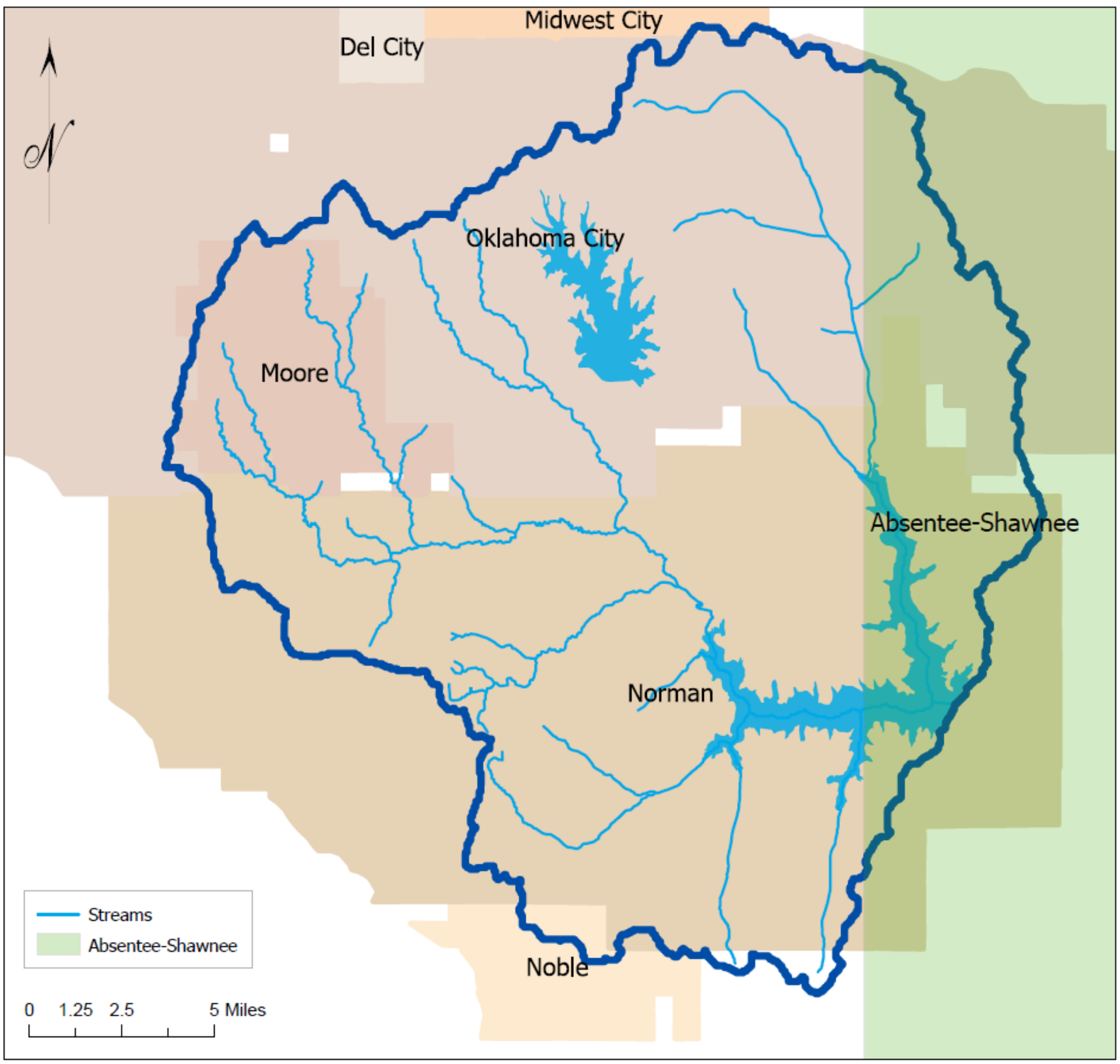
Section 1A - Watershed Boundaries and Land Uses

Watershed Boundaries

The Lake Thunderbird watershed has an area of 256 square miles of residential, commercial, and agricultural lands. It encompasses the southeast section of Oklahoma City, the majority of Norman, and most of Moore. Midwest City and Noble have small sections within the central and southern portion of the boundary, respectively. In addition, the Absentee-Shawnee Tribal boundary extends into the eastern part of the watershed (see Figure 1).

Figure 1.

Lake Thunderbird Watershed Boundaries



Overview of Land Use

Based the 2016 National Land Cover Database (NLCD) summarized in Table 4 and Figure 2, the land use within the watershed is mostly attributed to deciduous forest and grassland/herbaceous vegetation at 37% and 34%, respectively. Open water within the watershed accounts for 5% of the land use. Developed (urban) areas make up a total of 19% of the watershed area. Four percent of the watershed area is used for cultivated crops (1%) and hay/pasture (3%).

Comparing 2016 land use to 2011 land use, there was a small increase in developed land of 2%, from 17% in 2011 to 19% in 2016 (see rows 2-5 in Table 4). Most of the developed high and medium intensityareas are occurring in Moore and Norman on the westernmost portion of the watershed. The majority ofthe cultivated crops and hay/pasture areas are situated along or near the streams.

Figure 2

Lake Thunderbird Watershed 2016 Land Use

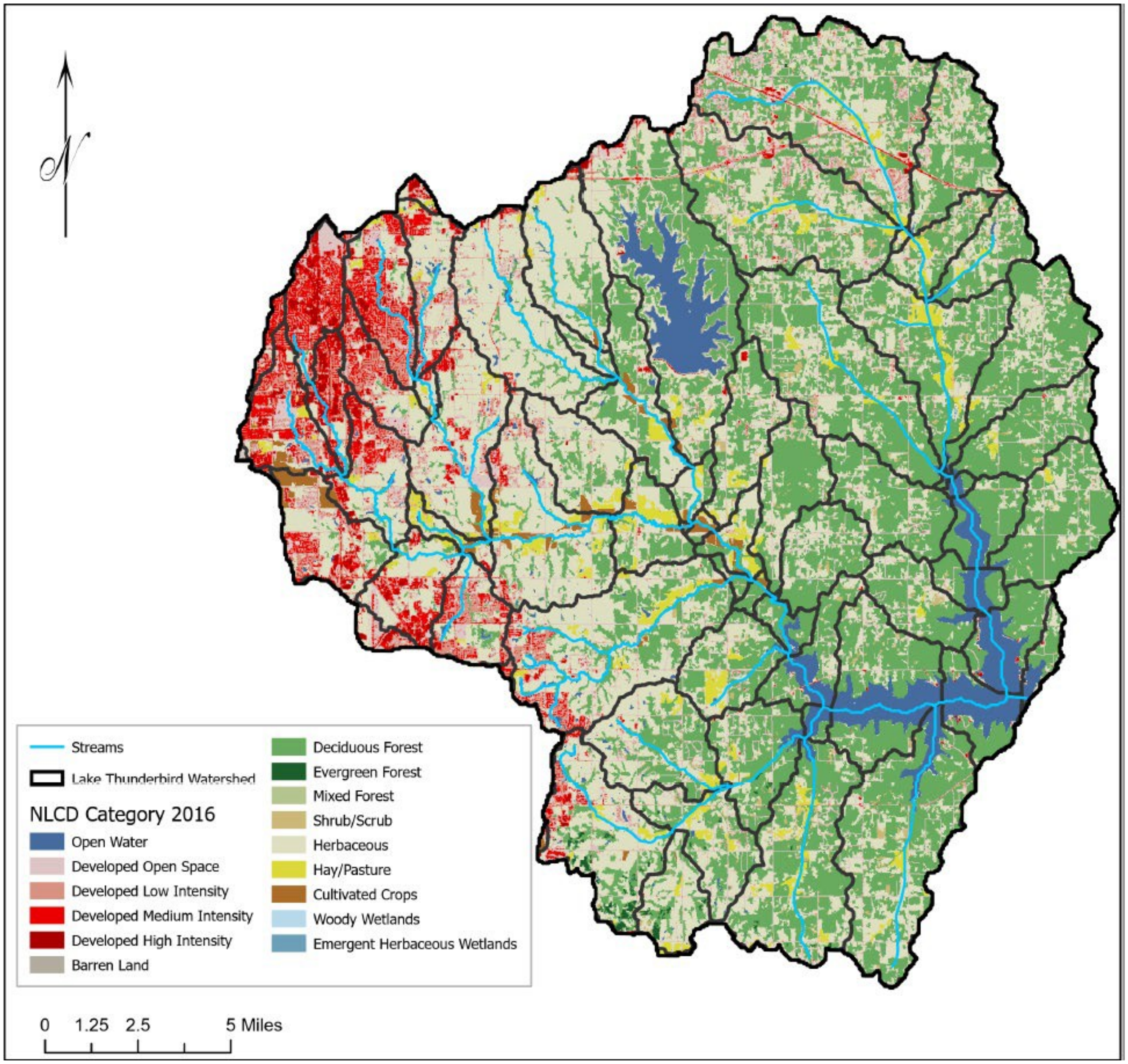


Table 4

Lake Thunderbird Watershed 2016 Land Use Percentages

Category	2011 Percent of Watershed Area	2016 Percent of Watershed Area
Open Water	4	5
Developed, Open Space	8	8
Developed, Low Intensity	5	6
Developed, Medium Intensity	3	4
Developed, High Intensity	1	1
Barren Land	0	0
Deciduous Forest	37	37
Evergreen Forest	0	0
Mixed Forest	0	0
Shrub/Scrub	1	2
Herbaceous	36	34
Hay/Pasture	3	3
Cultivated Crops	1	1
Woody Wetlands	0	0
Emergent Herbaceous Wetlands	1	0

Urbanized areas in the west produce increased runoff from impervious areas, carrying pollutants characteristic of residential and business districts such as car wash water or oil and grease, litter, fertilizers, pet and yard waste, road salt, and some metals, to municipal stormwater drainage systems and eventually the streams. The quantity of runoff also affects transport of sediment as the geomorphology of the streams change due to higher velocities of incoming water and as the channel widens with time. This increased runoff impacts stream banks and increases erosion and sediment transport.

The pasture/ranchland and less dense areas in the central and east areas also produce polluted runoff due to sediment from gravel roads, septic system or livestock waste disposal, road salt, decaying foliage, boat wash water or oil and grease.

Table 5 below summarizes the pollutants associated with each source and its impacts on the watershed.[2]

[2] Adapted from *Typical stormwater pollutants, summary of sources and potential concerns for harvest and use.* Minnesota Stormwater Manual. (2020, April 16). https://stormwater.pca.state.mn.us/index.php/Typical_stormwater_pollutants,_summary_of_source s_and_poten tial_concerns_for_harvest_and_use

Table 5

Potential Watershed Stormwater Pollutants

Pollutant	Sources	Impacts
Nitrogen, phosphorus	Atmospheric deposition, sediment, fertilizers, pet waste, sewage, yard waste, fallen foliage	Algae growth contributing to eutrophication in lake
Suspended sediment	Impervious surfaces, gravel roads, bare soil, construction sites, stockpiles	Carries nutrients and organic matter that may lead to low dissolved oxygen levels, increased turbidity affecting the warm water aquatic community
Chlorides	De-icing or water softening chemicals	Toxic to plants, impact corrosivity of drinking water, can create leaching conditions in the distribution system as the chloride to sulfate ratio changes
Pathogens	Animal waste, insects, waste management, sewage	Human health risk and impact on recreation, impacts water treatment
Metals	Vehicle exhaust, roofing materials, industrial stormwater runoff	Toxic to plants, impacts water treatment
Organic Chemicals (pesticides, industrial chemicals or solvents, petroleum derived chemicals)	Golf courses, city maintained vegetated areas, residential lawns, industrial stormwater runoff	Toxic to plants, humans and animals. Impacts water treatment

Section 1B - Watershed Climate, Topography, Geology, and Soils

The holistic picture of land use, climate, topography, geology, and soils provides an understanding of the fate of precipitation in the watershed. The portion that does not evaporate nor is captured by vegetation can infiltrate the surface and move downhill laterally within the soil as interflow, it can percolate deeper into groundwater, or it can travel on the surface of the watershed and runoff as overland flow.

Climate

Climate is an extremely crucial factor on water resources and biological processes in a watershed. According to the Köppen climate classification system, the Lake Thunderbird watershed is within the humid subtropical climate (Cfa). Summers are hot and humid with mild to cold winters with periods of extreme cold being infrequent and typically not lasting more than a few days.

Table 6 provides temperature, precipitation, wind speed, and sunshine observation data for Oklahoma and Cleveland counties.[3] Air temperature influences evaporation, transpiration, and vegetation growth while wind conditions affect evapotranspiration and wind erosion. Precipitation, such as rain, snow, and dew, provides the water within the watershed (Heathcote, 2009). Prevailing winds are from the south to southeast throughout most of the state from the spring through autumn months while winter wind is equally split between northerly and southerly winds. Additionally, evaporation and percolation into the soil expend about 80% of Oklahoma's precipitation (OCS, 2021).

Table 6

Climate Summary by County in the Lake Thunderbird Watershed

County	Temperature (deg F)			Precipitation (in)		Avg Humidity (%)	Avg Wind Speed (mph)	Annual Fraction of Sunshine Observed (%)
	Avg Annual	Avg Max	Avg Min	Avg Annual Rainfall	Avg Annual Snowfall			
Oklahoma	61.5	72.2	50.8	36.52	7.0	67	7	55-80
Cleveland	60.2	71.3	49.2	38.88	6.8	68	10	55-80

At Lake Thunderbird, the USACE monitors and calculates daily evaporation rates based on solar radiation, wind speed, relative humidity, and average air temperature. The reports from 2015-2019 are summarized in

[3] Oklahoma Climatological Survey |

Table 7. The average rainfall for the time period was 18,973 acre-feet per year and the average evaporation was 32,021 acre-feet per year. As discussed above, in a typical year evaporation exceeds rainfall. In this case the average ratio of evaporation to rainfall is 1.7.

Table 7

Rainfall and Evaporation at Lake Thunderbid as Reported by the USACE

	2019		2018		2017		2016		2015	
	Rain	**Evap.**	**Rain**	**Evap.**	**Rain**	**Evap.**	**Rain**	**Evap.**	**Rain**	**Evap.**
Jan	503	1,233	98	1,691	573	1,471	141	1,198	359	1,363
Feb	250	1,138	1,731	1,405	586	1,942	494	2,296	279	1,434
Mar	2,029	2,135	161	2,924	944	2,898	705	2,619	835	1,936
Apr	1,775	3,254	1,500	3,606	3,067	2,966	3,090	2,912	1,738	2,477
May	3,854	3,213	2,140	4,413	2,354	3,746	1,478	2,834	14,096	2,638
Jun	2,700	4,461	2,565	3,975	60	4,186	1,233	3,601	4,911	4,752
Jul	-	5,062	1,806	3,905	506	4,374	4,145	4,367	3,356	4,772
Aug	2,029	4,188	1,558	4,023	3,360	3,490	145	3,122	374	3,269
Sep	780	3,526	2,634	2,450	1,340	2,874	1,231	2,527	900	3,497
Oct	2,203	2,397	1,508	1,538	1,275	2,700	180	1,998	1,089	2,185
Nov	944	1,332	468	1,397	59	1,658	221	1,386	2,194	1,259
Dec	374	1,459	1,704	1,178	431	1,126	196	1,010	1,607	1,319
Total	17,441	33,398	17,873	32,505	14,555	33,431	13,259	29,870	31,738	30,901

Topography

The quality of groundwater, lakes, and streams of a watershed depends on the pollutants present and the movement of water through soils, deeper rock formations, man-made structures, and the bodies of water themselves. The topography, geology, soils, and land use of a specific point and its surrounding area are what influence the movement of water and determine where pollutants accumulate and interact with existing conditions to cause impairment.

The topography of a watershed is what defines its boundaries, but it also influences spatial distributions of temperature, local slopes, subcatchment areas, and vegetation. Soils interact with these factors and their own individual characteristics to play a major role in the transport and storage of water through the landscape. Therefore, topography helps define soil moisture through four main factors as described below. One thing to note is that these factors represent general relationships that affect and may also be affected by other characteristics of the soil including the hydraulic conductivity, its parent material, and soil conservation and management practices (Florinsky, 2012).

1) Slope gradient – As slope gradient increases, the velocity of water increases and moisture decreases, thus increasing runoff and transport of water out of the area.
2) Slope aspect – Slope aspect is the orientation of a slope as it relates to cardinal direction. Areas with differing degrees of exposure to direct sunshine impact the redistribution of snow over land and rates of freezing or melting, hence contributing to soil moisture. Increased soil moisture can indicate areas more likely to pond or saturate leading to increased surface runoff.
3) Horizontal and vertical curvatures – The curvature in topography is the “slope of the slope” and determines whether a surface is linear, convex, or concave in varying directions (Kimerling et. Al, 2011). These values help estimate overland and intrasoil water flow through where it is likely to converge or diverge as well as its accelerate or decelerate. For example, saturated zones are observed in areas of convergence and deceleration (Florinsky, 2012).

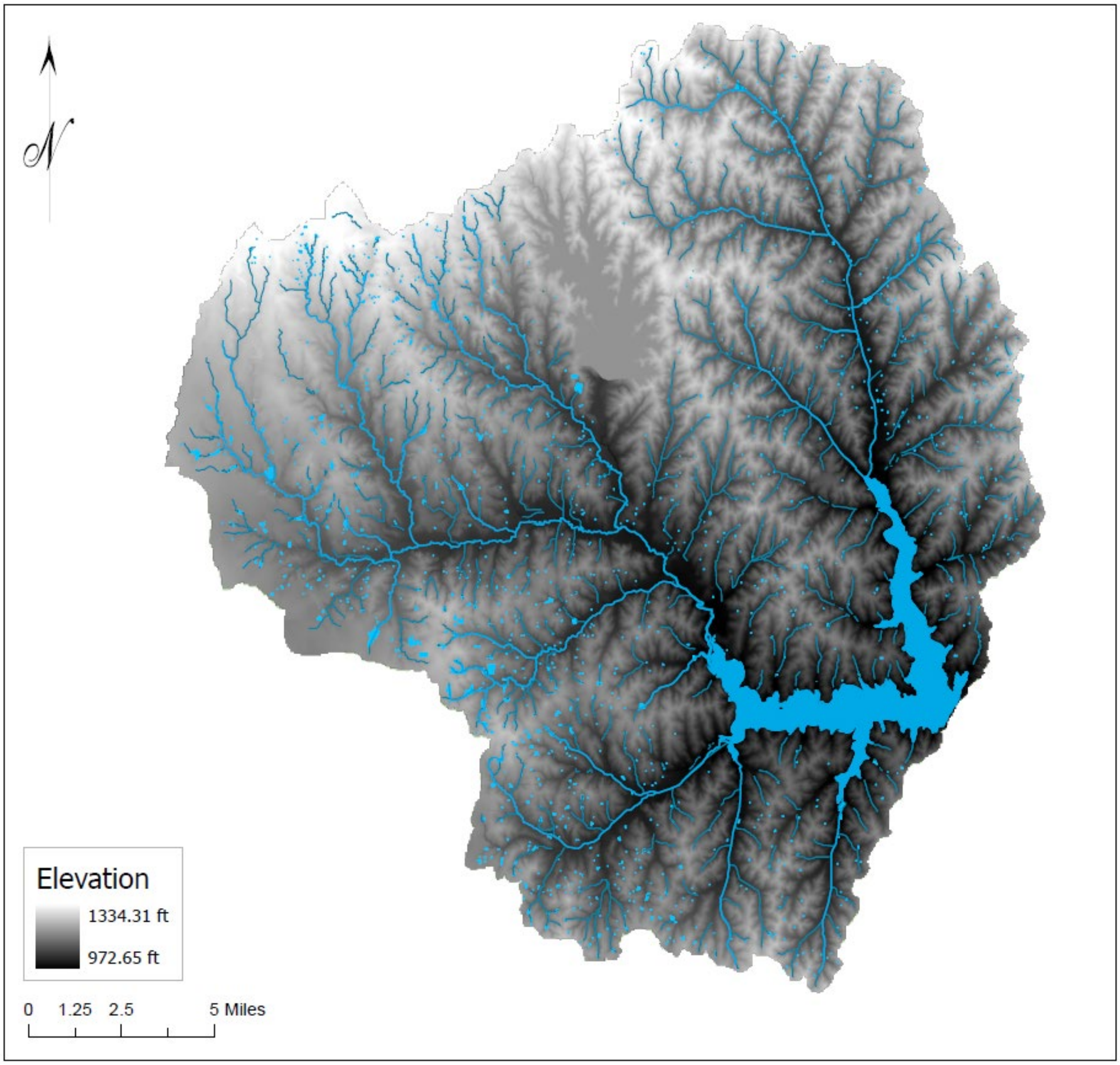
4) Location of a point in a catchment area – Slope gradient and the location of an area within a catchment area helps define the topographic index, which is one measure of flow accumulation and high soil moisture.

These four factors impact soil moisture, which in turn impacts water quality. For example, areas more likely to saturate and pond can accumulate pollutants that are washed off through surface runoff in a larger storm. A low spot in a small ranchette storing manure in an uncovered area nearby can receive stormwater mixed with nutrients and contribute to polluted runoff once it is saturated or overflown.

Figure 3 below shows only elevation within the Lake Thunderbird watershed, ranging from approximately 973 – 1334 ft. The watershed is within the relatively flat geographical region, the Red Bed Plains, consisting of flat plains and gently rolling hills.

Figure 3

Lake Thunderbird Watershed Elevation Map

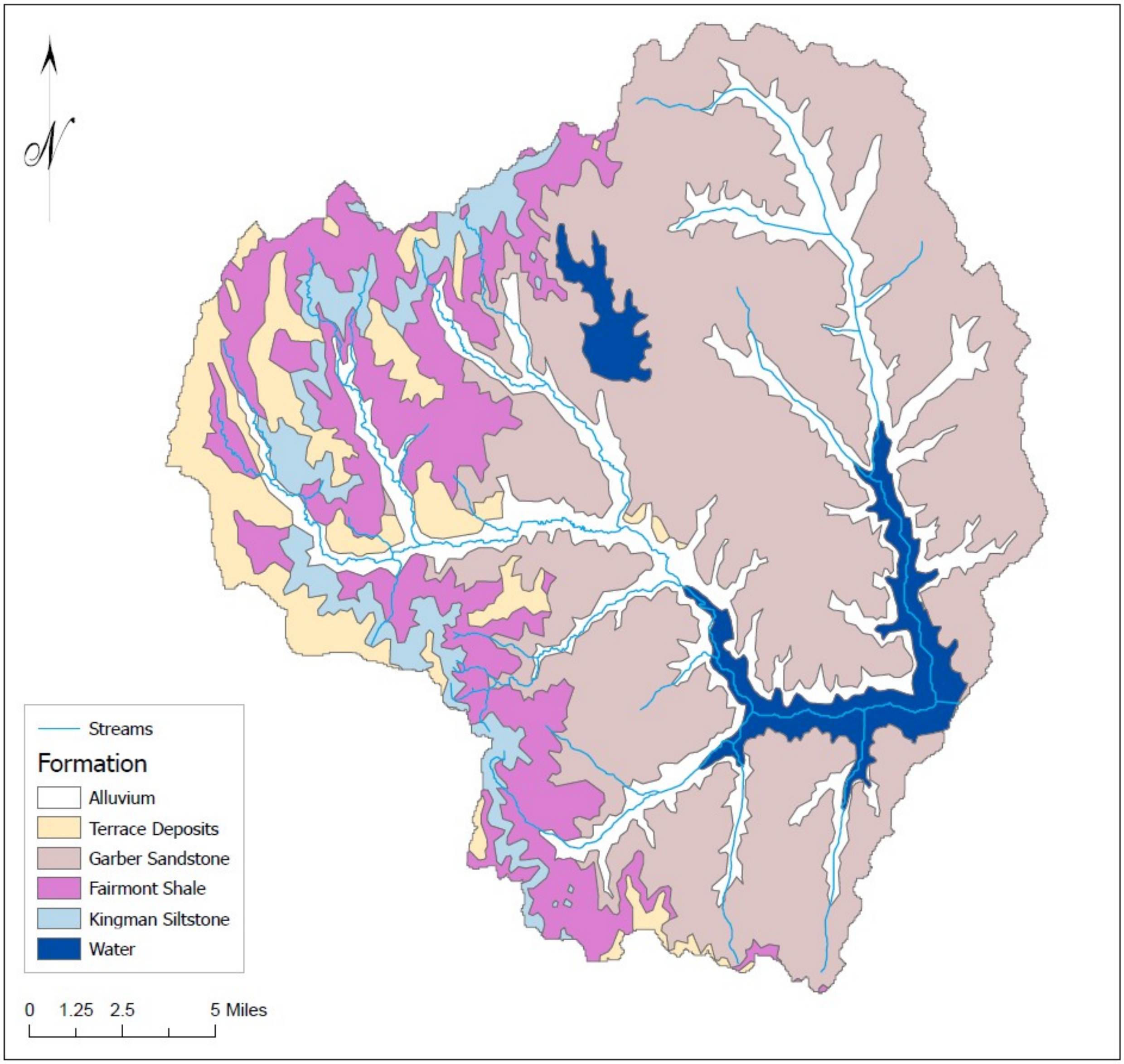


Geology

Figure 4 shows a definitive north to south partition of the bedrock underlying the watershed. The eastern side encompasses a section of the area's Garber Wellington Formation which is primarily cross-bedded, fine-grained sandstone with some floodplain deposits or mudstones (Smith, 2004). To the west, the Permian-age Hennessey Group formations encompass interbedded red shale, clay, and some siltstone. The terrace and alluvium deposits located along the major streams are lenticular beds of unconsolidated or loosely consolidated clays, silts, sand, and gravel (USGS & OWRB, 2019).

Figure 4

Lake Thunderbird Watershed Bedrock



The geology of the area defines the availability of fresh groundwater and the dynamics of its flow through the formation of aquifers. The Central Oklahoma Aquifer lies below the Lake Thunderbird watershed and has the vertical extent shown in Figure 5 below (USGS & OWRB, 2019). The aquifer is known as the Garber Wellington Aquifer because most of the groundwater yield available exists within that formation, compared to the bedrock areas of shale, siltstone and the shallower terrace deposits. The predominant clay and lower hydraulic conductivity of the Hennessey Group acts as a confining layer, and the terrace and alluvial deposits hold a comparatively lower fraction of the total available water. The first water depth of the aquifer within the watershed begins at approximately 57-107 ft.[4] The maximum annual yield (MAY) of the Garber Wellington was tentatively determined to be 2.0-acre feet per acre per year by OWRB in August 2019.[5]

The aquifer can also be divided into confined areas, bordering the Hennessey Group, and both shallow and deep unconfined areas in the central region. Brine lays at deeper depths and is not available as fresh water. The relationship between the aquifer and the watershed is twofold. First, the availability of groundwater reduces the reliance on Lake Thunderbird as the sole source of drinking water. Second, unconfined aquifer areas and streams in the watershed are hydrologically connected, meaning that precipitation that recharges groundwater is witnessed as the baseflow of streams. Activities such as pumping from shallow wells can alter that recharge and flow relationship if overused. The confined aquifer is not readily recharged by precipitation and chemical processes differ from those in shallower areas. In the watershed, the City of Norman has faced levels of arsenic beyond those acceptable by EPA water quality standards in its deep wells and has participated in pilot studies and research to determine the best course of action.

Figure 5[6]

Extent of the Central Oklahoma Aquifer

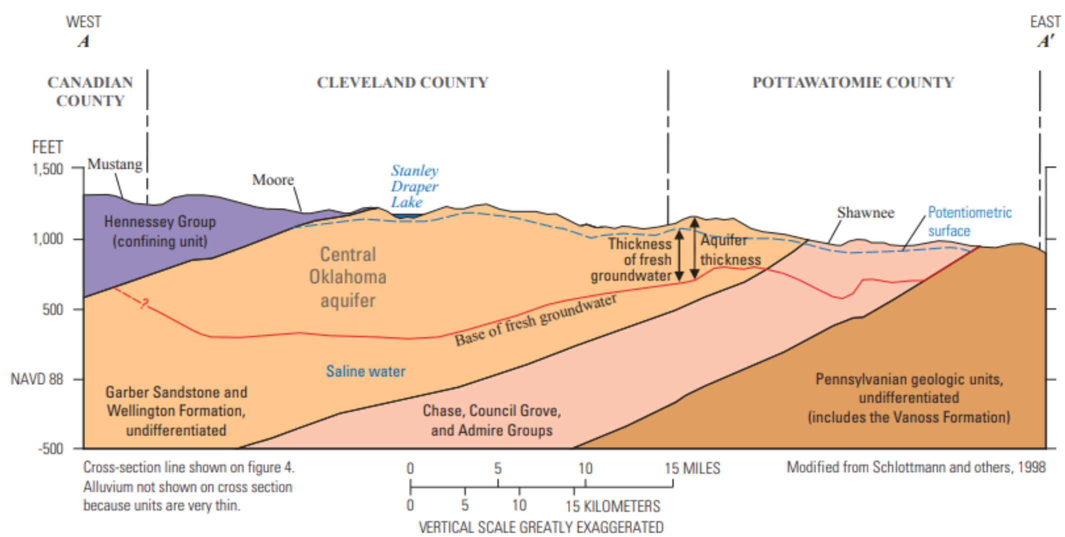


Figure 5. Cross-section *A–A′* diagram (shown on figure 4) showing bedrock geologic units of the Central Oklahoma aquifer.

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[4] Average of watershed elevation and does not reflect average value of wells in the area

[5] From OWRB's Maximum Annual Yield (MAY) Fact Sheet, the MAY of a groundwater basin is "used to describe thetotal amount of fresh groundwater that can be withdrawn while allowing a minimum 20-year life of the basin"

[6] This figure is reprinted from publicly available data from the OWRB and USGS in their 2019 study *Hydrogeologyand simulation of groundwater flow in the Central Oklahoma (Garber-Wellington) Aquifer, Oklahoma, 1987 to 2009, and simulation of available water in storage*

The components of the rock also contribute to the composition of soils on the surface. However, although soils overlaying bedrock are composed of the same material, older formed soils are affected by climate and chemical and physical processes that can alter their characteristics.

Soils

Soil taxonomy consists of 6 levels, with the *series* being the lowest category (highest specificity). This is also the name typically used to name soil map units as provided by the United States Department of Agriculture (USDA) Web Soil Survey. In the Lake Thunderbird Watershed, the soil series that make up approximately 50% of all soils are Newalla (22%), Darsil (10%), Pulaski (9%), Renfrow (6%) and Stephenville (6%).[7] Table 8 includes a description of each and Figure 6 shows their distribution.

Table 8

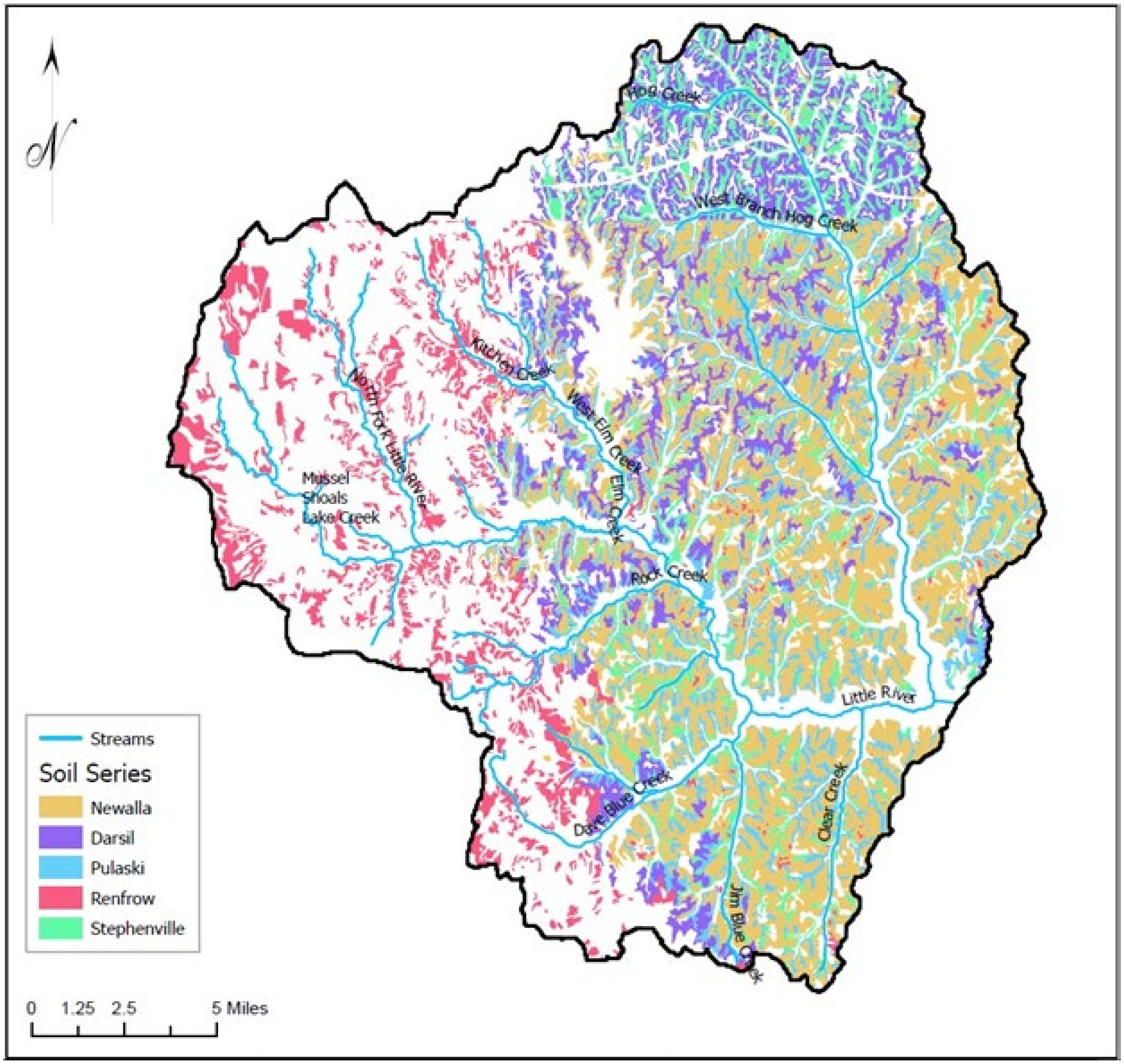
Predominant soils in the Lake Thunderbird Watershed

Soil Series	Description
Newalla	Deep, moderately well drained, very slowly permeable soils. The upper part formed in material weathered from sandstone and the lower part formed in material weathered from shale of Permian age.
Darsil	Shallow, excessively drained, soils that formed in material weathered from weakly cemented sandstone of Permian age. These soils occur on convex ridge crests of low hills.
Pulaski	Very deep, well drained, moderately rapidly permeable flood plain soils that formed in loamy alluvial sediments of Holocene age. These nearl level to very gently sloping flood plain soils are on small tributaries.
Renfrow	Very deep well drained soils that formed in material weathered from clayey shale of Permian age. These soils are on summits and backslopes of low hills.
Stephenville	Moderately deep, well drained, soils formedin material weathered from sandstone of Permian age. These soils are on very gently sloping to moderately steep side slopes of hills.

[7] These are approximate percentages since there is a discrepancy between soil map unit identification at theCleveland & Oklahoma County border in the NRCS Soil Survey

Figure 6

Lake Thunderbird Watershed Predominant Soils



Specific soil types vary widely within a watershed as categorized by not just their soil series, but the various components in each area and their slope, erosion status and other properties. However, when looking at only one attribute clearer patterns emerge. The following discussion is an overview of a few soil properties relevant to the water quality of the watershed.

In Figure 7, the hydraulic conductivity of each soil unit area is mapped for the watershed.[8] Hydraulic

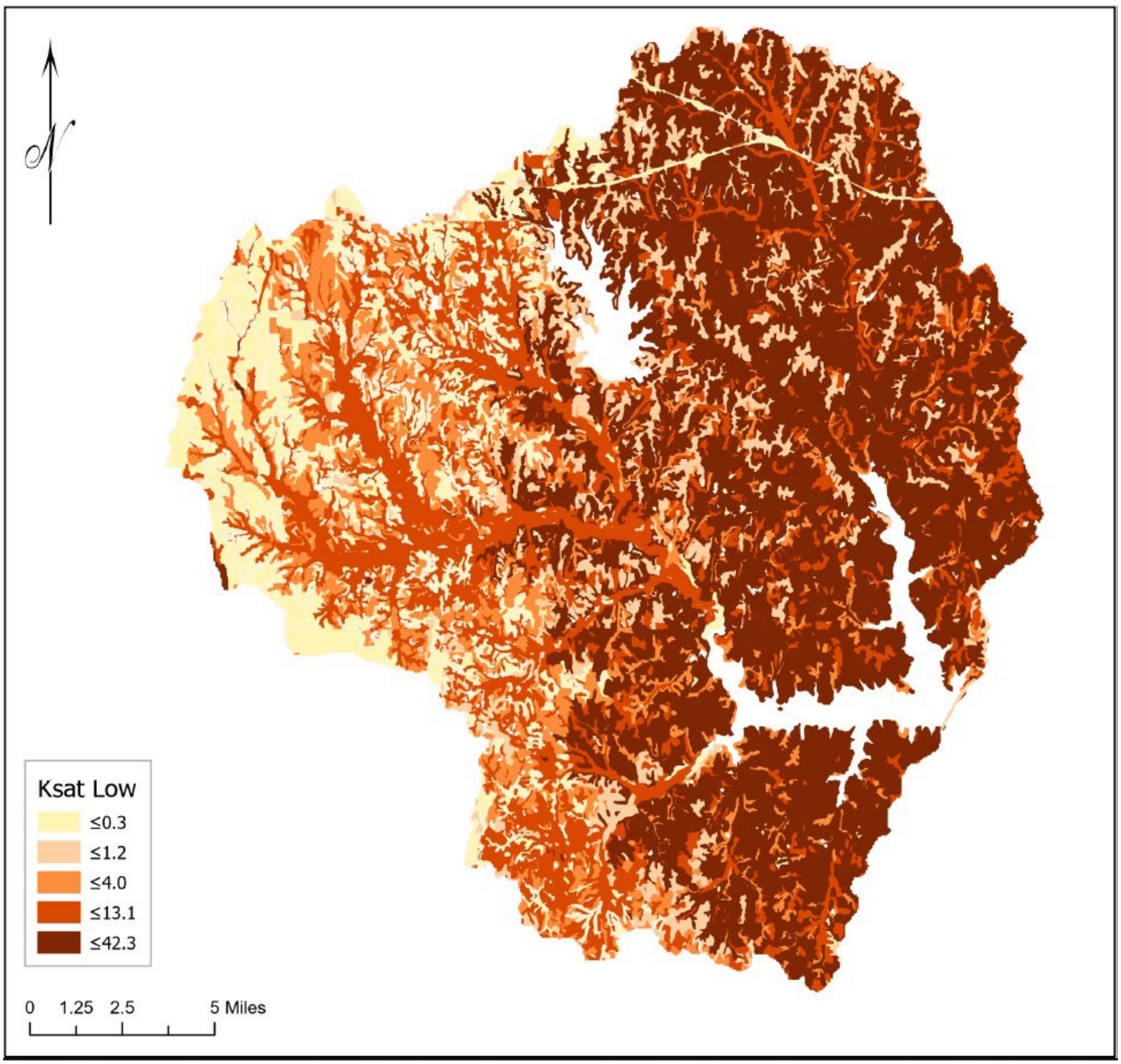
[8] "Hydraulic conductivity of the material can be defined as the ability of the fluid to pass through the pores andfractured rocks" (https://www.sciencedirect.com/topics/earth-and-planetary-sciences/hydraulic-conductivity)

conductivity (Ksat) is the rate at which water moves through soil and represents the ease with which it flows through the pores and fractures of soil. The porosity or types and sizes of those pathways represent the permeability of the soil and depend on available organic matter, aggregation and other factors.

As in the geological map above, there is a dividing line between the hydraulic conductivity of the soils on the east versus west side of the watershed. The latter, overlaying shale and siltstone formations, have a lower hydraulic conductivity limit than the sandier (greater percentage of sand components in each soil map unit area) soils of the east.

Figure 7

Lake Thunderbird Watershed Soil Hydraulic Conductivity

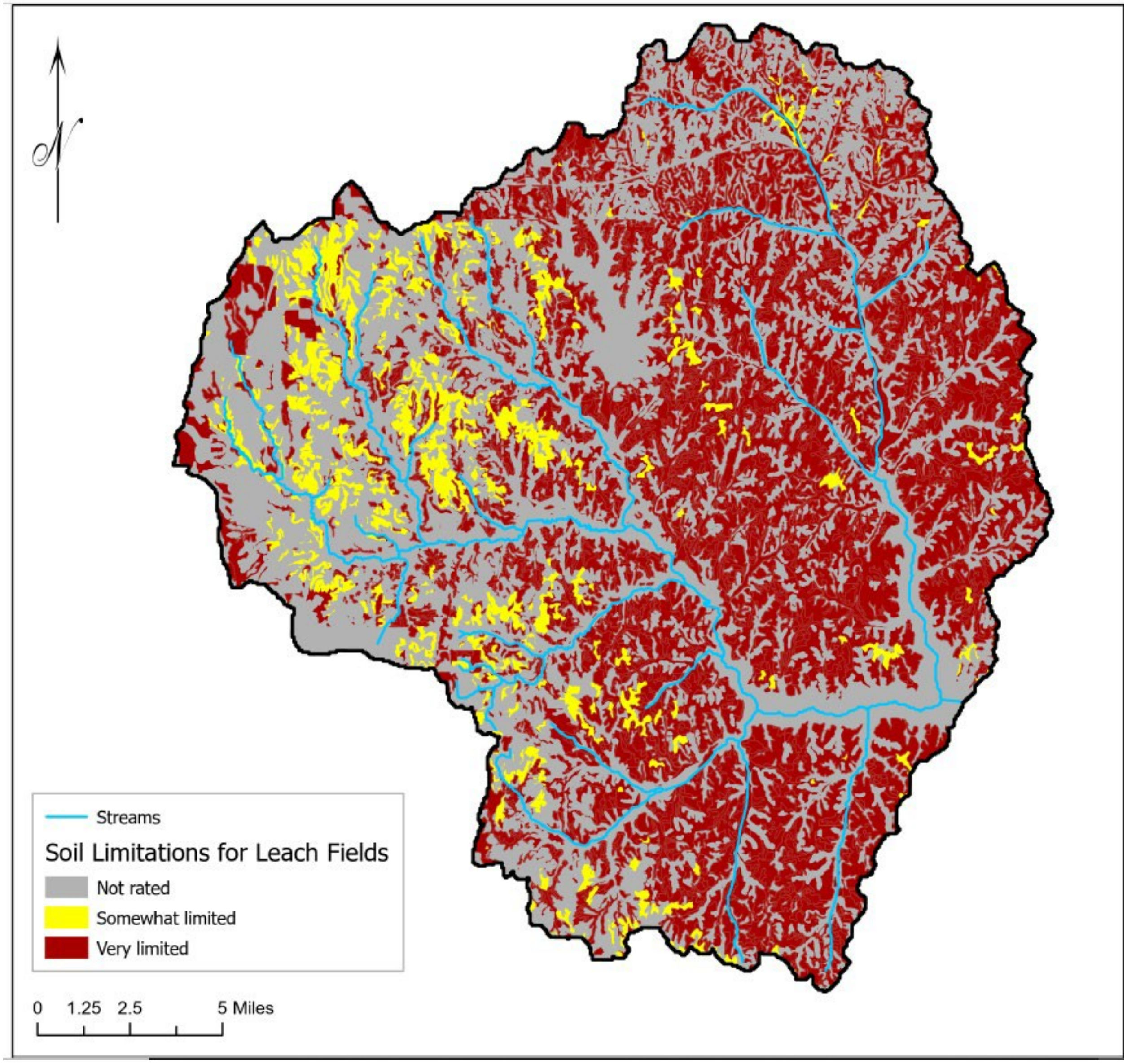


The runoff class assigned to soils is based on Ksat and the percent slope. This characteristic identifies the soil as falling into one of 6 categories: negligible, very low, low, medium, high, or very high. Hydrologic soil groups (A through D) are also assigned based on factors that affect runoff potential including depth to a seasonal high water table, infiltration rate and permeability after prolonged wetting, and depth to a very slowly permeable layer. As discussed previously, runoff of stormwater carries pollutants from different land uses into nearby streams and lakes.

Related characteristics also define the adequacy of soils or a soil area to different applications. Limits to the adequacy of soils for septic tank leach fields, for example, are based on seepage, water movement rate, slope, depth to bedrock, flooding and depth to the saturated zone. In Figure 8 below, the rating class "very limited" indicates that the soil has one or more features that are unfavorable for septic tank leach field application. Malfunctioning septic tanks or leach fields are one of many known possible contributors of nutrients and bacteria to nearby streams and lakes. However, few studies have been completed in the watershed for a comprehensive analysis of current septic tank influence.

Figure 8

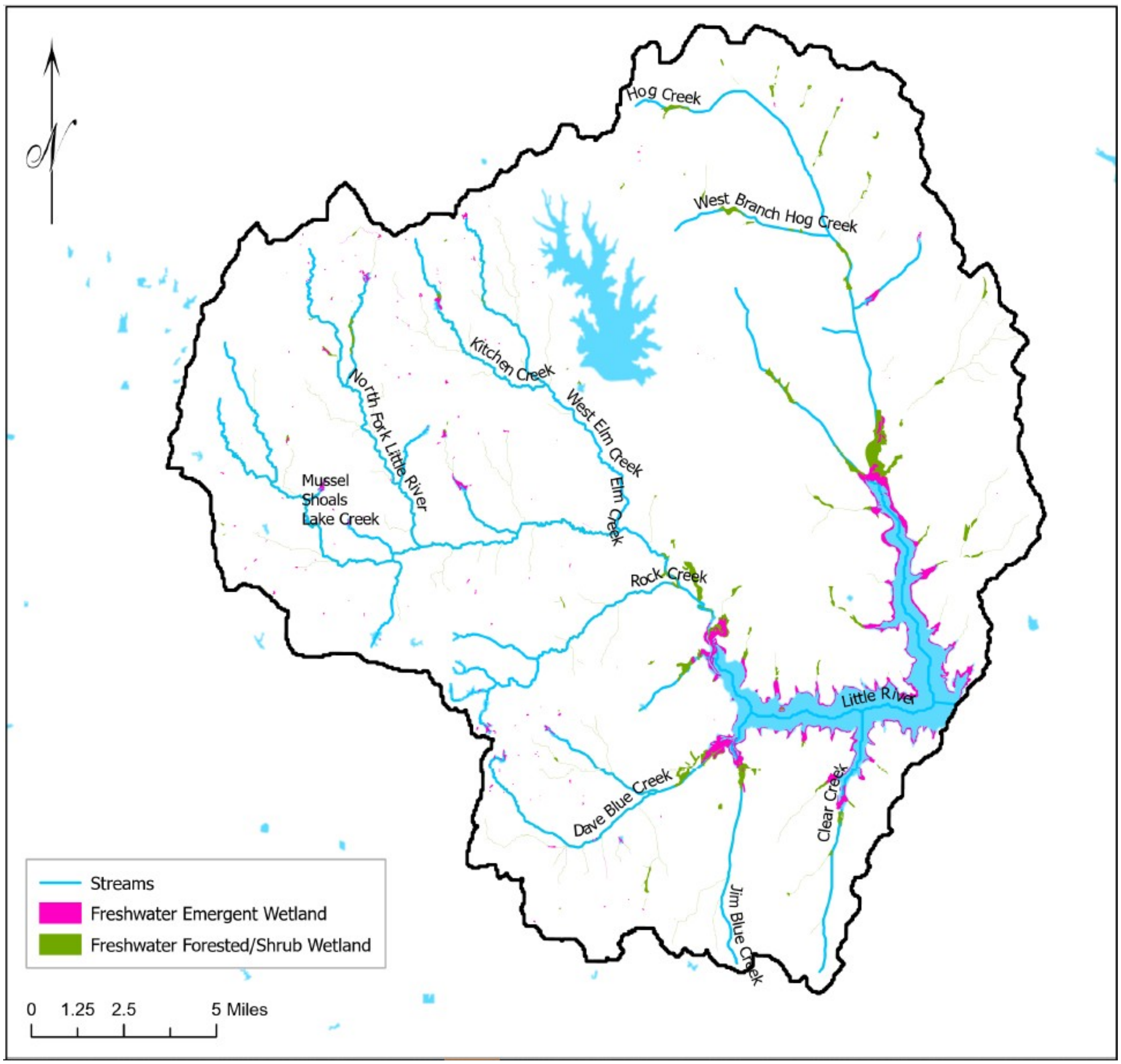
Lake Thunderbird Watershed Septic Tank Leach Field Application Limited Areas



Soils can also present clues on how to use the natural environment for water quality improvement in the watershed. One aspect to note is that none of the soils in the watershed have a hydric rating ("Under natural conditions, these soils [hydric soils] are either saturated or inundated long enough during the growing season to support the growth and reproduction of hydrophytic vegetation") (USDA, 2016). The lack of hydricsoils indicates that wetlands were not a historically prevalent land cover category in the area, and likely could be seen only as narrow riparian wetlands. The 1981 National Wetland Inventory mapping (see Figure9) shows an increase in wetland land cover, compared to historical data, suggesting that the creation of the Lake Thunderbird reservoir helped establish freshwater emergent and freshwater forested/shrub wetlands along the downstream areas of its tributaries. These wetlands are helpful in capturing nutrients,sediment and other pollutants as water slows down and enters pooled areas where storage and biological processes by soils and vegetation can capture and transform pollutants into biologically beneficialversions. Considering existing and potential new constructed wetlands, the 2011 Oklahoma ConservationCommission (OCC) study on wetland feasibility found that both small- and large-scale wetland construction would be applicable to improving Lake Thunderbird water quality (OCC, 2011).

Figure 9

Lake Thunderbird Watershed Wetlands



Section 1C - Stream Flow

Models developed for nonpoint source pollutant runoff to streams and lakes in the watershed depend highly on stream flow data for load calculations and for calibration to ensure the model reflects local watershed dynamics. However, the only USGS gauging stations in the watershed are at the Lake Stanley Draper dam and the Lake Thunderbird dam. The ODEQ 2013 TMDL model estimated flow using the HSPF watershed model and did not use existing measured flows.

In recent years, the availability of data has expanded. Each municipality has monitoring stations for both water quality and discharge in the streams within their boundaries (refer to section "Watershed features") as part of compliance with TMDL guidelines. Therefore, as that data is analyzed and reviewed for quality control, there will be an opportunity for watershed-wide analysis of pollutant loads, flooding and low flow patterns, and a seasonal and long-term evaluation of streamflow relationships to impairment, both within the streams and at the lake. To date, the data has not been fully analyzed.

Section 2 - Watershed Features

As discussed, Lake Thunderbird is a reservoir, whose dam is on the southeastern side of the lake. Called the Norman Dam, COMCD describes it as "a zoned earthfill embankment with a volume of about 3 million cubic yards. The crest of the dam is 30 feet wide, 7,263 feet long, and about 144 feet high. The spillway is located in the left abutment and has a morning-glory inlet with an ungated crest of 22-feet 4-inch diameter" (COMCD, 2021).

Little River State Park around Lake Thunderbird is highlighted as well as a few Land Conservation Easements in Norman.[9] There are no designated wildlife management areas in the watershed per the Oklahoma Department of Wildlife Conservation's online maps. However, there are designated fishing areas and daily limits within the lake. In addition, COMCD has authority from the BOR to control feral hog populations as necessary. In recent months, there has not been much activity on that front. The Little Doctor Homestead is a historic Absentee Shawnee homestead in what is now called the Post Oak Campground (Bureau of Reclamation, 2009).

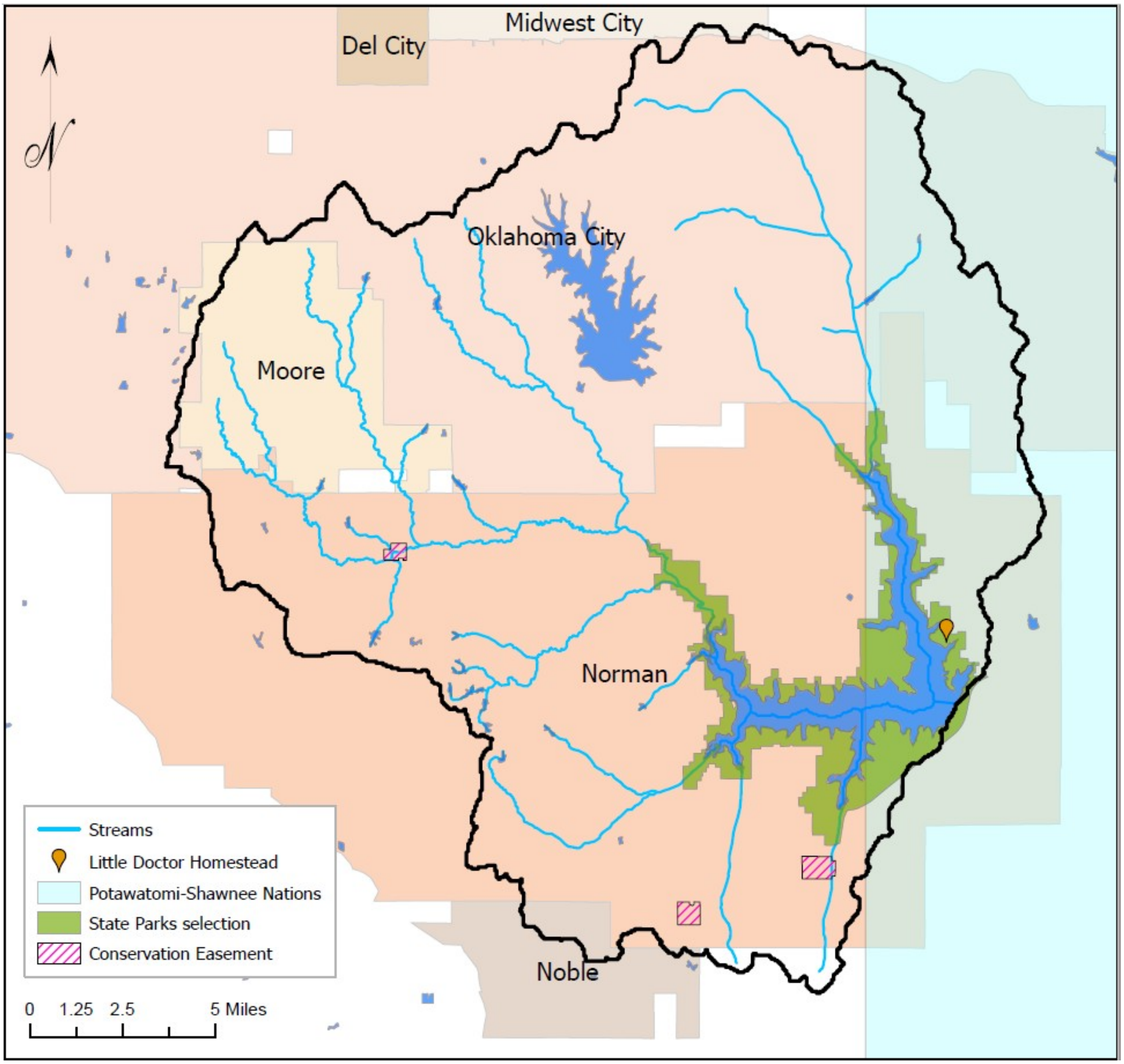
Lake Stanley Draper is another reservoir in the watershed from which Oklahoma City sources a portion of its drinking water. However, there is minimal discharge downstream of the lake into East Elm Creek and so is typically excluded from stormwater modeling of the Lake Thunderbird Watershed. This report does not evaluate Lake Stanley Draper as a water source for the watershed.

Figure 10 below shows these features spatially.

[9] Note: these areas were estimated from City of Norman GIS data available online but not downloadable

Figure 10

Lake Thunderbird Watershed Features



Key potential pollutant source locations Within Lake Thunderbird Watershed

There are no point sources in the watershed from which pollutants are discharged directly into a body of water from wastewater or industrial activities[10]. However, there are a few other locations of note when documenting the current state of industrial/construction practices in the area and their potential contribution to water quality impairment. The following discussion identifies locations as monitored by the EPA or the state. Figure 12 below presents them spatially.

[10] There are no municipal wastewater facilities, industrial wastewater facilities, or concentrated animal feeding operations (CAFO) within the Lake Thunderbird watershed.

The EPA publishes Toxic Release Inventory (TRI) data every year on those facilities that release any of the listed 770 chemicals that can cause significant chronic or adverse human health effects or significant adverse environmental effects. Not all industrial facilities must participate in the program but those that are, report on any release to water, air, or land. The watershed has four TRI locations as listed in Table 9 below:[11]

Table 9

Lake Thuderbird Watershed EPA Toxic Release Inventory Locations

Facility Name	Chemical	Fugitive Air (lbs)	Water (lbs)	On-site release total (lbs)
SOUTHWESTERN WIRE INC	Nickel	0	0	0
	Zinc compounds	383	0	383
	Lead and lead compounds	0.2	0	0.2
JOHNSON CONTROLS INC-NORMAN	Copper	79.2	24.7	103.9
MOORE BATCH PLANT	Lead and lead compounds	0	0	0
	Nitrate compounds (reportable only when in aqueous solution)	0	0	0
BIO-CIDE INTERNATIONAL INC	Chlorine dioxide	0	0	0

The National Pollutant Discharge Elimination System (NPDES) was established to regulate point source pollutant discharges. The program includes both stormwater and industrial and municipal wastewater discharges. In Oklahoma, ODEQ issues the permits in most areas. The EPA issues permits for activities in areas where ODEQ is not the permitting authority.

As stated previously, there are no point source industrial or wastewater discharges within the watershed. However, there are stormwater discharge sites. The Lake Thunderbird Watershed encompasses 15 OKR05 Multi-Sector General Permit (MSGP) stormwater discharge sites as listed in Table 10. These sites are allowed to discharge stormwater from their property into nearby bodies of water but are required to sample and monitor it. The site that released copper to water in 2019 according to the TRI, Johnson Controls, Inc., reported the total as 100% stormwater sourced and estimated the total quantity through sampling. Its MSGP Permit allows for stormwater discharge into the Little River.

[11] This data is for 2019. Environmental Protection Agency. (2019). *2019 TRI Factsheet: State*-Oklahoma.

Table 10

Lake Thunderbird Watershed Current MSGP Permits

	Facility	City	Permit	EffectiveDate	Standard Industrial Classification (SIC) Description	Sensitive Waters
1	SOUTHEAST OKC LANDFILL	OKC	OKR050 488	4/1/2019	Refuse Systems	No
2	WILLIAMS LAND	OKC	OKR052 553	6/25/2019	Miscellaneous Nonmetallic Minerals	No
3	Vickers S&G $4	Noble	OKR053 128	1/14/2019	Miscellaneous Nonmetallic Minerals	No
4	Butler Yard	OKC	OKR052 700	4/1/2019	Crushed and Broken Stone	No
5	SPAULDING AUTO SALVAGE	Norman	OKR051 422	5/16/2018	Motor Vehicle Parts, Used	No
6	Derichbourgh Recycling USA	Norman	OKR053 695	9/1/2019	Motor Vehicle Parts, Used	No
7	E & S EQUIPMENT, INC.	Norman	OKR051 761	9/1/2019	Industrial Valves	No
8	Norris Rods Inc - 12500S Sunnylane Rd	Moore	OKR053 758	12/5/2019	Oil and Gas Field Services	No
9	FEDEX FREIGHT EAST INC- OKLAHOMA CUSTOMER CENTER	Oklaho ma City	OKR051 530	5/10/2018	Trucking, ExceptLocal	No
10	Max WesheimerAirport	Norman	OKR050 565	2/5/2019	Airports, Flying Fields, & Services	Yes
11	Silver Star - PMI	Moore	OKR050 570	6/14/2019	Asphalt Paving Mixtures and Blocks	No
12	Johnson Controls Inc - Norman	Norman	OKR050 347	4/30/2019	Refrigeration and Heating Equipment	No
13	SOUTHWESTERN WIRE CO	Norman	OKR051 014	10/1/2019	Miscellaneous Fabricated Wire Products	No
14	Del Real Foods LLC	Moore	OKR053 627	5/1/2019	Frozen Specialties	No
15	RUPPERT ENTERPRISES INC	Moore	OKR050 252	12/30/2019	Motor Vehicle Parts, Used	No

The NPDES program also requires stormwater permits for construction sites (OKR10 permits). The active OKR10 permits are included here because runoff from disturbed land can contribute sediment loads to streams. The three municipalities with TMDL limits designated by ODEQ are required to include any potential contribution from sites with authorized Industrial or Construction Stormwater permits within their waste load allocations.[12][13]

Also included in the map are total retention facilities, or wastewater treatment sites managed by small entities that do not discharge into a stream or lake. However, the potential exists for some contribution of pollutants from these sites if they overflow or if the collection system connected to the lagoons malfunctions.

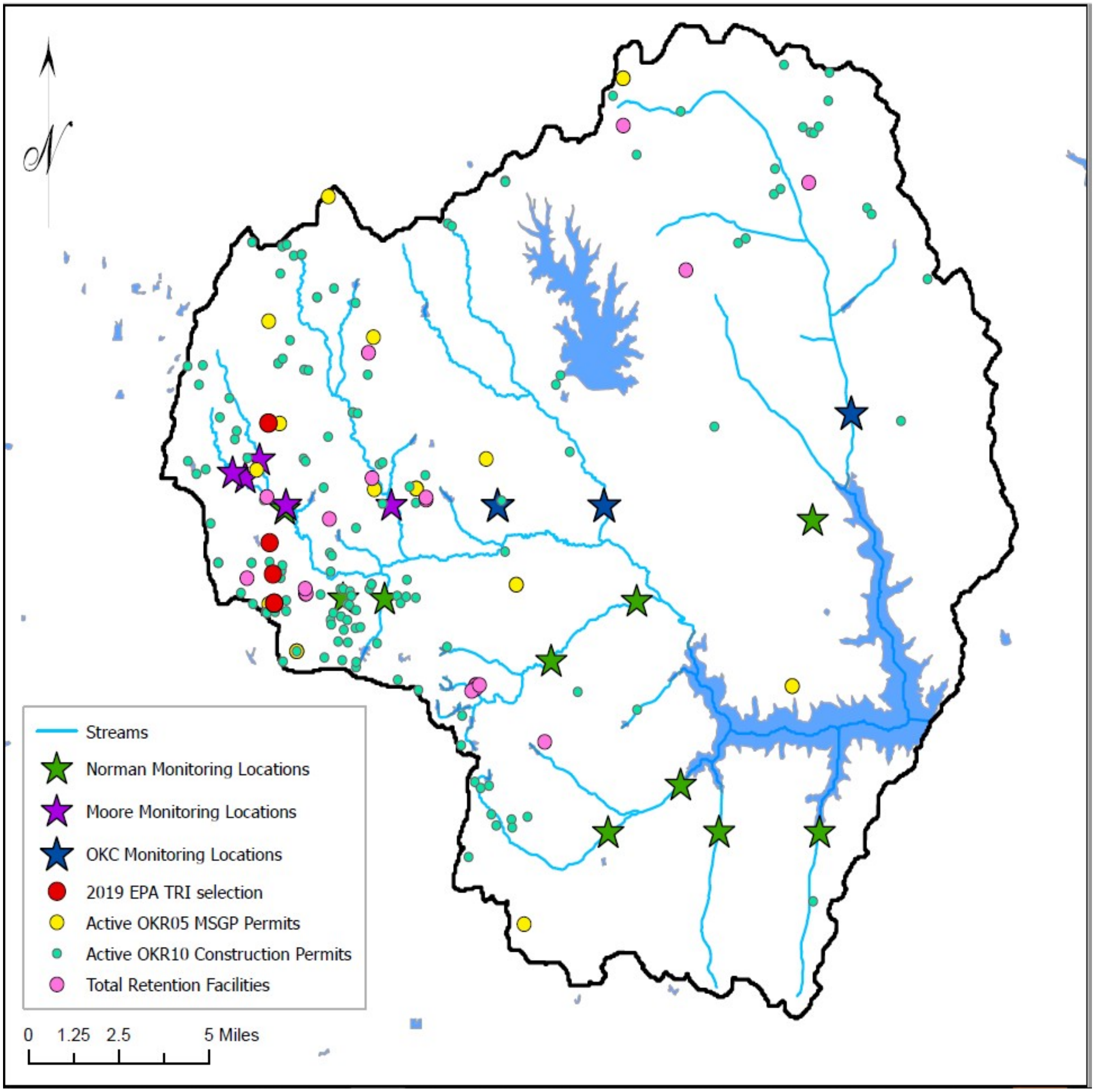
Note that in most past models produced by ODEQ and other agencies in the area, the discharging and potentially discharging locations discussed are not emphasized in the analysis, since the contamination likelihood is considered to be minimal and dynamic compared to that of nonpoint source runoff.

Finally, the map includes monitoring station locations managed by each of the three cities. These stations are on important streams that feed Lake Thunderbird, and the data collected are used to establish baseline conditions and to identify progress towards TMDL compliance. Due to their spatial distribution, they are also likely to capture changes in water quality from permit location discharges.

[12] Stated on Page 3 of The Lake Thunderbird report prepared by ODEQ in 2013.
[13] Note that the sites discussed in this section are all permitted sites. There is the potential for additional unpermitted sites to exist within the watershed and contribute to pollutant loads.

Figure 11

Lake Thunderbird Watershed Toxic Release Inventory and Permit Locations



Section 3 Water Uses & Users

Watershed stakeholders encompass a wide variety of groups, and all are impacted by water quality and quantity issues. For example, recreation clubs benefit from healthy streams where swimming, camping, and a healthy ecosystem is key to maximizing benefits from being and experiencing the outdoors. Many residents of the area and of outside the watershed get their drinking water from the lake as it is treated by their municipalities. The cities and local businesses benefit from tourism to the area and the lake itself offers many opportunities for recreation.

Below are some of the groups involved in research, recreation, and management of the watershed:

City of Norman
City of Moore City of Del City
City of Midwest City Cleveland County Extension Blue Thumb
Oklahoma Water Resources Board Oklahoma Conservation Commission
Oklahoma Department of Environmental Quality Center for Restoration of Ecosystems and Watersheds
Thunderbird Sailing Club
Central Oklahoma Master Conservancy District Oklahoma Water Survey

The 2019 census population estimate for the cities within the watershed is provided in Table 11.

Table 11

Lake Thunderbird Uses and Users

City	Estimated 2019 Population
Del City	21,712
Midwest City	57,407
Moore	62,055
Noble	7,053
Norman	124,880
Oklahoma	655,057

The watershed's largest water consumption comes from the residents of Norman, Del City, and Midwest City who source a significant part of their drinking water from Lake Thunderbird.[14] COMCD holds the water rights for supply from the lake. The proportion allocated to each city (based on a maximum total supply per year of 21,600 acre feet) is as follows: Norman is permitted to use up to 43.8% of the annual total available to COMCD. Del City can use up to 15.8% and Midwest City can use up to 40.4%. The actual volumes differ per year based on available supply. Midwest City's water treatment plant is designed to treat 13 MGD and Del City's plant is designed for 5 MGD.

With the growing demand for water and statewide plans that have indicated potential signs of scarcity in the future, all three cities have supplemental groundwater sources. In addition, the City of Norman has the ability to purchase water from the City of Oklahoma City.

[14] Water Supply from Lake Stanley Draper is not included in this report.

Based on the 2012 Oklahoma Comprehensive Water Plan, the 2010 and estimated 2060 water demands for Cleveland County, by industry, are provided in Figure 12 and Figure 13 below. (OWRB, 2012). The municipal and industrial sector accounts for the majority of the water demand and will continue to in 2060.

Figure 12

Cleveland County Water Uses 2010

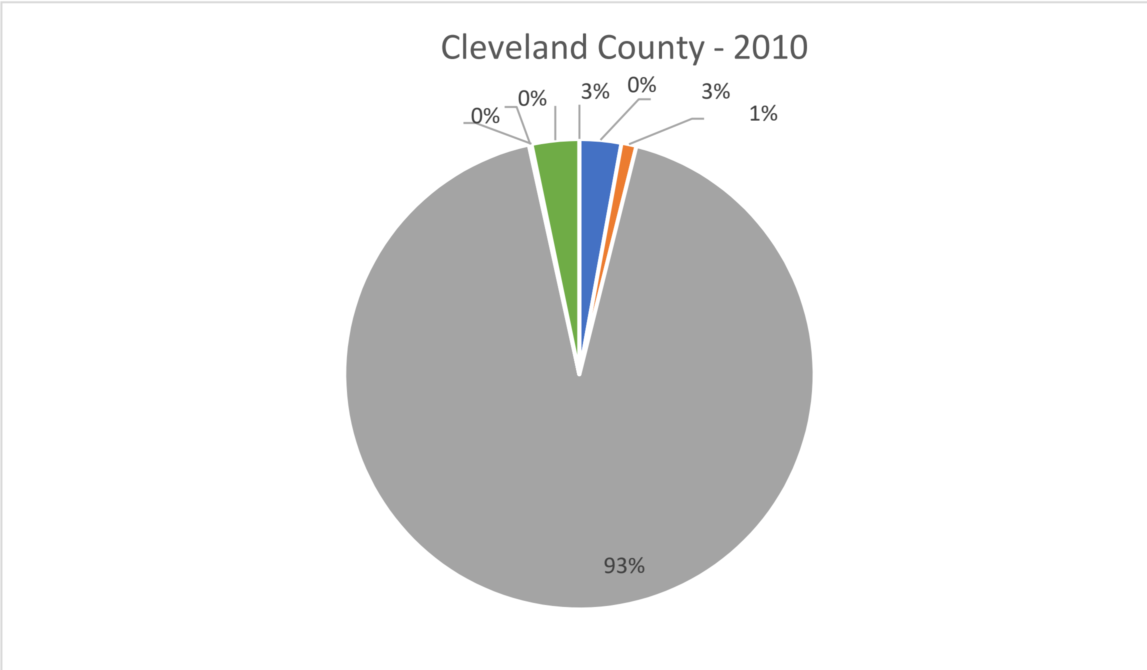
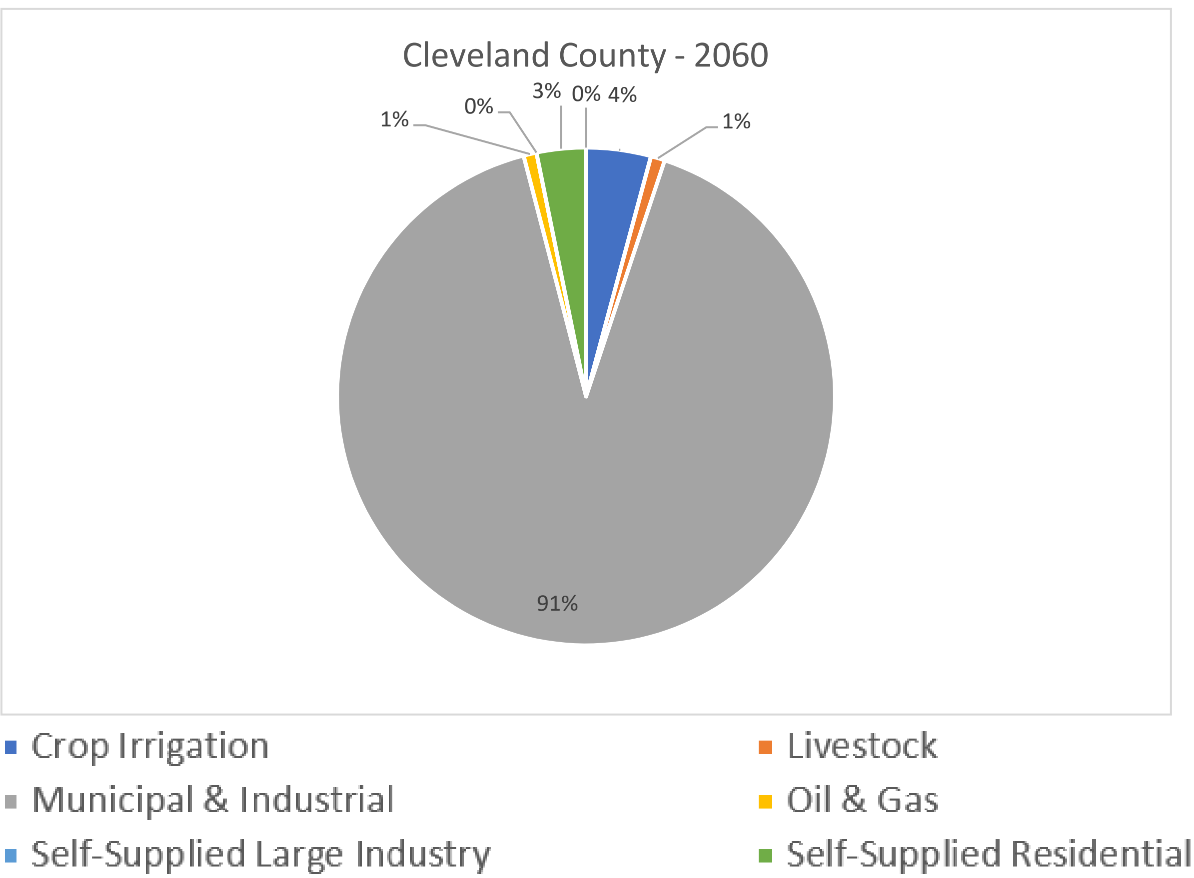


Figure 13

Cleveland County Water Uses 2060



Section 4 Watershed health

After establishing an overview of the context of the watershed through the characteristics discussed in previous sections, the TAG provided research and data ranging from city stormwater management plans to annual Lake Thunderbird water quality reports to studies on best management practice (BMP) applicability. There were over 80 studies identified for the project team to review (Refer to Appendix B for the comprehensive list). The studies, along with discussions with the TAG, were used to develop a list of issues in the watershed.

The overarching measure of success of the work done by different groups in the watershed has been the level to which water quality standards at the lake are attained with the goal of delisting it as an impaired water body. This would require attaining a long-term average chlorophyll a concentration of 10 µg/L at a depth of 0.5 meters, a surface dissolved oxygen concentration of more than 5.0 mg/L during the summer and fall, 6.0 mg/L in the spring and less than 50% of the total volume at a concentration of 2.0 mg/L. For turbidity, the water quality standard is 25 NTUs with less than 10% of collected samples exceeding the value in a 10-year dataset (OWRB, 2018).

Table 12 summarizes the water quality standards. These efforts do not only focus on the lake itself, since, by definition, the whole watershed impacts the resulting water quality in the lake. Research on the streams and the influence of all land uses and practices continues to provide clues into the most effective ways of advancing the goal to improve water quality in the watershed.

Table 12

Lake Thunderbird Parameters Monitored for TMDL and Impairment

Parameter	Criteria	Specific Threshold	OWRB 2017-2018 BUMP Data from Lake Thunderbird	OWRB Long term 10-year average (2009-2019)	Reference
Dissolved Oxygen (DO)	Surface criteria for WWAC lakes: 10% or less of surface samples across all life stages and seasons	April 1 – June 15: < 6.0 mg/L OR June 16 – March31: < 5.0 mg/L	N/A	N/A	OWRB 785:46-15-5(b)(5)(A)
	Water column criteria for WWAC lakes: less than 50% of the volume or 50% or less of the water column ofall sample sites in the lake	< 2.0 mg/L	Up to 67% of water column < 2mg/L in July	[15]	OWRB 785: 46-15-5(b)(6)(A)
Chlorophyll-a	Long- average (ten-year data used in ODEQ 2013 TMDL report)	< 0.010 mg/L or10 µg/L at a depth of 0.5 meters	0.021 mg/L	26 µg/L with 82% of samples exceeding 10 µg/L	OAC 785: 45-5-10(7)
Turbidity	Lakes: 10% or less ofthe samples may exceed specific threshold	< 25 NTU	Average: 14 NTU with 4% of values > OWQS of 25 NTU	Average: 24.8 NTU with 26.4 % samples exceeding 25 NTU	OAC 785:45-5-12(7)

Existing Data on Physical Characteristics

The studies in this section show that sediment accumulation within Lake Thunderbird is contributed to by streambank erosion in the watershed streams and lake shoreline erosion. The problem caused by sediment is increased turbidity and conveyance of nutrients within the sediment that can be deposited within layers at the lake bottom. If the lake remains eutrophic with excessive algae growth, anoxic conditions at the lake bottom can cause a re-release of those nutrients, further contributing to the cycle. More research is needed to identify the best sediment transport modeling method and best strategies for mitigating erosion in both the lake and streams, but quick implementation is a priority. With better modeling, quantification of the sediment transport would be possible and would better identify priority areas. This would also allow for a measure of progress in erosion control and the magnitude of impairments.

- Dutnell, R. (2015). Investigation of the Hydrology, Fluvial Geomorphology, and SedimentTransport in the Lake Thunderbird Watershed in Central Oklahoma.

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[15] One violation in 2019 as 52% of lake's total volume was anoxic water .This value is for 2019 only , not the long termaverage. No long term average value was reported in the 2019 OWRB Water Quality Report for the lake

Seven stream channel sites (Elm Creek, North Fork Little River, two at the Little River, Rock Creek,Hog Creek, and Dave Blue creek) within the Lake Thunderbird watershed were evaluated for existing hydrology and classified according to fluvial geomorphology surveys. The purpose was toprovide a baseline of their existing condition to understand current and future sediment accumulation at the lake through suspended sediment transport from the watershed. Most of thechannels were identified as unstable to highly unstable, meaning that they are undergoing changeand contributing to sediment transport due to streambank and bed erosion.

- ❖ Oklahoma Water Resources Board (2005). Demonstration Project: Mitigation of NPS Impact to Littoral Zone of Lake Thunderbird Cleveland County, Oklahoma

Littoral plants help absorb nutrients that would otherwise encourage algae growth, provide foodand habitat for fish and prevent shoreline erosion. If erosion has prevented or damaged littoral plants, stabilizing the shoreline requires intervention. The study showed that 150 feet of effectivebreakwater allowed plants to begin growing behind it. However further observation was neededto confirm that the plants would continue to grow and preserve shoreline, survive the waves, anddissipate wave energy. Other methods for breakwaters and erosion mitigation should be explored(to identify less expensive methods and less laborious installation) but the study proved that aquatic macrophytes can be established even if gravel substrate is poor.

- ❖ Oklahoma Water Resources Board (2005). Lake Thunderbird Hydraulic and Nutrient Budget

A study done in 2005 quantified the inputs (inflow, rainfall) and outputs (evaporation, water supply and releases) of Lake Thunderbird to monitor the annual hydraulic budget and compare ityear to year for drought and flood analysis. The results showed that the estimated inputs and outputs resemble the actual volume changes closely.

- ❖ Oklahoma Water Resources Board (2001). Lake Thunderbird Capacity and Water Quality for the Central Oklahoma Master Conservancy District.

In 2001, the OWRB reported that sediment had accumulated in the upper portion of Lake Thunderbird's conservation pool at a rate close to the planned rate of 350-acre feet per year. In addition, the aeration recently installed was under powered and was encouraging algae growth by allowing the transfer of nutrients from the sediment to the epilimnion. The next proposed evaluation was to oxygenate the hypolimnion.

- ❖ Hollis Allen All Environment Consulting (2001). Shoreline Erosion Control Plan Lake Thunderbird, Cleveland County, Oklahoma

The lake has several reaches of shoreline with category 5 erosion (the highest category of the range used in this study which refers to greater than 4 feet of escarpment, not much of a toe lakeside of the escarpment and no vegetation in the water). Since erosion is extensive, the study recommended prioritizing erosion control in picnic/campground areas using volunteer labor andsupport from yacht, fishing, and wildlife clubs/organizations, as well as education and training tobuild support and funding. It suggested to start with less severe sites for illustrating success and then proceed to more difficult reaches of shoreline.

Existing Data on Biological/Ecosystem Characteristics

The studies below refer to available information on the existing ecosystem and organisms in the watershed, but do not provide information on the water quality or quantity impact to their habitat. Further research and surveys of organisms in the watershed creeks are needed to offer insight into whether stream specific impairments are causing biological impacts apart from physical and chemical impacts.

- Tetra Tech (2010). Critical Need Water Supply Project Environmental Assessment

The environmental assessment completed by Tetra Tech was an evaluation of the impacts of constructing a waterline from the Atoka Pipeline to Lake Thunderbird, that would allow for COMCD to purchase water from Oklahoma City to fulfill their demand during drought conditions. A comprehensive wildlife, vegetation andaquatic resources assessment showed that the Lake Thunderbird area has more than 300 vertebrate species, with the highest proportion of the total being bird species. The three federally endangered, threatened or candidate species likely found in the area are the black capped vireo,snowy and piping plovers and whooping cranes. Out of three considered alternatives, the preferred alternative was to connect a buried pipe to the Atoka Pipeline at an existing valve near Willow Branch Creek. The water would discharge directly into the creek, disturbing less area than the other alternatives, having no impact on wetlands, and having a faster and lower cost construction process.

- GBM & Associates & Olsson Associates (2016). City of Norman, OK Lake Thunderbird Complianceand Monitoring Plan

The City of Norman will partner with the Oklahoma Conservation Commission for bi-annual biological monitoring through macroinvertebrate sampling at Rock Creek, Little River and Dave Blue Creek, and visual qualitative habitat assessments.

Existing Data on Pollutant/Chemical Characteristics

The studies and future studies in this section focus on the investigation of sources and causes of pollutants in the watershed. Water quality data available up to 2019 show that the lake continues to have eutrophic conditions and that the water quality parameters (chlorophyll a, turbidity, and dissolved oxygen) measured indicate impairment. This causes less than ideal transparency for recreational and aesthetic uses and leads to taste and odor complaints from watershed residents whose drinking water is sourced from the lake. Studies and analysis of long-term data will offer insight into the magnitude of improvements in the lake over the last 20 years and the ability to develop detailed nutrient budgets. The goal is to pinpoint the major causes of impairment to cater management strategies to be most effective. Apart from nutrients and sediment, contaminants of emerging concern have been studied more recently due to City of Norman proposals and future pilot study proposals on reuse of reclaimed water. The focus is on ensuring that specific treatment methods at the source of discharge and natural processes within the streams will mitigate harmful chemicals from reaching the lake. If not, they pollute recreation areas and could be conveyed in the inflow to water treatment plants sourcing water from the lake. However, these chemicals are present in Lake Thunderbird and water bodies around the state already, prior to any implementation of reclaimed water discharge, emphasizing the need to curtail inputs from stormwater and other sources. Though the list below includes studies on the presence of CECs, pesticides, and herbicides within the lake, and the effect of natural treatment occurring in the streams, further studies are needed on the effects of CEC, pesticide and herbicide uses once they enter water treatment plant processes. They have the potential to affect taste and odor and water reuse potential, specifically within the watershed.

- ❖ Oklahoma Conservation Commission – Blue Thumb (1992 – present)

Blue Thumb represents the education section of the water quality division within the Oklahoma Conservation Commission. It encompasses a science program through which citizens statewide can volunteer to learn about and perform water sampling to benefit the community for years to come. Data collected from this program is available by request and is available online for anyoneto view. The streams sampled depend on the volunteers available in the area.

- ❖ Oklahoma Water Resources Board (2021). Long-term Trend Analysis of Lake Thunderbird Water Quality Data

In 2021, OWRB is set to begin an evaluation of the 20 years of monitoring data and studies they have completed to analyze trends and identify the best next steps in reducing nutrient and sediment load to and within the lake.

- ❖ Oklahoma Water Resources Board (2000-2019). Lake Thunderbird Water Quality for the Central Oklahoma Master Conservancy District.

The OWRB has been monitoring water quality within Lake Thunderbird since 2000 at seven to tensites, depending on the year. They measure chlorophyll –a, turbidity, secchi disk depth, total Kjeldahl nitrogen, nitrate, total organic carbon, ortho-phosphorus, nitrite, total phosphorus, ammonia, dissolved oxygen concentration, specific conductance, dissolved oxygen saturation, oxidation reduction potential, water temperature, pH, air temperature, precipitation, site depth, wind, wave action, cloud cover, and barometric pressure. They also document the thermal stratification pattern, seasonal nutrient concentrations, taste and odor complaints from the cities' water departments, and the efficacy of the SDOX system installed in 2011. From these annual reports, the OWRB has indicated that the Lake has remained categorized as eutrophic, in which there is an excess level of nutrients that causes abnormal algae growth and oxygen depletion. Theoxygen depletion allows bacteria at the lake bottom to use other elements to consume the decaying algae, thus releasing more nutrients from the sediment and further encouraging the cycle.

A few general relationships observed throughout the 20 years and of typical of lakes are:

- Inorganic turbidity and nutrient availability is greater in riverine locations within the lake(close to where streamflow enters the lake) is higher than lacustrine locations
- Algae production increases in the warmer surface waters of the summer
- In healthy lakes that are not eutrophic, phosphorus is the limited nutrient, not nitrogen (when ratios of TN to TP greater than 65). In these cases, green algae is more common than blue green algae which causes taste and odor complaints after treatment and toxicity concerns within the lake.
- Trophic state index (TSI) is used to quantify primary productivity of a lake and determineto what magnitude it has excessive nutrient availability and algae growth. In Lake Thunderbird, chlorophyll-a is used as a the TSI metric because of its relationship to algal biomass.
- One measure of total organic carbon's (TOC) relationship to eutrophication is that median organic carbon content of 12 mg/L represent a eutrophic lake. Reducing TOC can reduce

drinking water treatment costs since disinfection by products are formed when chlorine reacts with organic matter.

- Typical value for secchi disk depth measure of turbidity is less than 1 meter in Oklahomaand riverine areas have the smallest depths
- Taste and odor complaints due to Geosmin and 2-methylisoborneol (MIB) typically increase when the lake turns over in the fall. After being stratified in the summer when warming of the surface water allows it to remain on top due to being less dense, colder fall temperatures cause the surface water to sink. This leads to mixing between layers andrelease of compounds previously isolated in the hypolimnetic layer.

❖ Horton, A.D. (2018). Baseline Concentrations of Contaminants of Emerging Concern in the Lake Thunderbird Watershed, Planning for Indirect Potable Reuse in Oklahoma

The study analyzed baseline concentrations of CEC in the lake and periodic tendencies of the concentrations, compared results to other studies and identified sources for those CECs found. Sampling took place in 2016-2017, once each season, for industrial chemicals, pesticides, pharmaceuticals and personal care products (PPCPs) and others (113 total). Sources were determined by delineating subwatersheds and their land use, density of domestic wells and density of storage tanks. The compound NP (nonylphenol) was detected in three seasons, more than other industrial compounds, atrazine and simazine were detected every season (ag and lawnrunoff), as well as artificial sweeteners and DEET (maybe from recreational use of the lake).

❖ Thornton, E. (2017). Microcosm Assessment of Natural Processes Affecting Chemicals of Emerging Concern in Secondary Effluent

The microcosm studies were developed by using sediment from Dave Blue Creek mixed with Norman's Water Reclamation Facility effluent to test treatment and reduction of Contaminants of Emerging Concern (CECs) through sorption and photodegradation. Photodegradation was more effective at reducing pharmaceutical and personal care products (PPCPs) and sorption was more effective at decreasing pesticide detection. Other tested CECs were endocrine disrupting chemicals (EDCs) fire retardant, preservatives and artificial sweeteners. It is important to note that CECs have been proven to degrade through natural attenuation, but the buffer capacity of each natural system differs and specific studies must be done on the area to receive reclaimed effluent. Oklahoma did not have water reuse standards until 2012 and in 2017 regulations were still in development.

❖ Oklahoma Water Resources Board (2005). Lake Thunderbird Hydraulic and Nutrient Budget

A study done in 2005 developed a phosphorous budget for Lake Thunderbird based on sampling data of internal inputs and outputs as well as vertical profiles to differentiate the quantities distributed over the layers of water in the lake. The results showed that the proportion and location of ortho phosphorus in the hypolimnion compared to total phosphorus represent anoxicconditions as supported by sampling data of other parameters. This shows that internal dynamicsof nutrient release is a large factor in determining overall water quality. However, inflow load estimates and dry deposition were not included in the analysis for comparison.

Known impaired areas

The list of studies below focuses on reports indicating specific water quality deficiency areas in the watershed. Nonpoint sources are the main contributor of pollutants through stormwater runoff as found by different modeling efforts.

- Oklahoma Department of Environmental Quality (2018). Appendix C – 2018 Oklahoma 303(d) Listof Impaired Waters

The ODEQ publishes a list of impaired water bodies every year statewide. The assessment is basedon the designated beneficial uses applicable to each stream or lake and whether the water qualitystandards associated with each are attained. As discussed in the introduction of this report thereare various streams with one or more impaired uses. See Table 13.

Table 13

2018 ODEQ Water Quality Report for Lake Thunderbird Watershed Streams and Lakes

Site Name	2018 ODEQ Water Quality Report									
	Category	Aesthetic	Agriculture	Warm Water Aquatic Comm	Fish Consumption	Navigation	Primary Body Contact Recreation	Secondary Body Contact Recreation	Public and Private Water Supply	Sensitive Water Supply
Thunderbird Lake	4a	I	F	N	F		F		N	*
Hog Creek	5a	I	F	F	X		N		I	*
West Hog Creek	5a	I	I	N	X		I		X	*
Clear Creek	3	X	X	X	X		X			
Dave Blue Creek	3	X	X	X	X		X		X	
Jim Blue Creek	3	X	X	X	X		X		X	
Little River	5a	X	N	N	X		N		X	
Rock Creek	5a	X	F	I	X		N		X	
Elm Creek	5a	F	N	F	X		N		X	
East Elm Creek	3	I	I	I	X		I		X	
East Elm Creek										
West Elm Creek	5a	X	F	I	X		N		X	
Kitchen Creek	3	X	X	X	X		X		X	
Kitchen Lake	3	X	X	X	X		X			
North Fork Little River	2	I	F	I	X		X		X	
Moore Creek	5b	F	N	I	X		X		F	
Mussel Shoals Lake Creek	3	X	X	X	X		X		X	

(F) fully supporting, (I) insufficient information, (X) not assessed, (N) not supporting

(2)Attaining some of the designated uses, no use is threatened and insufficient or no data available to determine if remaining uses are attained; (3) insufficient or no data and information to determine if any designated use is attained; (4a) TMDL has been completed; (5a) TMDL is underway or will be scheduled; (5b) A review of the water quality standards will be conducted before a TMDL is scheduled.

- ❖ Dynamic Solutions, prepared for the Oklahoma Department of Environmental Quality (2013). Final Lake Thunderbird Report for Nutrient, Turbidity, and Dissolved Oxygen TMDLs

The Oklahoma Department of Environmental Quality (ODEQ) completed a TMDL report for Lake Thunderbird after it was listed on Oklahoma's 303(d) list of impaired water bodies in 2010 due toelevated levels of chlorophyll a, high turbidity and low dissolved oxygen. It found that the main contribution of pollutant sources (suspended sediment, nitrogen, phosphorus) to LakeThunderbird comes from urban stormwater runoff from the three MS4 permitted cities. Nevertheless, rural areas also contribute pollutants. The document dictates that each permittee (Norman, Oklahoma City, and Moore) must develop a TMDL compliance plan, a pollutant monitoring and tracking program, annual reports (included in their annual MS4 reports), and an evaluation of progress generally every 5 years.

- ❖ Oklahoma Conservation Commission (2008). Watershed Based Plan for the Lake Thunderbird Watershed

In 2008, the OCC developed a plan for the Lake Thunderbird Watershed based on the modeling conducted by Vieux & Associates in 2007. It concluded that an adaptive plan was required to restore the beneficial use of the water bodies in the watershed through public outreach/education, BMP implementation, and monitoring and data collection/review. It included an estimate of costs for each implementation step, a preliminary schedule and milestones, as well as methods for monitoring successes from implementation and the need to establish baseline conditions for future planning, including biological assessments and surveys. The only permitted nonpoint sources, apart from MS4 permits, include 12 total retention lagoons that may contribute pollutants if they leak or overflow. There are no permitted point sources.

- ❖ Vieux & Associates, Inc. (2007). Lake Thunderbird Watershed Analysis and Water Quality Evaluation.

Vieux & Associates modeled the nonpoint source contribution of pollutants into Lake Thunderbirdwith two scenarios, a baseline/existing condition and a future build out condition as the municipalities in the watershed continue to develop. They found that in the early 2000s chlorophyll-a averaged 30.8 ug/L in the lake (the water quality target is 20 ug/L.) For the build- out scenario, it was estimated to increase to 44 ug/L. From their model, total phosphorus increased from 0.25 to 0.54 kg/ha due to urban development under the build-out scenario. Modeling indicates that statutory fertilizer reduction, wetlands, and structural controls to the entire basin, can reduce total phosphorus load by 74% for baseline and by 84% for build-out scenarios. Based on the contributions from each area, the City of Norman alone cannot reduce chlorophyll-a to meet the water quality target without additional reductions by the other cities.

Existing Information on Social and Economic Systems

The three MS4 cities in the watershed continue to grow and expand in population and development. Recent comprehensive plans developed through community engagement demonstrate common citizen opinions including land use that reflects connected and walkable neighborhoods with more attractive green spaces. Lake Thunderbird recreational opportunities are at the heart of the watershed and serve as the basis for outdoor activities for not just citizens of the area but many other visitors. The following documents capture glimpses of the trends in the watershed and public opinion on recreational opportunities, growth, and the environment.[16]

- Wu, I., Liu, H., Caneday, L. (2019). Lake Thunderbird State Park Resource Management Plan. Cleveland County, Oklahoma

The resource management plan, an update to the 2009 document, describes management responsibilities to balance use of water and land resources related to recreation. Lake Thunderbird hosts more than a million visitors annually. Service quality evaluations were based on park staff and Oklahoma State University (OSU) cooperative project analyzing service quality, satisfaction and willingness to pay for an entrance fee (in 2014 through Facebook). The results showed that the mean scores (1 for strongly disagree and 7 for strongly agree) were 4.2 for satisfaction, 5.6 for visiting the park again and 5 for recommending it to others. Recommendationsincluded increased focus on accessibility, doubling the current number of park rangers and support staff, completing a carrying capacity study, development of proper and consistent signage for trails and update maps, encouragement of the OK legislature to fully fund the lake maintenance and construction needs, continuing to address pollutants that cause impairment of designated beneficial uses, adoption of BMPs by Oklahoma Tourism and Recreation Department(OTRD) for erosion protection and shoreline preservation, evaluation the building structure and elevation for Clear Bay Cafe, develop a new plan for disposal of waste, strengthening of park maintenance, evaluation of the exterior signage for the Park, development of strategies for branding the property as a state park, and development of a new plan for Fisherman's Point Campground, and host interns.

- City of Moore (2017). Envision Moore Plan 2040 Comprehensive Plan

The City of Moore's comprehensive plan engagement process offered insight into what its citizens expect of the City as summarized below. Only those points most relevant to the watershed's land uses are listed.

  - The population growth of the City of Moore has been more accelerated than those of the surrounding cities
  - Desire for enhanced landscaping and more pedestrian oriented design to preserve the small town feel of the city
  - Importance of safety and affordability in housing and neighborhoods
  - Importance of limiting commercial encroachment in neighborhoods and emphasizing natural space and attractive spaces
  - Improved street design, walkability and connectivity within the City

- City of Oklahoma City (2015). Planokc

Public engagement was included in developing all elements of Oklahoma City's Comprehensive Plan. A

[16] Current public input will be gathered through the Education and Outreach task of the LTWA's establishment and will be included and used for development of the Integrated Watershed Management Plan.

few of the key takeaways are listed below. Only those points most relevant to the watershed's land uses are listed.

- Citizens value living spaces that change in land use type to combine living, shopping and green spaces.
- Demand in housing may be met with potential lack of supply due to the housing type preferences projected over the next 15 years
- Oklahoma City households understand the value of key neighborhood amenities and expressed a willingness to pay for them
- The City needs to plan development more efficiently to avoid historical costs of casual, spontaneous growth
- Cultural inclusion of grocery store options

❖ City of Norman. (2004). Norman 2025 Land Use and Transportation Plan

Public engagement feedback during the creation of the plan highlighted most common public opinions from the citizens of Norman. Only those points most relevant to the watershed's land uses are listed.

- Appreciation for the quality of life enjoyed
- The importance of controlling the quality and location of growth
- Ensure that adequate public facilities are developed and constructed simultaneously with growth
- Desire for focus on aesthetics and attraction of commercial and industrial development
- Support for restricting development in rural areas and flood plains
- Desire for a Community Separator along the northern boundary of the City

Existing Water Quality Management

Entities within the watershed and throughout the state have been striving to improve water quality and plan for future capacity demands for many years. The following documents point to these efforts. Best Management Practices (BMPs) for stormwater infrastructure and nonstructural strategies of mitigating stormwater contamination and pollutant runoff have been implemented in local ordinances and multiple studies have been conducted within the watershed. The conclusion is that there are cost, water quality, and ecosystem service benefits derived from "green" practices that focus on on-site detention and treatment of stormwater as well as education and outreach on how day-to-day residential and commercial practices impact the environment. Similar trends outlined in the previous section on social and economic systems, combined with similar trends in stormwater management within the three MS4 permitted municipalities demonstrate that a cooperative effort to address water quality issues would advance the goals of all communities in the watershed.

❖ Oklahoma Conservation Commission & The Oklahoma Wetland Technical Work Group (2020). Oklahoma's Wetland Program Plan 2020-2025.

❖ B. Trammel, personal communication, March 11, 2021

This the second state Wetland Program Plan (updating the one published in 2013). The goal of thewetlands program is “to conserve, enhance, and restore the quantity, quality, and biological diversity of all wetlands in the state” and contains 5 key components: monitoring and assessment,regulation, voluntary restoration and protection, water quality standards, and education and outreach. The objectives included in this report are:

- Develop a monitoring and assessment strategy to track wetland health, prioritize restoration activities and guide compensatory mitigation projects (including OKRAM, Oklahoma Rapid Assessment Method)
- Promote greater understanding of the scope of the program
- Clearly establish integrative wetland restoration, enhancement, creation and protection goals
- Develop wetland specific water quality standards
- Provide landowners, land users, resource managers and policy makers with information to manage wetland resources and importance of wetlands

Since the onset of wetland preservation efforts in Oklahoma, the OCC has worked through varioustasks to advance the program. Below are four key areas of effort and their current status:

(1) The OCC developed a wetland registry where landowners can contact the group to establish part of their land back to its natural state, by being put into contact with other groups looking to purchase mitigation credits. However, compensatory mitigation regulation and programs have not taken flight in Oklahoma as much as in some other states, undermining the effectivity and use of the OCC’s registry. In addition, areas to be preserved or returned to their natural state to offer ecosystem services cannot be used for other activities such as hunting.
(2) The OCC also developed a tool called the Restorable Wetland Identification Protocol (RWIP) to locate and rank those areas that can be restored to wetlands offering full ecosystem services. They modified and upgraded the tool in 2018 and included statewidedata and have found it to be more than 80% accurate. The goal is to offer a map availableto the public from which developers and landowners can weigh the costs and benefits ofrestoring an area.
(3) They have also worked with ODOT on a pilot project through Central Oklahoma to determine the need and feasibility for an in-lieu fee program for projects that impact waters of the state. However, various events have caused delays and gaps in this effort.
(4) The OCC has participated in mitigation bank efforts as an Interagency Review Team Member with the U.S. Army Corps of Engineers.

❖ Nguyen, D.X. (2018). Evaluation of Stormwater Treatment by Various Reactive Media for Bioretention Cell Design Considerations

Fly ash and oxyhydroxide mine drainage residuals used as bioretention cell media removed over 84% of phosphorus and were most cost effective. All media tested removed copper and lead at over 84% and APT (a commercially available granulated and hardened peat product) had the highest lead removal rate. Nitrate was hard to remove with all media.

❖ Holzbauer-Schweitzer, B.K. (2016) Evaluating Low Impact Development Best Management Practices as an Alternative to Traditional Urban Stormwater Management.

Presence of LID BMPs at the study site had a positive influence on water quantity and quality, while providing an economic benefit in the form of ecosystem services.

BMPs consisting of 18 rain gardens, 17 rain barrels, diverted downspouts, and 120 square feet of permeable pavement in Norman's Trailwoods neighborhood were compared to a control site in the same neighborhood using traditional stormwater management. The impact of the BMPs wasanalyzed in three ways: by the difference in storm event volumes and peak discharges, by their ability to decrease urban stormwater pollutant concentrations and loads and by looking at the relevant ecosystem services provided. 10 precipitation events were analyzed for water quality and quantity. Results showed that peak discharge rates were lower for all 10 events and total discharge rates were lower for 50 percent of events. Mean concentrations of pollutants and loading rates were lower for the portion of the neighborhood with BMPs except for when lookingat ammonia and phosphorus compounds. In terms of economic benefit for each water user, the ecosystem service analysis showed that BMPs can provide long term economic benefits worth beyond the initial cost of construction.

- ❖ Oklahoma State University (Department of Biosystems and Agricultural Engineering) (2016). Bioretention Cells for Mass Load Reduction of Phosphorous and Sediment in Urban Watersheds in Oklahoma

Stormwater monitoring in areas with bioretention cells took place between May 2014 and November 2015 (the original Grand Lake BRCs had been installed in 2007 while the OKC site wasnew). The samples were flow-weighted composites and were tested for indicators such as anions, cations, heavy metals, microbes and nutrients. Soil and filter media samples were also analyzed. Results showed that bioretention cells (BRCs) do have the potential to reduce phosphorus and other pollutant loading into streams and lakes and could help delist Hog Creek and Grand Lake from the 303(d) Impaired waters list.

- ❖ Coffman, R. (2014). Trailwoods Neighborhood Best Management Practices
- ❖ Nairn, R.W. (2015). Lake Thunderbird Watershed Implementation Project: TrailwoodsDemonstration Site Monitoring – Draft Final Report
- ❖ Coffman, R., Lui, R., Mitchell, K., Ladoceur, A. (2014). Update Life Cycle Cost Model and Analysis

Various groups including the Oklahoma Conservation Commission, University of Oklahoma, City of Norman, Ideal Hopes Development and two consulting firms cooperated in establishing a newresidential development in which half was designed to include green infrastructure such as rain gardens and porous paving and the other half had conventional stormwater management. The purpose was to compare the impact of best management practices on water quality and quantityand to help educate the community. Evaluation of the green infrastructure was difficult but resultsdid show that peak discharge rates were decreased and solids retention and denitrification helpedimprove stormwater quality. However, other constituents such as phosphorous were not as wellcontrolled from entering stormwater effluent.

The cost benefit analysis evaluates sustainability of the Trailwoods Greenstreet over 30 years (triple bottom line), based on the typical lifetime of conventional stormwater infrastructure. Thecost analysis put green infrastructure for the site at $208,332 and conventional stormwater infrastructure at $89,193. Financial benefits are runoff reduction, energy saving and increased property values. The environmental benefits are improved air quality and reduced TSS. The socialbenefits are reduced heat island effect, community cohesion, increased public awareness, improved aesthetics and increased recreation and heat stress reduction. The net benefit of greeninfrastructure was $93,468 which is greater than the $89,193 cost of conventional stormwater infrastructure (life cycle wise).

- Nairn, R.W. (2014). Wetland Treatment Study

The study was based on the applicability of restoring or constructing wetlands in the Lake Thunderbird Watershed in order to improve stormwater quality and hence the water quality within the lake. The conclusions are that a few large-scale wetlands low in the watershed intercepting stormwater from upstream sources, in areas like OKC and Moore, coupled with manysmall-scale treatment wetlands at upstream source areas in the watershed would result in improvement.

- Municipal Stormwater Management Plans

The cities of Moore, Oklahoma City and Norman are required by their state authorized MS4 permits to develop and implement a stormwater management plan. Since they have been assigned WLAs as well due to the TMDL of Lake Thunderbird, their plans must address ways to comply with those limits in addition to providing annual reports on progress towards achievement. All three cities have monitoring, education and outreach, and ordinances to mitigate stormwater caused flooding, erosion, and water quality degradation.

- Municipal TMDL Monitoring and Compliance Plans

The cities of Moore, Oklahoma City, and Norman are required by ODEQ to develop and implementTMDL Monitoring and Compliance Plans to achieve their WLAs. Every five years they are to be updated and revised for effectivity and annual reporting of progress is required. The Watershed Features Section in this report contains a figure with each City's monitoring locations.

- Oklahoma Conservation Commission (2013). Thunderbird Lake Watershed ImplementationProject Phase II – Impediments to Low Impact Development in Lake Thunderbird Watershed

This document was developed to identify gaps in the City of Norman's codes that were still creating impediments to low impact development. The recommendations, based on a scorecard from the Center for Watershed protection, included narrow residential streets to reduce impervious surfaces, an increase in the number of homes per unit street length to reduce pavement, curb/gutter, storm sewer, utilities, minimum percentage of parking lot to be landscaped, require onsite treatment of stormwater, and implement native plant and treeconservation.

Section 5 Scoping of Issues

The watershed problem areas were identified from the review of the documents provided and developed further with feedback from the TAG. The scoping of the issues was completed in the following sequence (Heathcote, 2009):[17]

(1) Collected and reviewed existing studies
(2) Compiled summary of existing studies
(3) Identified misinformation or data gaps
(4) Grouped identified issues into the following categories:
    a) Degraded water quality
    b) Bank erosion
    c) Shoreline erosion
    d) Water supply and capacity
    e) Further research and monitoring needed
(5) Boundary setting of each issue by identification of the following:
    a) Geographical area
    b) Time period
(6) Definition of each issue by identification of the following:[18]
    a) Impaired use
    b) Reason for impairment
    c) Possible causes
(7) Issue Prioritization

In step seven (7), the TAG was tasked with filling out a prioritization rubric to provide feedback on which issues should be addressed by the LTWA and included in the Integrated Watershed Management Plan. Eight total rubrics were submitted (See Appendix D). The criteria in the rubric were developed based on the impact to the designated uses of the water bodies (such as Agriculture and Warm Water Aquatic Community) and the perspective that the LTWA is better fit to serve issues that require more collaboration between different municipalities and groups. The criteria did not include management strategy applicability to each issue since the goal was to prioritize based on impact and applicability to the LTWA's efforts. The decision to limit the number of issues as described below was made to help the LTWA focus on the most prominent problem areas while still incorporating the many uses of the watershed in its scope: recreation, water supply and capacity, water quality, environmental health, regulatory compliance.

To analyze the results from the submitted rubrics, the following steps were taken:

(1) Listed all prioritization rubrics submitted and calculated average of all scores to get a final ranking.
(2) Listed top 10 rankings from each submitted rubric. If more than one issue had the same score, all issues with that score were given the same rank. Therefore, 10 rankings did not always equivalate to only 10 issues.
(3) Tallied how many times each issue (from step 2) appeared considering all rubrics.

[17] Note: additional clarification questions to the TAG were identified in this process and were emailed tothe appropriate members.

[18] See Appendix C for a table summarizing steps 1 through 6

(4) Listed all issues, ranked by number of tallies. Again, if more than one issue had the same tally score, all issues with that score were given the same rank.

(5) Results from steps 1 and 4 were compared to identify issues included in one list but not the other.

   a) The only issue not included in step 4 from step 1 was Water Capacity (Sediment Accumulation at Lake Thunderbird). This issue was excluded from the prioritized list regardless, because the bank and shoreline erosion issues listed in the top rankings address the issue.

(6) For those issues not included in the top 10 rankings of either list, geographic location, current monitoring status, ranking of the issue as perceived by the analysis of the 80+ documents, and input from clarification questions emailed to individual TAG members were taken into consideration to decide whether to include the item in the main list as an issue for further monitoring and research or not at all.

   a) All bank erosion issues that were not in the top-ranking issues of step 4 were placed in the further research section since more than one TAG rubric indicated that bank erosion and strategies to address it needed to be researched further. Kitchen Creek and Clear Creek were placed in the further research section due to no known current impairments at either location and current City of Norman monitoring at Clear Creek. High Total Dissolved Solids (TDS) at Little River requires more research to determine sources. Bacteria related and low DO issues were not included in any of the lists since input from TAG members showed consensus in ranking them low.

Priority Issues to Address

According to the method in the previous section, Table 14 and Table 15 below show the final prioritized watershed issues:

Table 14

Priority Issues for LTWA to Address in the Integrated Watershed Management Plan

No	Issue Category	Specific Issue	Geographical Area
1	Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River
2	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Upper Little River
3	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Little River
4	Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River
5	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	North Fork Little River
6	Shoreline Erosion	High TSS	Lake Thunderbird
7	Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek
7	Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek
7	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Hog Creek
10	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Dave Blue Creek
11	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	West Elm Creek

Priority Issues for Further Research

Table 15

Priority Issues for Further Research to Address in the Integrated Watershed Management Plan

No	Issue Category	Specific Issue	Geographical Area
1	Water Quality Degradation	More data /studies on septic tank potential impacts on water quality. Specific area studies on density, proximity to stream, etcetera	Where developments arenot connected to city wastewater systems
2	Water Quality Degradation	More data on internal loading/ legacy loadingof nutrients in Lake Thunderbird	Lake Thunderbird
3	Water Supply & Capacity	More data on Taste and odor complaints from each of the cities and implications for treatment. This includes evaluation of presence of CEC's, pesticides, and herbicides.	Lake Thunderbird
4	Degraded Water Quality	Bank erosion	All watershed streams where erosion has been identified
5	Degraded Water Quality	Flooding effects on water quality	Where flooding is common
6	Bank Erosion	High TSS / Potential for high phosphorus levels/ low DO	Rock Creek
7	Degraded Water Quality	High TDS	Little River
8	Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek
9	Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek (currently monitored)

Conclusions

To restore the beneficial uses (public/private water supply and WWAC) of Lake Thunderbird, existing characteristics and data on the watershed was obtained and reviewed to understand the nature and extent of use impairments and identify the causes of impairments. Over 80 studies were identified, with help from the TAG, and reviewed.

The research and prioritized list of issues point to four main nonpoint stormwater runoff pollutants contributing to current and future water body impairment: sediment, nitrogen, phosphorus and potentially emerging contaminants (including personal care products, pharmaceuticals, endocrine disrupters, etc.).

Most channels within the watershed are unstable to highly unstable due to streambank and bed erosion, and the lake has several reaches of shoreline with category 5 erosion. Consequently, sediment accumulation within the lake's conservation pool is occurring at a rateof 400-acre feet per year (OWRB, 2001). Sediment results in increased turbidity and under anoxic conditions, contributes to higher level of nutrients and lower dissolved oxygen. This encourages the eutrophication of the lake which is measured through chlorophyll-a, a proxy of algal biomass (OWRB, 2018). The major causes of streambank and bed erosion are increased velocities and flows from urban areas. Locally, livestock can damage streambanks and beds. Shoreline erosion is often due to overland runoff, obstruction of longshore currents, recreational activities on boats, and/or loss of the littoral zone.The key areas identified by the TAG as priorities for erosion were:

- Bank erosion at the Upper Little River
- Bank erosion at the Little River
- Bank erosion at the North Fork Little River
- Shoreline erosion at Lake Thunderbird
- Bank erosion at Hog Creek
- Bank erosion at Dave blue Creek
- Bank erosion at West Elm Creek

Nutrients (nitrogen and phosphorous) were mainly found to be from urban stormwater runoff containing fertilizers, animal waste, oil/grease, road salt although less dense areas and agricultural land can also contribute to nutrient loads (septic system or livestock waste, road salt, decaying foliage, boat wash water, or oil/grease). Increased input of nutrients into streams eventually leads to lake algae growth and an increase in oxygen demand, resulting in elevated chlorophyll-a levels and lower dissolved oxygen, as well as taste and odor complaints. The key areas identified by the TAG as priorities for nutrients were:

- Degraded water quality at the Upper Little River
- Degraded water quality at the North Fork Little River
- Degraded water quality at Dave Blue Creek
- Degraded water quality at Jim Blue Creek

The process also identified data gaps and issues that require further study and consideration to specify sources, causes and impacts. The reason for insufficient information on these items includes projects performed many years ago that were not followed up on with the recommended monitoring or additional studies, lack of priority in funding or research projects, developing issue involving public perception that requires more data, and simply complex undertakings that would involve analyzing the entire watershed for many years. The areas to be further assessed and discussed are:

- Improved sedimentation transport modeling from streambank erosion and mitigation methodsfor lake shoreline erosion such as breakwaters
- Septic tank spatial influence on stream water quality within the watershed specifically
- Internal loading/legacy loading of nutrients in Lake Thunderbird
- Further testing and research on CECs. Seasonal testing showed there was nonylphenol, atrazine,simazine, artificial sweeteners and DEET were detected in three or all four samples.
- Drinking water taste and odor complaints and implications
- Bank erosion along Rock Creek
- Degraded water quality within Little River, Kitchen Creek, and Clear Creek

Although Lake Thunderbird is within the City of Norman, the Lake Thunderbird watershed area boundary primarily contains the cities of Moore, Norman, and Oklahoma City with 19% of the of the watershed area being urban development and 4% attributed to agricultural use (71 % is undeveloped and 5% is open water). The high and medium intensity areas occur primarily in the western portions of the watershed within Moore and Norman while the agricultural lands are primarily along or near streams. Per the ODEQ 2013 TMDL report, Oklahoma City and Moore contribute significant levels of nutrients and sediment (TN, TP, TSS) from urban nonpoint source runoff to Lake Thunderbird along with Norman. Furthermore, build-out model scenarios performed within these municipalities resulted in an increased nutrient load from urban area stormwater compared to baseline conditions. In addition, OWRB water quality monitoring within the lake up to 2019 indicates the Lake has remained eutrophic. Therefore, the effort to improve the water quality of Lake Thunderbird must include the three major cities within the watershed, along with urban and agricultural communities within the watershed boundary.

Next Steps

The priority issues and conclusions presented in this report will be used to develop a list of applicable management strategies for each prioritized issue as well as parameter goals and monitoring time frames to evaluate success in implementation. The TAG will have a continued role in providing feedback on the most effective management strategies for each issue to be promulgated by the LTWA. The management strategies and parameter requirements will be documented in the IWMP.

The applicable management strategies may include further research on certain issues or analysis of data that has been compiled for some time. For example, OWRB is beginning an evaluation of 20 years of monitoring data and studies to analyze trends and identify the best next steps in reducing nutrient and sediment load to and within the lake. The three municipalities have monitoring stations that have been in place for approximately five (5) years that have produced data that is currently or will be analyzed to determine the next steps towards TMDL compliance and provide insight into management strategies of stormwater that have been successful.

Public Input

The incorporation of the findings presented in this report into the Integrated Watershed Management Plan require gathering public input through as many effective methods as possible. The planned strategies are described below:

- Develop an Esri hosted site designed by Guernsey and called “Guernsey Interactive” by which anyone with access to the internet can learn about the LTWA and provide feedback, comments, and respond to surveys
- Paper surveys handed out at City hosted watershed clean up events
- Postcards with QR codes to Guernsey Interactive handed out at City hosted drive-through waste collection or rain barrel events
- Outdoor public meetings/ open houses to introduce the LTWA and gather feedback in warmer months with appropriate COVID-19 restrictions

The survey responses, comments and conversations with the public will be documented and analyzed for reassessing the prioritized list of issues provided in this report and to gain public support in the creation of the LTWA as a cooperative organization. Public and stakeholder input will be sought throughout the existence of the LTWA through participation in meetings, training and volunteer opportunities, and watershed community events.

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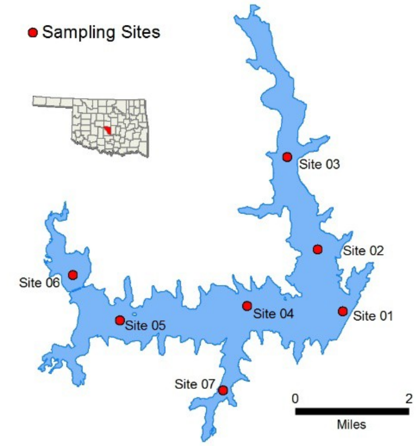
Appendix A

Thunderbird



Sample Period	Times Visited	Sampling Sites
November 2017 – August 2018	4	7

General		
	Location	Cleveland County
	Impoundment	1965
	Area	6,070 acres
	Capacity	119,600 acre-feet
	Purposes	Flood Control, Water Supply, Recreation, Fish & Wildlife

Paramet		Parameter (Descriptions)	Result	Notes/Comments
	In Si	Average Turbidity	14 NTU	4% of values > OWQS of 25 NTU
		Average Secchi Disk Depth	59 cm	
		Water Clarity Rating	Average	
		Chlorophyll-a	21 mg/m3	
		Trophic State Index	61	Previous value = 56
		Trophic Class	Hypereutrophic	
	Profil	Salinity	0.13 – 0.26 ppt	
		Specific Conductivity	281.5 – 530 µS/cm	
		pH	7.14 – 8.68 pH units	Neutral to slightly alkaline
		Oxidation-Reduction Potential	90.2 to 454 mV	
		Dissolved Oxygen	Up to 67% of water column < 2 mg/L in July	Occurred at sites 1, the dam
	Nutrients	Surface Total Nitrogen	0.665 mg/L to 1.025 mg/L	
		Surface Total Phosphorus	0.025 mg/L to 0.104 mg/L	
		Nitrogen to Phosphorus Ratio	23:1	Phosphorus limited

Beneficial Uses	Click to learn more about Beneficial Usesn	Turbidity	pH	Dissolved Oxygen	Metals	TSI	True Color	Sulfates	Chlorides	Total Dissolved Solids	Enterro. & E. coli	Chlor-a
	Fish & Wildlife Propagation	NS	S	NS	S							
	Aesthetics					NEI*	S					
	Agriculture							S	S	S		
	Primary Body Contact Recreation										S	
	Public & Private Water Supply											NS

S = Fully Supporting
NS = Not Supporting
NEI = Not Enough Information

Notes
* The lake is listed in the Oklahoma Water Quality Standards (WQS) as a Nutrient Limited watershed (NLW). This listing means that the lake is considered threatened from nutrients until a more intensive study can confirm the Aesthetics beneficial use non-support status.

NTU = nephelometric turbidity units
µS/cm = microsiemens per centimeter
E. coli = Escherichia coli
OWQS = Oklahoma Water Quality Standards
mV = millivolts
Chlor-a = Chlorophyll-a
mg/L = milligrams per liter
µS/cm = microsiemens/cm
ppt = parts per thousand
En = Enterococci

Appendix B

Document	Prepared By	Year
Shoreline Erosion Plan Lake Thunderbird, Cleveland County, OK 2001	Hollis Allen All Environment Consulting for the OWRB	2001
Lake Thunderbird Capacity and Water Quality 2001 for the Central Oklahoma Master Conservancy District	OWRB	2001
2001. Development of a storm water management plan (City of Norman)	Senior Capstone Class Projects	2001
Lake Thunderbird Algae and Water Quality 2002 for the Central Oklahoma Master Conservancy District	OWRB	2002
2002. Development of an environmental management and control plan (Little River Zoo/Clear Creek)	Senior Capstone Class Projects	2002
Lake Thunderbird Water Quality 2003 for the Central Oklahoma Master Conservancy District	OWRB	2003
Lake Thunderbird Pilot Plant Study 2003 for the Central Oklahoma Master Conservancy District (with City of Midwest City)	OWRB	2003
2003. Sustainable development of new research campus (OU)	Senior Capstone Class Projects	2003
Lake Thunderbird Water Quality 2004 for the Central Oklahoma Master Conservancy District	OWRB	2004
Lake Thunderbird Hydraulic and Nutrient Budget 2005 for the Central Oklahoma Master Conservancy District	OWRB	2005
2005. Evaluation of erosion control devices (City of Norman)	Senior Capstone Class Projects	2005
Mitigation of NPS Impact to Littoral Zone of Lake Thunderbird Cleveland County Oklahoma	OWRB	2005

Lake Thunderbird Water Quality 2006 for the Central Oklahoma Master Conservancy District	OWRB	2006
Lake Thunderbird Water Quality 2007 for the Central Oklahoma Master Conservancy District	OWRB	2007
Lake Thunderbird Watershed Analysis and Water Quality Evaluation	Vieux & Associates, Inc. for OCC	2007
Watershed Based Plan for the Lake Thunderbird Watershed	OCC	2008
Lake Thunderbird Water Quality 2008 for the Central Oklahoma Master Conservancy District	OWRB	2008
Lake Thunderbird/Norman Project Resource Management Plan 2009	BOR and OTRD	2009
Lake Thunderbird Water Quality 2009 for the Central Oklahoma Master Conservancy District	OWRB	2009
Lake Thunderbird Water Quality 2010 for the Central Oklahoma Master Conservancy District	OWRB	2010
Critical Need Water Supply Project	Tetra Tech and CH2M Hill	2010
Prioritizing research for trace pollutants and emerging contaminants in the freshwater environment	Kyle Murray	2010
Trailwoods Neighborhood Best Management Practices 2011	Kent State University for OCC and EPA	2011
Lake Thunderbird Water Quality 2011 for the Central Oklahoma Master Conservancy District	OWRB	2011
2011. Stormwater detention structure re-design (Deerfield/Northern Hills subdivisions)	Senior Capstone Class Projects	2011
COMCD grant for Title XVI Lake Thunderbird Water Reuse Feasibility Study 2012	City of Norman	2012

Oklahoma Comprehensive Water Plan Central Region Report 2012	OWRB	2012
Lake Thunderbird Water Quality 2012 for the Central Oklahoma Master Conservancy District	OWRB	2012
Lake Thunderbird Report for Nutrient, Turbidity, and Dissolved Oxygen TMDLs 2013	Dynamic Solutions LLC for the ODEQ	2013
Impediments to Low Impact Development in Lake Thunderbird Watershed	OCC	2013
Lake Thunderbird Water Quality 2013 for the Central Oklahoma Master Conservancy District	OWRB	2013
City of Norman Strategic Water Supply Plan 2014	City of Norman	2014
Wetland Treatment Study Lake Thunderbird Watershed Implementation Project, Phase II 2014	CREW for the OCC	2014
Trailwoods Neighborhood Best Management Practices 2014 (Final report doc)	Kent State University for OCC	2014
Life Cycle Cost Model and Analysis (Updated)	OCC	2014
Lake Thunderbird Augmentation (Treatment Alternative Evaluation)	Garver for COMCD	2014
Lake Thunderbird Water Reuse Preliminary Engineering (Review Workshop)	Garver for COMCD	2014
Lake Thunderbird Water Quality 2014 for the Central Oklahoma Master Conservancy District	OWRB	2014
Potential AOP Applications at Norman WRF for Trace Organic Contaminant Mitigation	Garver for COMCD	2015
Lake Thunderbird Water Quality Modeling and Evaluation for Water Reuse Preliminary Design	Garver for COMCD	2015

Lake Thunderbird Augmentation (Engineering Report)	Garver for COMCD	2015
Surveying the CEC Landscape (OK and TX Wastewater Effluents)	Garver for COMCD	2015
Lake Thunderbird Water Reuse Preliminary Engineering (Board Presentation)	Garver for COMCD	2015
Dutnell, Russell C. 2015. Investigation of the Hydrology, Fluvial Geomorphology and Sediment Transport in the Lake Thunderbird Watershed in Central Oklahoma. PhD dissertation (environmental engineering), 414 pp. (co-advised with R. Kolar)	Dutnell, Russell C	2015
Martin-Mikle et al. 2015. Identifying priority sites for low impact development in a mixed-use watershed	Landscape and Urban Planning Journal	2015
Lake Thunderbird Water Quality 2015 for the Central Oklahoma Master Conservancy District	OWRB	2015
Rice, Michael. 2015. An Evaluation of Retrofitting Best Management Practices for Stormwater Quality Improvement. MS special topics (environmental engineering), 35 pp.	Rice, Michael	2015
City of Norman Lake Thunderbird Compliance and Monitoring Plans	GBM & Associates, Olsson	2015
Vegetation in Dryland Bioretention Systems. Landscape Research Record, 4:58-71.	Coffman, R.R., D. Graves, **J.R. Vogel**, and G.O. Brown	2015
City of Norman Final MS4 Reports 2011 to 2015	City of Norman	2015
Lake Thunderbird Watershed Implementation Project: Trailwoods Demonstration Site Monitoring	CREW for the OCC	2016
City of Moore Stormwater Management Program	City of Moore	2016
City of Norman Water Conservation Plan 2016	City of Norman	2016
Norman Utilities Authority grant from BOR for hexavalent chrome treatment options from groundwater wells 2016	City of Norman	2016

Holzbauer-Schweitzer, Brandon K. 2016. Evaluating Low Impact Development Best Management Practices as an Alternative to Traditional Urban Stormwater Management. MS thesis (environmental science), 131 pp.	Holzbauer-Schweitzer, Brandon K	2016
Lake Thunderbird Water Quality 2016 for the Central Oklahoma Master Conservancy District	OWRB	2016
Bioretention Cells for Mass Load Reduction of Phosphorus and Sediment in Urban Watersheds in Oklahoma	OSU for EPA	2016
City of Norman SWMP	City of Norman	2016
Lake Thunderbird Water Reuse Project (Modeling Results and Pilot Plan)	Garver for COMCD	2017
Lake Thunderbird CEC Study	Oklahoma Geological Survey / OU	2017
City of Oklahoma City Water Conservation Plan 2017	City of Oklahoma City	2017
Lake Thunderbird Water Reuse Project (Phase 2 Modeling Impact of IPR)	Garver for COMCD	2017
Lake Thunderbird Water Quality 2017 for the Central Oklahoma Master Conservancy District	OWRB	2017
Thornton, Erin. 2017. Microcosm Assessment of Natural Processes Affecting Chemicals of Emerging Concern in Secondary Effluent. MS thesis (environmental engineering), 74 pp.	Thornton, Erin	2017
Lake Thunderbird Water Reuse Project (Phase 3 Process Pilot Plan	Garver for COMCD	2017
Way, Amanda. 2017. Comparative Hydraulic and Cost Analyses of Single and Dual Water Distribution Systems Using Nonpotable Water for Urban Irrigation in Norman, Oklahoma	Way, Amanda	2017
DO NOT POST Berg-Mattson, Noah. 2018. Evaluation of Catchment-Scale Stormwater Runoff Management on First-Flush Water Quality and Storm Discharge Quantity. MS thesis (environmental science), 129 pp.	Berg-Mattson, Noah	2018
City of Oklahoma City Storm Water Quality Best Management Practices Manual 2018	City of Oklahoma City	2018
City of Oklahoma City Storm Water Quality Management Plan 2018	City of Oklahoma City	2018

Horton, Ashley. 2018. BASELINE CONCENTRATIONS OF CONTAMINANTS OF EMERGING CONCERN IN THE LAKE THUNDERBIRD WATERSHED, PLANNING FOR INDIRECT POTABLE REUSE IN OKLAHOMA	Horton, Ashley	2018
Nguyen, Derrick X. 2018. Evaluation of Stormwater Treatment by Various Reactive Media for Bioretention Cell Design Considerations. MS thesis (environmental engineering), 208 pp.	Nguyen, Derrick X	2018
Lake Thunderbird Water Quality 2018 for the Central Oklahoma Master Conservancy District	OWRB	2018
2018. Low Impact development/green infrastructure design retrofit (City of Norman Municipal Complex)	Senior Capstone Class Projects	2018
Lake Thunderbird Water Quality 2019 for the Central Oklahoma Master Conservancy District	OWRB	2019
2019. Evaluation of hydrologic effects of indirect potable reuse (Dave Blue Creek)	Senior Capstone Class Projects	2019
Lake Thunderbird State Park Resource Management Plan		2019
City of Oklahoma City Storm Water Quality Management Annual Report	City of Oklahoma City	2019
Oklahoma Wetland Program Plan 2020 to 2025	OCC and Oklahoma Wetland Technical Work Group	2020
City of Norman Monitoring Data	City of Norman	2020
COCMD & OWRB Internal Loading of Lake Thunderbird	COCMD and OWRB	2021
COCMD & OWRB Long-term Trend Analysis of Lake Thunderbird Water Quality Data	COCMD and OWRB	2021
2021. Reservoir water quality assessment including best management practice recommendations (Lake Thunderbird)	Senior Capstone Class Projects	2021
Floating Wetlands funded through COMCD with BOR 2018	OWS	Ongoing

City of Moore MS4 and Lake Thunderbird TMDL Compliance Plan	City of Moore	Ongoing
Blue-Green Algae Bloom Monitoring in Lake Thunderbird	PhD Work	Ongoing
Lake Thunderbird Watershed, Hog and Elm Creek	Guernsey and OWS for City of OKC	Ongoing

Appendix C

	Definition of the problem			
Issue	**Geographical Area**	**What use is impaired?**	**Why is it considered impaired?**	**Possible Causes**
Degraded Water Quality	Lake Thunderbird	aesthetic, warm water aquatic community, public and private water suppply	turbidity, low DO, chlorophyll a	Inflow of nutrients and sediment from watershed that cause a cycle of increased algae growth, low DO, and accumulation of debris at lake bottom and internal loading of nutrients
Degraded Water Quality	Hog Creek	aesthetic, primary body contact recreation, public and private water supply	Enterococcus	Grazing in riparian areas, onsite treatment systems, rangeland grazing , residential districts, wastes from pets, wildlife other than waterfowl
Degraded Water Quality	West Hog Creek	aesthetic, agriculture, warm water aquatic community, primary body contact recreation	low DO	Discharges from municipal separate storm sewer systems, residential districts, wastes from pets, wildlife. Approx 50% percent of length impacted by reduction of riparian buffer (Norman 2016 TMDL Compliance Plan)
Degraded Water Quality	Clear Creek	UKN	Potential for high nutrient levels/ low DO	**Non point sources:** rangeland/grasslands, stream bank erosion, septic tanks, un paved roads (Norman 2016 TMDL Compliance Plan)
Degraded Water Quality	Dave Blue Creek	UKN	Potential for high nutrient levels/ low DO	**Non point sources:** residential areas in upper portion, rangeland/grasslands, stream bank erosion, septic tanks, un paved roads (Norman 2016 TMDL Compliance Plan)
Degraded Water Quality	Jim Blue Creek	UKN	Potential for high nutrient levels/ low DO	**Non point sources:** rangeland/grasslands, stream bank erosion, septic tanks, un paved roads (Norman 2016 TMDL Compliance Plan)
Degraded Water Quality	Little River (Flow through more agricultural and pasture areas than the North Fork)	agriculture, warm water aquatic community, primary body contact recreation	low DO, TDS, **Selenium (newly listed in 2018)**, Enterococcus, E Coli	**DO** grazing in riparian or shoreline zones, impacts from land application of wastes, crop production (non irrigated), on-site treatment systems, rangeland grazing, residential distrcits, waste from pets, wildlife **TDS** highway or road runoff (non construction), petroleum activities (legacy) **Enterococcus and E Coli** grazing in riparian areas, onsite treatment systems, rangeland grazing , residential districts, wastes from pets, wildlife other than waterfowl
Degraded Water Quality	Rock Creek (Captures flow from urban edges of Norman and then flows through rural areas categorized as hay and pasture)	warm water aquatic community, primary body contact recreation	Enterococcus, E Coli	Grazing in riparian areas, onsite treatment systems, rangeland grazing , residential districts, waste from pets, wildlife other than waterfowl
Degraded Water Quality	East Elm Creek	aesthetic, agriculture, warm water aquatic community, primary body contact recreation,	low DO	**DO** grazing in riparian or shoreline zones, impacts from land application of wastes, crop production (non irrigated), on-site treatment systems, rangeland grazing, residential disticts, waste from pets, wildlife
Degraded Water Quality	West Elm Creek	warm water aquatic community , primary body contact recreation	Enterococcus, E Coli	Grazing in riparian areas, onsite treatment systems, rangeland grazing , residential districts, waste from pets, wildlife other than waterfowl

Issue	Geographical Area	What use is impaired?	Why is it considered impaired?	Possible Causes
Degraded Water Quality	Kitchen Creek	UKN	Potential for high nutrient levels/ low DO	Increased urbanization
Degraded Water Quality	North Fork Little River	aesthetic and warm water aquatic community	Potential for high nutrient levels/ low DO	Increased urbanization
Degraded Water Quality	Moore Creek (tributary to North Fork of Little River)	agriculture, warm water aquatic community	TDS	Petroleum or natural gas production activities (legacy)
Degraded Water Quality	Mussel Shoals Lake Creek (Upper Little River)	UKN	Potential for high nutrient levels/ low DO	Increased urbanization
Shoreline Erosion	Lake Thunderbird	aesthetic, warm water aquatic community, public and private water suppply	Suspended solids, whether washed in from the drainage basin or re-suspended in the reservoir, serve to prevent or eliminate the establishment of an aquatic plant community in the littoral zone (OWRB 2005 Mitigation of NPS Impact to Littoral Zone)	Once erosion has ocurred, re-establishing a littoral zone to protect the shoreline takes time and requires intervention. Recreational activities on boats may contribute to erosion (OCC WBP). Overland runoff and erosion that cause gullies Obstruction of longshore currents that cause deposition of sediments in deeper parts of the lake
Bank Erosion	Hog Creek	aesthetic, agriculture, warm water aquatic community,	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport)	Increased urbanization
Bank Erosion	Elm Creek	aesthetic, agriculture, warm water aquatic community,	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport)	Increased urbanization
Bank Erosion	North Fork Little River	aesthetic, agriculture, warm water aquatic community,	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport)	Increased urbanization

Issue	Geographical Area	What use is impaired?	Why is it considered impaired?	Possible Causes
Bank Erosion	Upper Little River	aesthetic, agriculture, warm water aquatic community,	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport)	Increased urbanization
Bank Erosion	Little River	aesthetic, warm water aquatic community, public and private water supply	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport) Turbidity from increased sediment can reduce productivity and habitat health, which then leads to a decrease in food for living organisms	Greater runoff from increased urbanization and impervious surfaces Localized stream obstacles that constrict flow and accelerate velocity or stream channel alteration that creates "smoother" faster flowing channels
Bank Erosion	Rock Creek	aesthetic, warm water aquatic community	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport) Turbidity from increased sediment can reduce productivity and habitat health, which then leads to a decrease in food for living organisms	Greater runoff from increased urbanization and impervious surfaces. Lower rock creek: new construction, cattle, fertilized pastures and hay operations, rangeland/grasslands, un paved roads Upper rock creek: commerical and residential areas, stream bank erosion (Norman 2016 TMDL Compliance Plan) Localized stream obstacles that constrict flow and accelerate velocity or stream channel alteration that creates "smoother" faster flowing channels
Bank Erosion	Dave Blue Creek	aesthetic, warm water aquatic community	High, Very High or Extreme BEHI values (2015 Dutnell Paper Investigation of the hydrology, fluvial geomorphology and sediment transport) Turbidity can reduce productivity and habitat health, which then leads to a decrease in food for living organisms	Steep banks and minimal bank protection from vegetation (OU Capstone 2019 Celerity Environmental Final Report)

Issue	Geographical Area	What use is impaired?	Why is it considered impaired?	Possible Causes
Water Supply and Capacity	Lake Thunderbird	public and private water supply	Algae growth and lake turnover effect that cause taste and odor complaints even after treatment. This requires increased effort by the municipal WTPs to maintain a consistent water quality level throughout the year .	Blue Green algae growth within the lake. There is a possibility that these taste and odor complaints are due to herbicides like simazine. More research is needed to determine if out of season complaints are due to herbicides or compounds like chlorophenol.
Water Supply and Capacity	Lake Thunderbird	public and private water supply	Sediment accumulation and decrease of reservoir capacity for water supply and flood control	Influx of sediment from tributaries, shoreline erosion

Appendix D

Submitted by the Cleveland County Cooperative Extension

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	Specific Issue	Geographical Area	Severity of issue	Will resolving issue help remove LT from ODEQ 303(d) List?	Negative Impact to Tourism/ Recreation at Lake Thunderbird	Negative Impact to Aquatic Life within geographical area	Negative Impact to Water Supply (from Lake Thunderbird)	Negative Impact to Agriculture within geographical area	Negative Impact to Aesthetics within geographical area	Can Specific Area be Targeted?	Can Issue be Easily Monitored/ Measured?	Does it require more research to develop solution?	Does it have high visibility to the Public? (or High Volume of Complaints)	Level to which it has not been addressed by city or agency	Will it require more than one City to address (based on geographical area)?	Ranking
Shoreline Erosion	High TSS	Lake Thunderbird	3	1	3	2	1	1	3	3	3	2	4	2	1	29
Degraded Water Quality	**High turbidity, low DO, high chlorophyll**	Lake Thunderbird	3	1	3	2	1	1	3	3	3	2	4	2	1	29
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	2	1	2	2	2	1	3	3	3	2	4	2	1	28

Submitted by City of Norman

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	Specific Issue	Geographical Area	Severity of issue	Will resolving issue help remove LT from ODEQ 303(d) List?	Negative Impact to Tourism/ Recreation at Lake Thunderbird	Negative Impact to Aquatic Life within geographical area	Negative Impact to Water Supply (from Lake Thunderbird)	Negative Impact to Agriculture within geographical area	Negative Impact to Aesthetics within geographical area	Can Specific Area be Targeted?	Can Issue be Easily Monitored/ Measured?	Does it require more research to develop solution?	Does it have high visibility to the Public? (or High Volume of Complaints)	Level to which it has not been addressed by city or agency	Will it require more than one City to address (based on geographical area)?	Ranking
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	4	4	3	4	4	2	3	4	4	3	4	1	4	44
Degraded Water Quality	Potential for high nutrient levels/ low	Clear Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	Dave Blue Creek	3	4	2	4	3	2	3	4	4	3	2	3	4	41
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	Potential for high phosphorus levels/	Dave Blue Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	Hog Creek	3	4	2	4	3	2	3	4	4	3	2	3	4	41
Bank Erosion	Potential for high phosphorus levels/	Hog Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	Little River	3	4	2	4	3	2	3	4	4	3	2	3	4	41
Bank Erosion	Potential for high phosphorus levels/	Little River	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	North Fork Little River	3	4	2	4	3	2	3	4	4	3	2	3	4	41
Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	Potential for high phosphorus levels/	North Fork Little River	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	Rock Creek	3	4	2	4	3	2	3	4	4	3	2	3	4	41

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Bank Erosion	Potential for high phosphorus levels/ low DO	Rock Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	Upper Little River	3	4	2	4	3	2	3	4	4	3	2	3	4	41
Bank Erosion	Potential for high phosphorus levels/	Upper Little River	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Degraded Water Quality	Potential for high nutrient levels/ low	Upper Little River	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Bank Erosion	High TSS	West Elm Creek	3	4	2	4	3	2	3	4	4	3	2	3	4	41
Bank Erosion	Potential for high phosphorus levels/	West Elm Creek	3	4	2	4	3	2	2	4	4	3	3	3	4	41
Degraded Water Quality	**High turbidity, low DO, high chlorophyll**	Lake Thunderbird	4	4	4	3	4	1	3	1	3	4	4	1	4	40
Shoreline Erosion	High TSS	Lake Thunderbird	2	4	3	3	3	1	2	4	3	4	1	2	1	33
Degraded Water Quality	**Low DO**	East Elm Creek	2	2	1	3	2	1	1	2	3	4	1	3	3	28
Degraded Water Quality	**High TDS**	Little River	2	2	1	3	3	1	1	2	2	4	1	3	3	28
Degraded Water Quality	**Low DO**	Little River	2	2	1	3	2	1	1	2	3	4	1	3	3	28
Degraded Water Quality	**High TDS**	Moore Creek	2	2	1	3	3	1	1	2	2	4	1	3	3	28
Degraded Water Quality	**Low DO**	West Hog Creek	2	2	1	3	2	1	1	2	3	4	1	3	3	28
Degraded Water Quality	**Enterococcus levels**	Hog Creek	2	1	1	2	2	1	1	2	2	4	1	3	3	25
Degraded Water Quality	**E Coli**	Little River	2	1	1	2	2	1	1	2	2	4	1	3	3	25
Degraded Water Quality	**Enterococcus levels**	Little River	2	1	1	2	2	1	1	2	2	4	1	3	3	25

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	**High Selenium**	Little River	2	1	1	2	2	1	1	2	2	4	1	3	3	25
Degraded Water Quality	**E Coli**	Rock Creek	2	1	1	2	2	1	1	2	2	4	1	3	3	25
Degraded Water Quality	**Enterococcus levels**	Rock Creek	2	1	1	2	2	1	1	2	2	4	1	3	3	25
Degraded Water Quality	**E Coli**	West Elm Creek	2	1	1	2	2	1	1	2	2	4	1	3	3	25
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	2	1	1	2	2	1	1	2	2	4	1	3	3	25

Submitted by COMCD

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	Specific Issue	Geographical Area	Severity of issue	Will resolving issue help remove LT from ODEQ 303(d) List?	Negative Impact to Tourism/ Recreation at Lake Thunderbird	Negative Impact to Aquatic Life within geographical area	Negative Impact to Water Supply (from Lake Thunderbird)	Negative Impact to Agriculture within geographical area	Negative Impact to Aesthetics within geographical area	Can Specific Area be Targeted?	Can Issue be Easily Monitored/ Measured?	Does it require more research to develop solution?	Does it have high visibility to the Public? (or High Volume of Complaints)	Level to which it has <u>not</u> been addressed by city or agency	Will it require more than one City to address (based on geographical area)?	Ranking
Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek	3	3	3	2	3	2	2	3	3	3	2	2	1	32
Bank Erosion	High TSS	Dave Blue Creek	2	3	2	3	3	2	2	3	4	3	3	3	1	34
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	3	3	3	2	3	2	2	3	3	3	2	2	1	32
Bank Erosion	Potential for high phosphorus levels/ low DO	Dave Blue Creek	2	2	2	2	3	2	2	3	3	3	2	3	1	30
Degraded Water Quality	**Low DO**	East Elm Creek	3	3	2	3	3	2	1	2	4	3	2	2	3	33
Degraded Water Quality	**Enterococcus levels**	Hog Creek	2	1	3	2	2	2	2	2	3	3	2	3	2	29
Bank Erosion	High TSS	Hog Creek	2	3	2	3	3	2	2	3	4	3	3	3	3	36
Bank Erosion	Potential for high phosphorus levels/ low DO	Hog Creek	2	2	2	2	3	2	2	3	3	3	2	3	4	33
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	3	3	3	2	3	2	2	3	3	3	2	2	1	32
Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek	2	3	3	2	3	2	2	3	3	3	2	2	3	33
Shoreline Erosion	High TSS	Lake Thunderbird	3	3	2	3	3	1	3	3	4	3	2	3	1	34
Degraded Water Quality	**High turbidity, low DO, high chlorophyll a**	Lake Thunderbird	4	4	3	3	3	2	4	3	4	4	4	2	4	44
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	2	3	2	3	2	1	3	1	4	3	2	2	4	32
Degraded Water Quality	**E Coli**	Little River	2	1	3	2	2	2	2	2	3	3	2	3	2	29

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	**Enterococcus levels**	Little River	2	1	3	2	2	2	2	2	3	3	2	3	2	29
Degraded Water Quality	**High Selenium**	Little River	2	1	1	2	1	2	1	2	3	3	1	3	4	26
Degraded Water Quality	**High TDS**	Little River	3	3	2	3	3	2	2	3	4	2	2	2	4	35
Bank Erosion	High TSS	Little River	2	3	2	3	3	2	2	3	4	3	3	3	4	37
Degraded Water Quality	**Low DO**	Little River	3	3	2	3	3	2	1	2	4	3	2	2	4	34
Bank Erosion	Potential for high phosphorus levels/ low DO	Little River	2	2	2	2	3	2	2	3	3	3	2	3	4	33
Degraded Water Quality	**High TDS**	Moore Creek	2	2	2	3	3	2	2	3	4	2	2	2	3	32
Bank Erosion	High TSS	North Fork Little River	2	3	2	3	3	2	2	3	4	2	2	3	4	35
Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River	4	3	3	2	3	2	2	3	3	3	2	2	3	35
Bank Erosion	Potential for high phosphorus levels/ low DO	North Fork Little River	2	2	2	2	3	2	2	3	3	3	2	3	4	33
Degraded Water Quality	**E Coli**	Rock Creek	2	1	3	2	2	2	2	2	3	3	2	3	2	29
Degraded Water Quality	**Enterococcus levels**	Rock Creek	2	1	3	2	2	2	2	2	3	3	2	3	2	29
Bank Erosion	High TSS	Rock Creek	2	2	2	3	3	2	2	3	4	2	2	3	1	31
Bank Erosion	Potential for high phosphorus levels/ low DO	Rock Creek	2	2	2	2	3	2	2	3	3	3	2	3	2	31
Bank Erosion	High TSS	Upper Little River	2	3	2	3	3	2	2	3	4	2	2	3	4	35
Bank Erosion	Potential for high phosphorus levels/ low DO	Upper Little River	2	2	2	2	3	2	2	3	3	3	2	3	4	33

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River	4	3	3	2	3	2	2	3	3	3	2	2	3	35
Degraded Water Quality	**E Coli**	West Elm Creek	2	1	3	2	2	2	2	2	3	3	2	3	2	29
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	2	1	3	2	2	2	2	2	3	3	2	3	2	29
Bank Erosion	High TSS	West Elm Creek	2	2	2	3	3	2	2	3	4	2	2	3	3	33
Bank Erosion	Potential for high phosphorus levels/ low DO	West Elm Creek	2	2	2	2	3	2	2	3	3	3	2	3	3	32
Degraded Water Quality	**Low DO**	West Hog Creek	3	3	2	3	3	2	1	2	4	3	2	2	3	33

Submitted by City of Norman Utilities

Answers for items in red are based on effect to IPR only IF it is implented in the future

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	Specific Issue	Geographical Area	Severity of issue	Will resolving issue help remove LT from ODEQ 303(d) List?	Negative Impact to Tourism/ Recreation at Lake Thunderbird	Negative Impact to Aquatic Life within geographical area	Negative Impact to Water Supply (from Lake Thunderbird)	Negative Impact to Agriculture within geographical area	Negative Impact to Aesthetics within geographical area	Can Specific Area be Targeted?	Can Issue be Easily Monitored/ Measured?	Does it require more research to develop solution?	Does it have high visibility to the Public? (or High Volume of Complaints)	Level to which it has not been addressed by city or agency	Will it require more than one City to address (based on geographical area)?	Ranking
Degraded Water Quality	**High turbidity, low DO, high chlorophyll a**	Lake Thunderbird	4	4	2	2	4	1	2	1	1	1	4	1	4	31
Bank Erosion	Potential for high phosphorus levels/ low DO	Hog Creek	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	2	1	2	2	1	1	1	1	1	2	2	4	3	23
Bank Erosion	Potential for high phosphorus levels/ low DO	Little River	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Bank Erosion	Potential for high phosphorus levels/ low DO	North Fork Little River	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Bank Erosion	Potential for high phosphorus levels/ low DO	Upper Little River	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Bank Erosion	Potential for high phosphorus levels/ low DO	West Elm Creek	3	2	1	3	1	1	1	1	1	1	3	2	3	23
Degraded Water Quality	**Low DO**	East Elm Creek	2	2	1	3	1	1	1	1	1	1	1	4	3	22

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	**High TDS**	Little River	3	1	1	1	3	1	1	1	1	1	1	4	3	22
Degraded Water Quality	**Low DO**	Little River	2	2	1	3	1	1	1	1	1	1	1	4	3	22
Degraded Water Quality	**Low DO**	West Hog Creek	2	2	1	3	1	1	1	1	1	1	1	4	3	22
Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek	3	2	1	3	1	1	1	1	1	1	3	2	1	21
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	3	2	1	3	1	1	1	1	1	1	3	2	1	21
Bank Erosion	Potential for high phosphorus levels/ low DO	Dave Blue Creek	3	2	1	3	1	1	1	1	1	1	3	2	1	21
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	3	2	1	3	1	1	1	1	1	1	3	2	1	21
Shoreline Erosion	High TSS	Lake Thunderbird	2	1	2	2	1	1	1	1	1	2	2	4	1	21
Degraded Water Quality	**High Selenium**	Little River	2	1	1	1	3	1	1	1	1	1	1	4	3	21
Bank Erosion	Potential for high phosphorus levels/ low DO	Rock Creek	3	2	1	3	1	1	1	1	1	1	3	2	1	21
Bank Erosion	High TSS	Dave Blue Creek	2	1	1	1	1	1	1	1	1	1	2	4	3	20
Bank Erosion	High TSS	Hog Creek	2	1	1	1	1	1	1	1	1	1	2	4	3	20
Bank Erosion	High TSS	Little River	2	1	1	1	1	1	1	1	1	1	2	4	3	20
Degraded Water Quality	**High TDS**	Moore Creek	3	1	1	1	3	1	1	1	1	1	1	4	1	20
Bank Erosion	High TSS	North Fork Little River	2	1	1	1	1	1	1	1	1	1	2	4	3	20
Bank Erosion	High TSS	Rock Creek	2	1	1	1	1	1	1	1	1	1	2	4	3	20
Bank Erosion	High TSS	Upper Little River	2	1	1	1	1	1	1	1	1	1	2	4	3	20

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Bank Erosion	High TSS	West Elm Creek	2	1	1	1	1	1	1	1	1	1	2	4	3	20
Degraded Water Quality	**Enterococcus levels**	Hog Creek	1	3	1	1	1	1	1	1	1	1	1	2	3	18
Degraded Water Quality	**E Coli**	Little River	1	3	1	1	1	1	1	1	1	1	1	2	3	18
Degraded Water Quality	**Enterococcus levels**	Little River	1	3	1	1	1	1	1	1	1	1	1	2	3	18
Degraded Water Quality	**E Coli**	Rock Creek	1	3	1	1	1	1	1	1	1	1	1	2	3	18
Degraded Water Quality	**E Coli**	West Elm Creek	1	3	1	1	1	1	1	1	1	1	1	2	3	18
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	1	3	1	1	1	1	1	1	1	1	1	2	3	18
Degraded Water Quality	**Enterococcus levels**	Rock Creek	1	3	1	1	1	1	1	1	1	1	1	2	1	16

Submitted by the OCC

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	Specific Issue	Geographical Area	Severity of issue	Will resolving issue help remove LT from ODEQ 303(d) List?	Negative Impact to Tourism/ Recreation at Lake Thunderbird	Negative Impact to Aquatic Life within geographical area	Negative Impact to Water Supply (from Lake Thunderbird)	Negative Impact to Agriculture within geographical area	Negative Impact to Aesthetics within geographical area	Can Specific Area be Targeted?	Can Issue be Easily Monitored/ Measured?	Does it require more research to develop solution?	Does it have high visibility to the Public? (or High Volume of Complaints)	Level to which it has not been addressed by city or agency	Will it require more than one City to address (based on geographical area)?	Ranking
Degraded Water Quality	**High turbidity, low DO, high chlorophyll a**	Lake Thunderbird	4	4	4	4	4	1	4	2	4	3	4	2	4	44
Bank Erosion	Potential for high phosphorus levels/ low DO	Upper Little River	4	4	4	2	4	1	3	3	4	3	2	3	4	41
Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River	4	4	4	2	4	1	3	3	4	3	2	3	4	41
Bank Erosion	High TSS	Upper Little River	3	3	3	3	3	1	3	3	4	4	3	3	4	40
Bank Erosion	High TSS	Little River	3	3	3	3	3	1	3	3	4	2	3	4	4	39
Degraded Water Quality	**Low DO**	Little River	4	4	2	3	3	1	2	3	4	4	3	2	4	39
Bank Erosion	Potential for high phosphorus levels/ low DO	Little River	4	3	3	3	3	1	3	3	3	3	3	3	4	39
Shoreline Erosion	High TSS	Lake Thunderbird	4	3	3	3	3	1	3	4	4	3	3	2	1	37
Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River	3	3	3	2	3	1	3	3	4	3	2	3	4	37
Bank Erosion	Potential for high phosphorus levels/ low DO	North Fork Little River	3	3	3	2	3	1	3	3	4	3	2	3	4	37
Degraded Water Quality	**Low DO**	West Hog Creek	4	3	2	3	3	1	2	4	4	3	2	4	1	36
Bank Erosion	High TSS	Hog Creek	3	3	3	2	3	1	3	3	3	3	3	3	2	35

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Bank Erosion	Potential for high phosphorus levels/ low DO	Hog Creek	3	3	3	2	3	1	3	3	3	3	3	3	2	35
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	3	3	3	2	3	1	2	1	3	3	3	3	4	34
Bank Erosion	High TSS	North Fork Little River	3	2	2	2	2	1	2	3	4	3	3	3	4	34
Degraded Water Quality	**E Coli**	Little River	3	3	2	1	2	1	1	3	3	4	3	3	4	33
Bank Erosion	High TSS	Rock Creek	3	2	2	2	2	1	2	3	3	3	3	3	1	30
Bank Erosion	Potential for high phosphorus levels/ low DO	Rock Creek	3	2	2	2	2	1	2	3	3	3	3	3	1	30
Degraded Water Quality	**E Coli**	West Elm Creek	3	3	2	1	2	1	1	3	3	4	3	3	1	30
Degraded Water Quality	**Enterococcus levels**	Little River	2	3	2	1	2	1	1	3	3	1	3	3	4	29
Degraded Water Quality	**E Coli**	Rock Creek	3	2	2	1	2	1	1	3	3	4	3	3	1	29
Bank Erosion	High TSS	Dave Blue Creek	2	2	2	2	2	1	1	3	3	3	2	4	1	28
Degraded Water Quality	**High Selenium**	Little River	1	2	1	1	3	1	1	1	2	4	3	3	4	27
Degraded Water Quality	**High TDS**	Little River	2	1	1	1	2	2	1	2	4	3	1	3	4	27
Degraded Water Quality	**Enterococcus levels**	Hog Creek	2	3	2	1	2	1	1	3	3	1	3	3	1	26
Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek	2	2	1	1	2	1	1	3	4	3	1	4	1	26
Degraded Water Quality	**Enterococcus levels**	Rock Creek	2	3	2	1	2	1	1	3	3	1	3	3	1	26
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	2	3	2	1	2	1	1	3	3	1	3	3	1	26
Bank Erosion	High TSS	West Elm Creek	2	1	1	1	1	1	1	3	4	4	3	3	1	26

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Bank Erosion	Potential for high phosphorus levels/ low DO	West Elm Creek	2	1	1	1	1	1	1	3	4	4	3	3	1	26
Degraded Water Quality	**High TDS**	Moore Creek	3	1	1	1	1	1	1	2	4	4	1	4	1	25
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	2	1	1	1	1	2	1	3	3	3	1	4	1	24
Bank Erosion	Potential for high phosphorus levels/ low DO	Dave Blue Creek	2	1	1	1	1	2	1	3	3	3	1	4	1	24
Degraded Water Quality	**Low DO**	East Elm Creek	1	1	1	3	1	1	1	3	4	2	1	4	1	24
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	2	1	1	1	1	2	1	3	3	3	1	4	1	24
Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek	2	1	1	1	1	1	1	3	4	3	1	3	1	23

Submiited by City of OKC

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	Specific Issue	Geographical Area	Severity of issue	Will resolving issue help remove LT from ODEQ 303(d) List?	Negative Impact to Tourism/ Recreation at Lake Thunderbird	Negative Impact to Aquatic Life within geographical area	Negative Impact to Water Supply (from Lake Thunderbird)	Negative Impact to Agriculture within geographical area	Negative Impact to Aesthetics within geographical area	Can Specific Area be Targeted?	Can Issue be Easily Monitored/ Measured?	Does it require more research to develop solution?	Does it have high visibility to the Public? (or High Volume of Complaints)	Level to which it has not been addressed by city or agency	Will it require more than one City to address (based on geographical area)?	Ranking
Bank Erosion	Potential for high phosphorus levels/ low DO	Hog Creek	3	3	3	2	2	1	2	3	3	3	2	2	1	30
Bank Erosion	Potential for high phosphorus levels/	West Elm Creek	2	2	2	2	2	1	2	3	3	3	1	2	1	26
Bank Erosion	High TSS	Hog Creek	3	2	2	2	2	1	2	3	3	2	1	1	1	25
Bank Erosion	High TSS	West Elm Creek	2	2	1	1	2	1	2	2	3	3	1	1	1	22
Degraded Water Quality	**Enterococcus levels**	Hog Creek	3	2	1	1	1	1	1	3	3	2	1	1	1	21
Degraded Water Quality	**E Coli**	West Elm Creek	3	2	1	1	1	1	1	3	3	2	1	1	1	21
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	3	2	1	1	1	1	1	3	3	2	1	1	1	21
Degraded Water Quality	**Low DO**	West Hog Creek	4	1	1	3	1	1	1	1	4	1	1	1	1	21
Degraded Water Quality	**Low DO**	East Elm Creek	1	1	1	1	1	1	1	1	4	1	1	1	1	16

Submitted by the OWRB (1)

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	**High turbidity, low DO, high chlorophyll a**	Lake Thunderbird	4	4	3	4	4		4	4	4		4		4	39
Shoreline Erosion	High TSS	Lake Thunderbird	3	4	2	3			3	4	4		3		4	30
Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek	3	4		3			3		4		3			20
Bank Erosion	High TSS	Dave Blue Creek	3	4		3			3		4		3			20
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	3	4		3			3		4		3			20
Bank Erosion	Potential for high phosphorus levels/ low DO	Dave Blue Creek	3	4		3			3		4		3			20
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	3	4		3			3		4		3			20
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	3	4		3			3		4		3			20
Bank Erosion	High TSS	Little River	3	4		3			3		4		3			20
Bank Erosion	Potential for high phosphorus levels/ low DO	Little River	3	4		3			3		4		3			20
Bank Erosion	High TSS	North Fork Little River	3	4		3			3		4		3			20
Bank Erosion	Potential for high phosphorus levels/ low DO	North Fork Little River	3	4		3			3		4		3			20
Bank Erosion	High TSS	Rock Creek	3	4		3			3		4		3			20

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Bank Erosion	Potential for high phosphorus levels/ low DO	Rock Creek	3	4		3			3		4		3			20
Bank Erosion	High TSS	Upper Little River	3	4		3			3		4		3			20
Bank Erosion	Potential for high phosphorus levels/ low DO	Upper Little River	3	4		3			3		4		3			20
Degraded Water Quality	**High TDS**	Little River	3	4		3			3		4		2			19
Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River	3	4		3			3		4		2			19
Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River	3	4		3			3		4		2			19
Degraded Water Quality	**Low DO**	Little River	3	4		3			2		4		2			18
Degraded Water Quality	**High Selenium**	Little River	3	1		2			2		4		2			14
Degraded Water Quality	**E Coli**	Little River	3	1		1			1		4		2			12
Degraded Water Quality	**Enterococcus levels**	Little River	3	1		1			1		4		2			12
Degraded Water Quality	**E Coli**	Rock Creek	3	1		1			1		4		2			12
Degraded Water Quality	**Enterococcus levels**	Rock Creek	3	1		1			1		4		2			12

Submitted by OWRB (2)

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	**High turbidity, low DO, high chlorophyll a**	Lake Thunderbird	4	4	3	3	4	2	3	3	4	3	3	3	3	42
Shoreline Erosion	High TSS	Lake Thunderbird	3	3	3	3	3	2	3	4	3	3	3	3	2	38
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	3	3	2	3	4	3	3	2	3	3	2	3	3	37
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	3	3	2	3	4	3	3	2	3	3	2	3	3	37
Degraded Water Quality	**High Selenium**	Little River	3	3	2	3	4	3	3	2	3	3	2	3	3	37
Degraded Water Quality	**High TDS**	Little River	3	3	2	3	3	3	3	2	3	4	2	2	4	37
Degraded Water Quality	**Enterococcus levels**	Hog Creek	3	3	2	3	4	3	2	2	3	3	2	3	3	36
Degraded Water Quality	**E Coli**	Little River	3	3	2	3	4	3	2	2	3	3	2	3	3	36
Degraded Water Quality	**Enterococcus levels**	Little River	3	3	2	3	4	3	2	2	3	3	2	3	3	36
Degraded Water Quality	**E Coli**	Rock Creek	3	3	2	3	4	3	2	2	3	3	2	3	3	36
Degraded Water Quality	**Enterococcus levels**	Rock Creek	3	3	2	3	4	3	2	2	3	3	2	3	3	36
Degraded Water Quality	**E Coli**	West Elm Creek	3	3	2	3	4	3	2	2	3	3	2	3	3	36
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	3	3	2	3	4	3	2	2	3	3	2	3	3	36

Instructions:

1) Please provide a score under each criteria (columns F-R) with a number from the dropdown in each cell (1 to 4)

2) Your input will determine top priority issues based on ranking. Next step will be to define more specific projects for top issues.

3) There are comments if you put your cursor over cells O3 and R3

A couple of notes to consider:

-The prioritization matrix was purposefully developed without considering management strategies

-The prioritization perspective came from the LTWA's role in promoting and facilitating cooperation among existing stormwater entities

-The Project Team will host an interactive site in the coming weeks to receive feedback from watershed residents and LTWA stakeholders on priority issues. This will offer an opportunity for public input on prioritization, vital for the integrated watershed management plan.

Issue Details			**Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)**													**Priority**
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Degraded Water Quality	**High turbidity, low DO, high chlorophyll a**	Lake Thunderbird	3.9	3.6	3.1	3.0	3.4	1.3	3.3	2.4	3.3	2.8	3.9	1.8	3.4	39.3
Degraded Water Quality	Potential for high nutrient levels/ low DO	Upper Little River	3.4	3.4	2.5	2.8	2.8	1.5	2.2	2.8	3.2	2.5	2.4	2.5	3.5	35.4
Bank Erosion	Potential for high phosphorus levels/ low DO	Upper Little River	3.0	3.2	2.3	2.8	2.8	1.5	2.2	2.8	3.2	2.5	2.6	2.8	3.8	35.3
Bank Erosion	High TSS	Little River	2.6	3.0	2.0	2.8	2.5	1.5	2.4	2.8	3.4	2.3	2.6	3.5	3.8	35.1
Bank Erosion	High TSS	Upper Little River	2.6	3.0	2.0	2.8	2.5	1.5	2.4	2.8	3.4	2.5	2.4	3.3	3.8	34.9
Bank Erosion	Potential for high phosphorus levels/ low DO	Little River	3.0	3.0	2.0	3.0	2.5	1.5	2.2	2.8	3.0	2.5	2.8	2.8	3.8	34.8
Degraded Water Quality	Potential for high nutrient levels/ low DO	North Fork Little River	3.2	3.2	2.3	2.8	2.5	1.5	2.2	2.8	3.2	2.5	2.4	2.5	3.5	34.5
Bank Erosion	Potential for high phosphorus levels/ low DO	North Fork Little River	2.8	3.0	2.0	2.8	2.5	1.5	2.2	2.8	3.2	2.5	2.6	2.8	3.8	34.4
Bank Erosion	High TSS	North Fork Little River	2.6	2.8	1.8	2.6	2.3	1.5	2.2	2.8	3.4	2.3	2.4	3.3	3.8	33.5
Shoreline Erosion	High TSS	Lake Thunderbird	2.9	2.7	2.6	2.7	2.3	1.2	2.6	3.3	3.1	2.8	2.6	2.7	1.6	33.0

Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Water Supply & Capacity	Sediment accumulation	Lake Thunderbird	2.7	2.7	2.4	2.7	2.4	1.2	2.5	2.0	3.2	2.6	3.0	2.4	3.2	32.9
Bank Erosion	Potential for high phosphorus levels/ low DO	Hog Creek	2.8	2.8	2.2	2.6	2.4	1.4	2.0	2.8	2.8	2.6	2.6	2.6	2.8	32.4
Bank Erosion	High TSS	Dave Blue Creek	2.4	2.8	1.8	2.6	2.3	1.5	2.0	2.8	3.2	2.5	2.4	3.5	2.3	31.9
Degraded Water Quality	Potential for high nutrient levels/ low DO	Dave Blue Creek	2.8	2.8	1.8	2.7	2.4	2.0	2.0	2.6	3.0	2.6	2.3	2.8	2.0	31.9
Degraded Water Quality	Potential for high nutrient levels/ low DO	Jim Blue Creek	2.8	2.8	1.8	2.7	2.4	2.0	2.0	2.6	3.0	2.6	2.3	2.8	2.0	31.9
Bank Erosion	Potential for high phosphorus levels/ low DO	Rock Creek	2.8	2.8	1.8	2.8	2.3	1.5	2.0	2.8	3.0	2.5	2.8	2.8	2.0	31.7
Bank Erosion	High TSS	Rock Creek	2.6	2.6	1.8	2.6	2.3	1.5	2.2	2.8	3.2	2.3	2.4	3.3	2.3	31.6
Degraded Water Quality	**Low DO**	Little River	2.8	3.0	1.5	3.0	2.3	1.3	1.4	2.0	3.2	3.0	1.8	2.8	3.5	31.5
Bank Erosion	High TSS	Hog Creek	2.6	2.6	2.0	2.4	2.4	1.4	2.2	2.8	3.0	2.4	2.2	2.8	2.6	31.4
Degraded Water Quality	**High TDS**	Little River	2.7	2.3	1.4	2.3	2.8	1.8	1.8	2.0	3.0	2.8	1.5	2.8	3.6	30.9
Degraded Water Quality	Potential for high nutrient levels/ low DO	Kitchen Creek	2.5	2.8	1.8	2.5	2.3	1.5	1.5	2.8	3.0	2.5	2.3	2.8	2.8	30.8
Degraded Water Quality	Potential for high nutrient levels/ low DO	Clear Creek	2.8	2.8	1.8	2.6	2.0	1.5	1.8	2.8	3.2	2.5	2.4	2.5	1.8	30.4
Bank Erosion	Potential for high phosphorus levels/ low DO	Dave Blue Creek	2.6	2.6	1.5	2.6	2.0	1.8	1.8	2.8	3.0	2.5	2.4	3.0	1.8	30.3
Bank Erosion	Potential for high phosphorus levels/ low DO	West Elm Creek	2.4	2.2	1.6	2.4	2.0	1.4	1.6	2.8	3.0	2.8	2.4	2.6	2.4	29.6

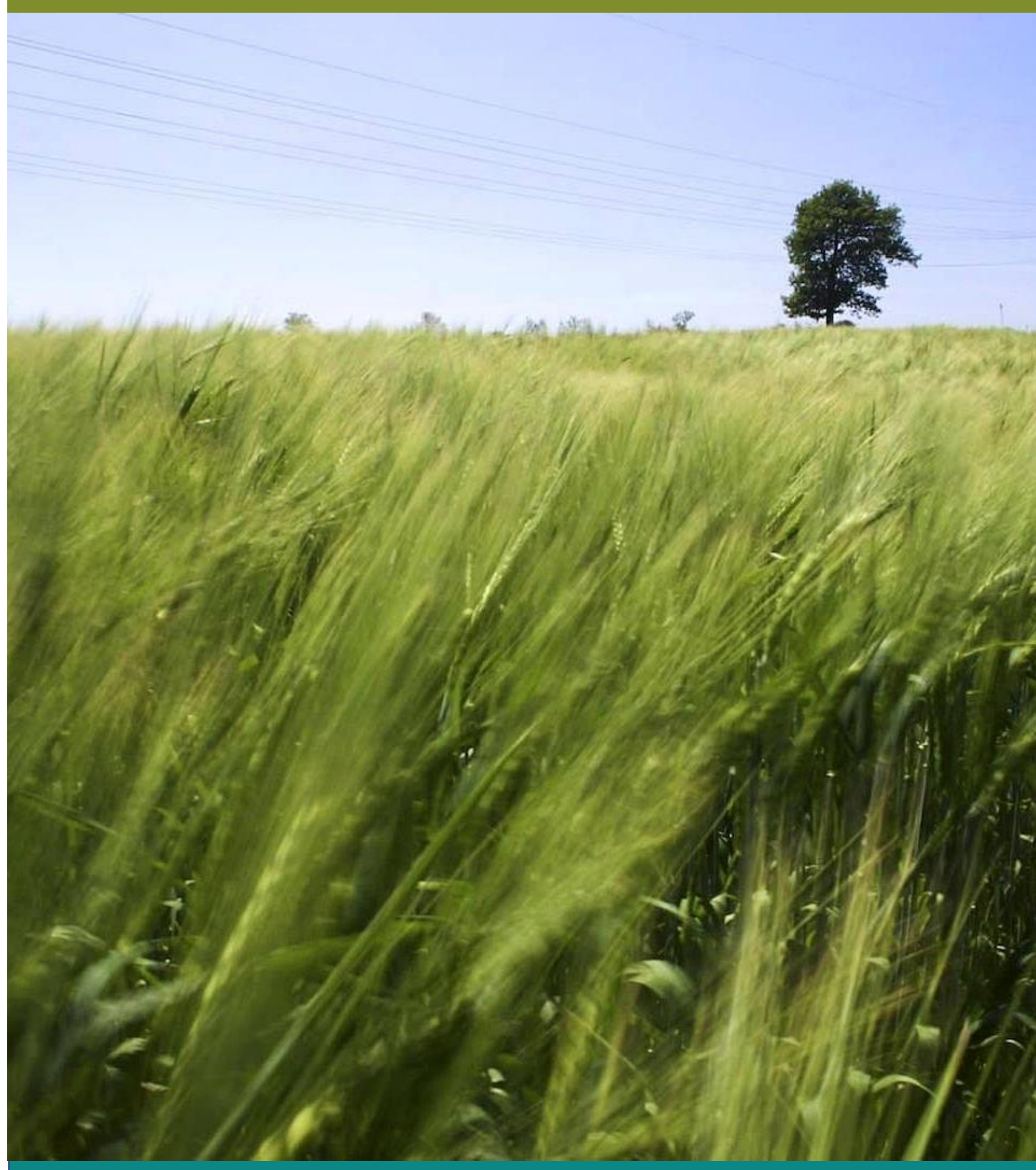
Issue Details			Score (1 = Very low/None/No, 2 = Low, 3 = Medium/Partially , and 4 = High/Yes)													Priority
Issue Category	**Specific Issue**	**Geographical Area**	**Severity of issue**	**Will resolving issue help remove LT from ODEQ 303(d) List?**	**Negative Impact to Tourism/ Recreation at Lake Thunderbird**	**Negative Impact to Aquatic Life within geographical area**	**Negative Impact to Water Supply (from Lake Thunderbird)**	**Negative Impact to Agriculture within geographical area**	**Negative Impact to Aesthetics within geographical area**	**Can Specific Area be Targeted?**	**Can Issue be Easily Monitored/ Measured?**	**Does it require more research to develop solution?**	**Does it have high visibility to the Public? (or High Volume of Complaints)**	**Level to which it has not been addressed by city or agency**	**Will it require more than one City to address (based on geographical area)?**	**Ranking**
Bank Erosion	High TSS	West Elm Creek	2.2	2.0	1.4	2.0	2.0	1.4	1.8	2.6	3.2	2.6	2.0	2.8	2.4	28.4
Degraded Water Quality	**E Coli**	Little River	2.3	2.0	1.8	1.7	2.2	1.6	1.3	2.0	2.7	3.0	1.8	2.8	3.0	28.2
Degraded Water Quality	**Low DO**	West Hog Creek	3.0	2.2	1.4	3.0	2.0	1.2	1.2	2.0	3.2	2.4	1.4	2.8	2.2	28.0
Degraded Water Quality	**High Selenium**	Little River	2.2	1.5	1.2	1.8	2.6	1.6	1.5	1.6	2.5	3.0	1.7	3.2	3.4	27.8
Degraded Water Quality	**Enterococcus levels**	Little River	2.2	2.0	1.8	1.7	2.2	1.6	1.3	2.0	2.7	2.4	1.8	2.8	3.0	27.5
Degraded Water Quality	**E Coli**	Rock Creek	2.3	1.8	1.8	1.7	2.2	1.6	1.3	2.0	2.7	3.0	1.8	2.8	2.4	27.5
Degraded Water Quality	**E Coli**	West Elm Creek	2.3	2.2	1.7	1.7	2.0	1.5	1.3	2.2	2.5	2.8	1.7	2.5	2.2	26.5
Degraded Water Quality	**Enterococcus levels**	Rock Creek	2.2	2.0	1.8	1.7	2.2	1.6	1.3	2.0	2.7	2.4	1.8	2.8	2.0	26.5
Degraded Water Quality	**High TDS**	Moore Creek	2.5	1.5	1.3	2.0	2.5	1.3	1.3	2.0	2.8	2.8	1.3	3.3	2.0	26.3
Degraded Water Quality	**Enterococcus levels**	Hog Creek	2.2	2.2	1.7	1.7	2.0	1.5	1.3	2.2	2.5	2.3	1.7	2.5	2.2	25.8
Degraded Water Quality	**Enterococcus levels**	West Elm Creek	2.2	2.2	1.7	1.7	2.0	1.5	1.3	2.2	2.5	2.3	1.7	2.5	2.2	25.8
Degraded Water Quality	**Low DO**	East Elm Creek	1.8	1.8	1.2	2.6	1.6	1.2	1.0	1.8	3.2	2.2	1.2	2.8	2.2	24.6

Appendix B

THE IMPACTS OF LAND USE ON LAKE THUNDERBIRD'S WATERSHED

What does "land use" mean?

- Describes the human use of land
- Represents economic and cultural activities
- Includes agricultural, residential, industrial, commercial, and recreational type uses



How does land use affect the environment?

- Affects air and water quality, watershed function, generation of waste, extent and quality of wildlife habitat, climate, and human health.
- As we grow and develop, we increase stormwater runoff by creating additional paved surfaces that can contribute to stormwater pollution, including:
    - Excess fertilizers from agricultural lands and residential areas;
    - Oil, grease, and toxic chemicals from urban stormwater runoff;
    - Sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks; and
    - Bacteria and nutrients from livestock, pet wastes and faulty septic systems.

RESIDENTIAL

WHAT CAN I DO?

1

Increase the cutting height on your lawn mower

Taller grass = Deeper roots = Less runoff

2

Pick up your pet waste and dispose of it in a trash can

3

Keep soil covered with plants or mulch

Enjoy the native plant community

4

Reduce or eliminate the use of lawn chemicals

Do a soil test and apply only what your lawn needs

5

Properly dispose of chemicals

(used motor oil, cleaners and paint)

6

Keep rainwater on your property

Install a rain barrel
Build a rain garden

COMMERCIAL & INDUSTRIAL

WHAT CAN I DO?

1

Ensure you are in compliance with local, state, and federal stormwater regulations

Check with your local municipality to see if your business needs a stormwater permit

2

Identify areas where stormwater pollution may occur, inspect them regularly, and implement appropriate best management practices

3

Incorporate green stormwater infrastructure at your business to slow and filter runoff

4

Properly dispose of chemicals

Do not pour anything down storm drains

RANCHING

WHAT CAN I DO?

Develop a rotational grazing plan to ensure the soil is protected by a healthy covering of vegetation year-round

1

Develop a manure management plan for areas where animals congregate

2

Install riparian fencing and alternative water sources to keep livestock out of streams

3

FARMING

WHAT CAN I DO?

1

Transition to reduced-tillage or no-till cropping methods

2

Use cover crops during fallow periods

3

Focus on improving soil health and reducing the use of synthetic fertilizers and pesticides

4

Leave or plant pollinator strips around the perimeter of cropped fields

RECREATIONAL

WHAT CAN I DO?

BOAT USERS

1. Inspect your boat for invasive species, such as Zebra mussels, and thoroughly clean and dry it before entering another lake
2. Avoid sensitive areas and drive slowly through shallow waters
3. Upgrade your boat motor from a two-stroke engine to a four-stroke engine
4. Clean any visible mud, plants, and animals from all equipment before leaving water access

HORSEBACK RIDERS / TRAIL USERS

1. Stay on designated trails and minimize contact with water
2. Utilize best practices when constructing trails and minimize contact with water

CAMPERS

1. Lay tent over flat, compacted soil instead of over vegetation
2. Camp at least 200 feet away from a water source
3. Collect firewood that is dead or has fallen, where allowed, or use locally harvested firewood
4. Restrict campfires to contained fire pits
5. Leave no trace!

Appendix C

LTWA SURVEY RESULTS

6/28/2021

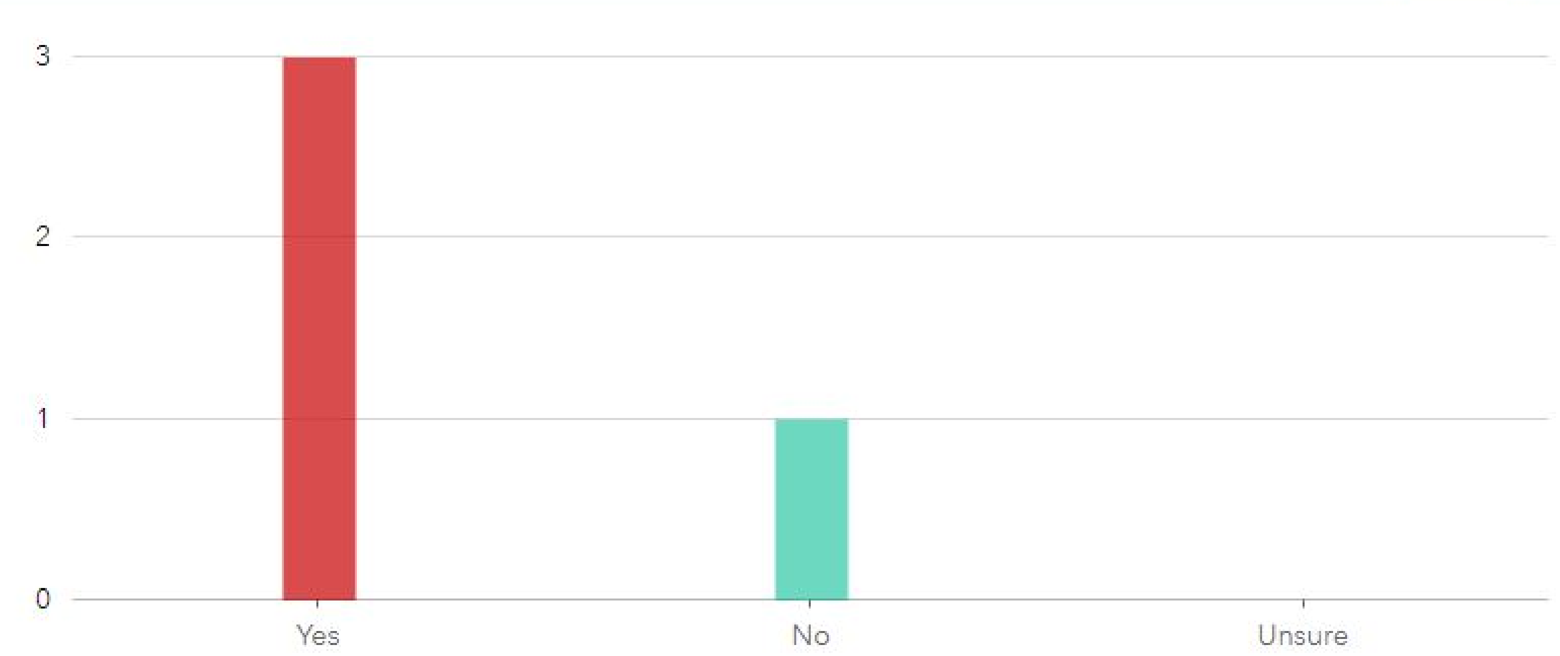
BEST MANAGEMENT PRACTICES SURVEY RESULTS

LAKE THUNDERBIRD
WATERSHED ALLIANCE

BEST MANAGEMENT PRACTICES SURVEY RESULTS

Question 1

If funding was available to help you implement a Best Management Practice on your property, would you b...



Hide table

Empty categories
Sort

Answers	Count	Percentage
Yes	3	75%
No	1	25%
Unsure	0	0%

Answered: 4 Skipped: 0

BEST MANAGEMENT PRACTICES SURVEY RESULTS

Question 2

BEST MANAGEMENT PRACTICES SURVEY RESULTS

Question 3

Are there any other Best Management Practices that you would like to see implemented within the Lake Thu... Word cloud

The word cloud requires at least 20 answers to show.

Hide table   Show words

Response	Count
restoration of riparian buffers to help with erosion and sediment and city ordinances to limit fertilizers in the water shed.	1
	0

Answered: 1 Skipped: 3

LTWA GENERAL SURVEY RESULTS

FROM GUERNSEY INTERACTIVE

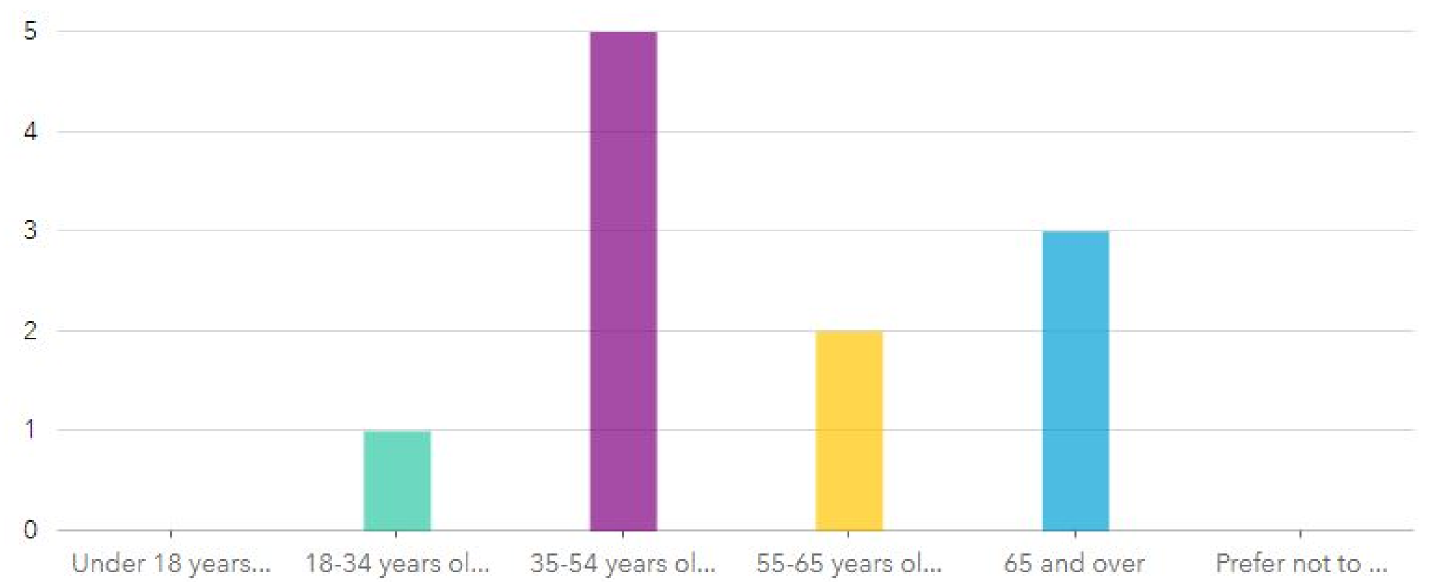
LAKE THUNDERBIRD WATERSHED ALLIANCE

LTWA GENERAL SURVEY RESULTS

Question 1

What is your age?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Under 18 years old	0	0%
18-34 years old	1	9.09%
35-54 years old	5	45.45%
55-65 years old	2	18.18%
65 and over	3	27.27%
Prefer not to answer	0	0%

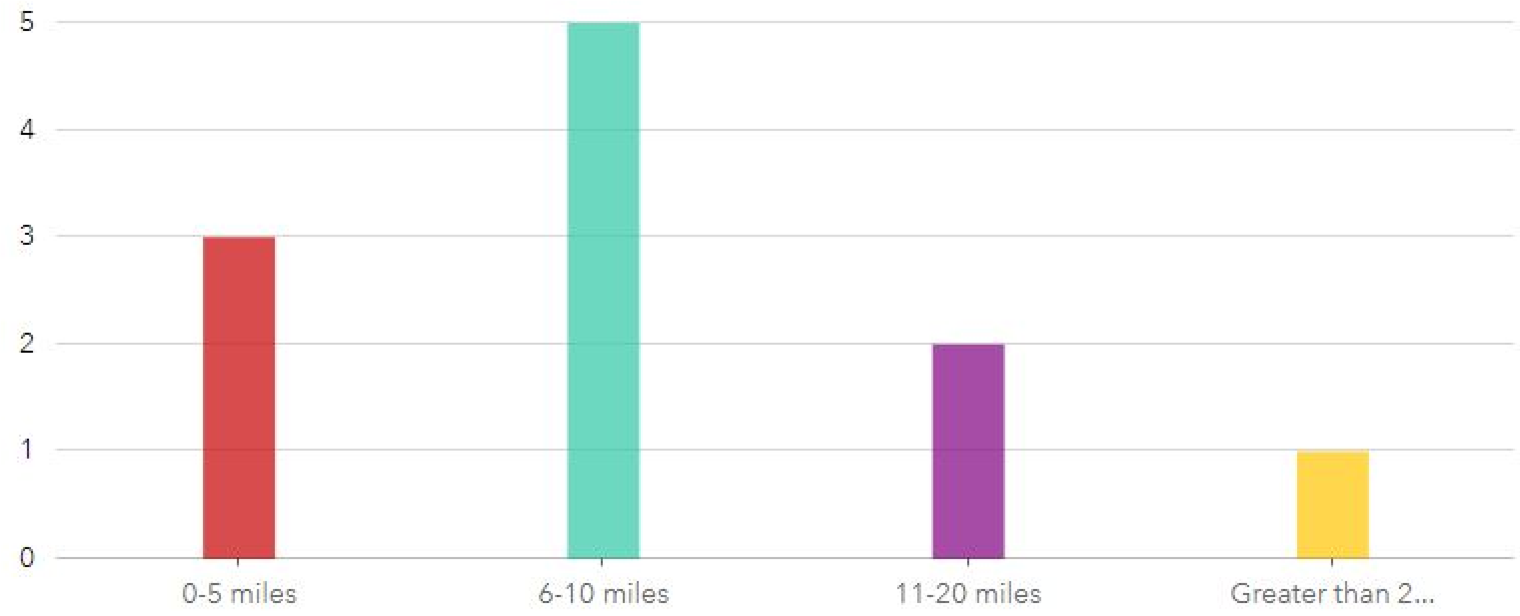
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 2

How close do you live or work to Lake Thunderbird?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
0-5 miles	3	27.27%
6-10 miles	5	45.45%
11-20 miles	2	18.18%
Greater than 20 miles	1	9.09%

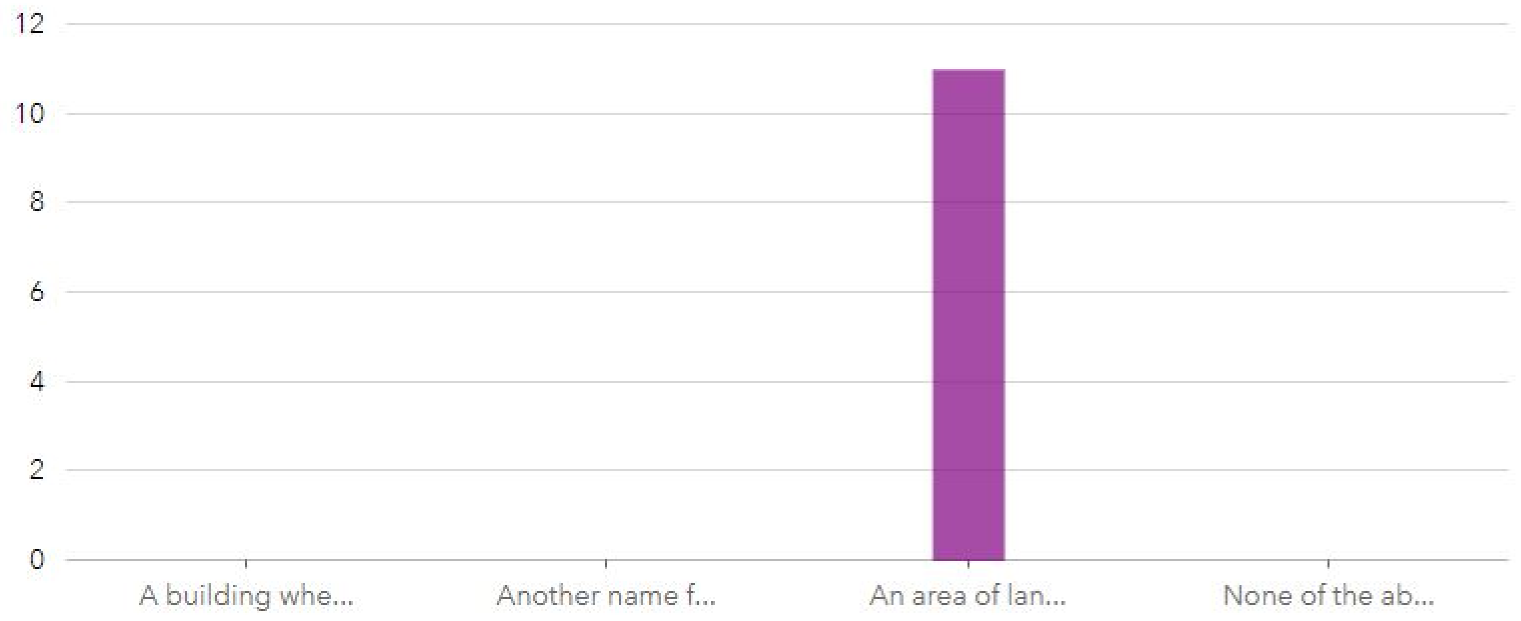
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 3

Do you know what a watershed is?

Column Bar



Hide table

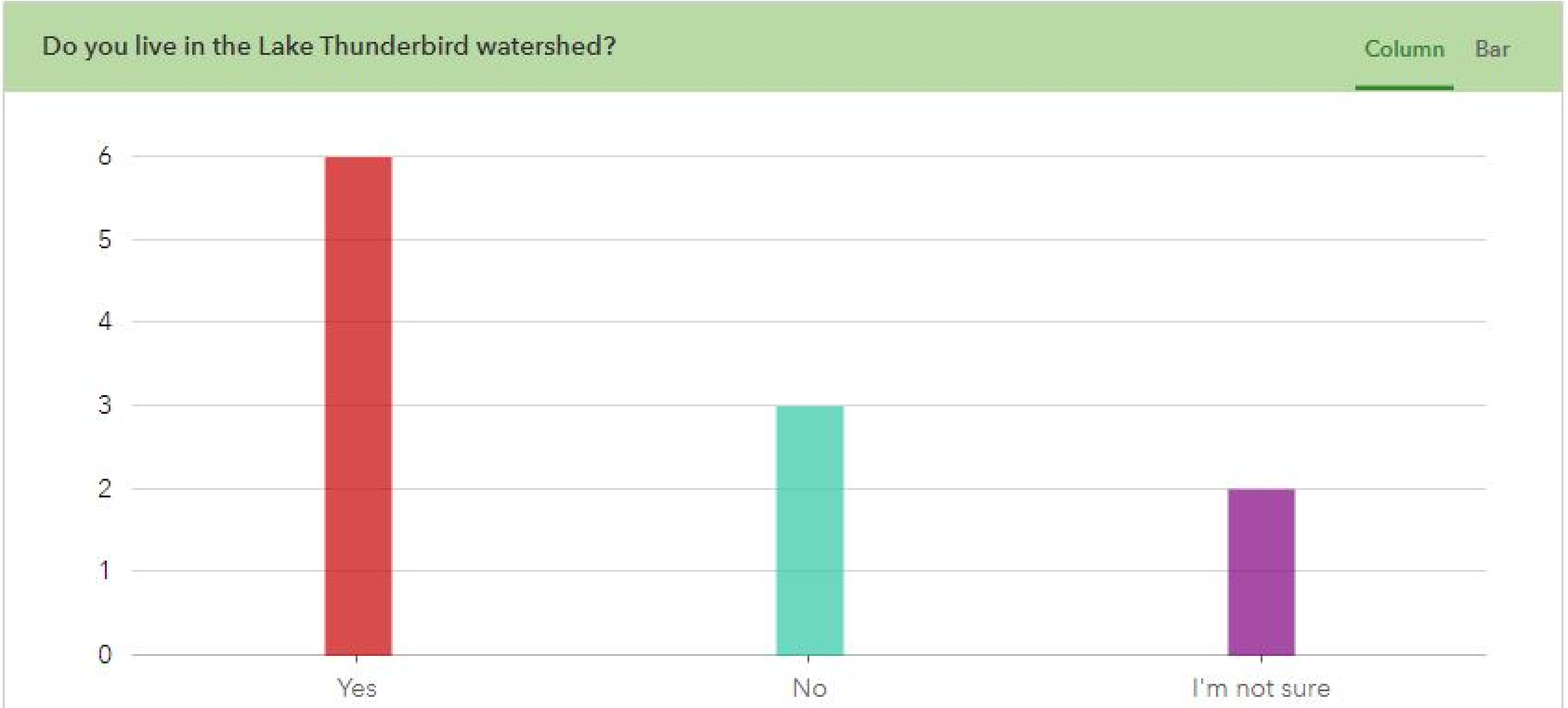
Empty categories Sort

Answers	Count	Percentage
A building where water is stored	0	0%
Another name for the water treatment plant	0	0%
An area of land when water falls on it, flows to one waterbody, like a river, lake, or ocean	11	100%
None of the above	0	0%

Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 4



Hide table

Empty categories
Sort

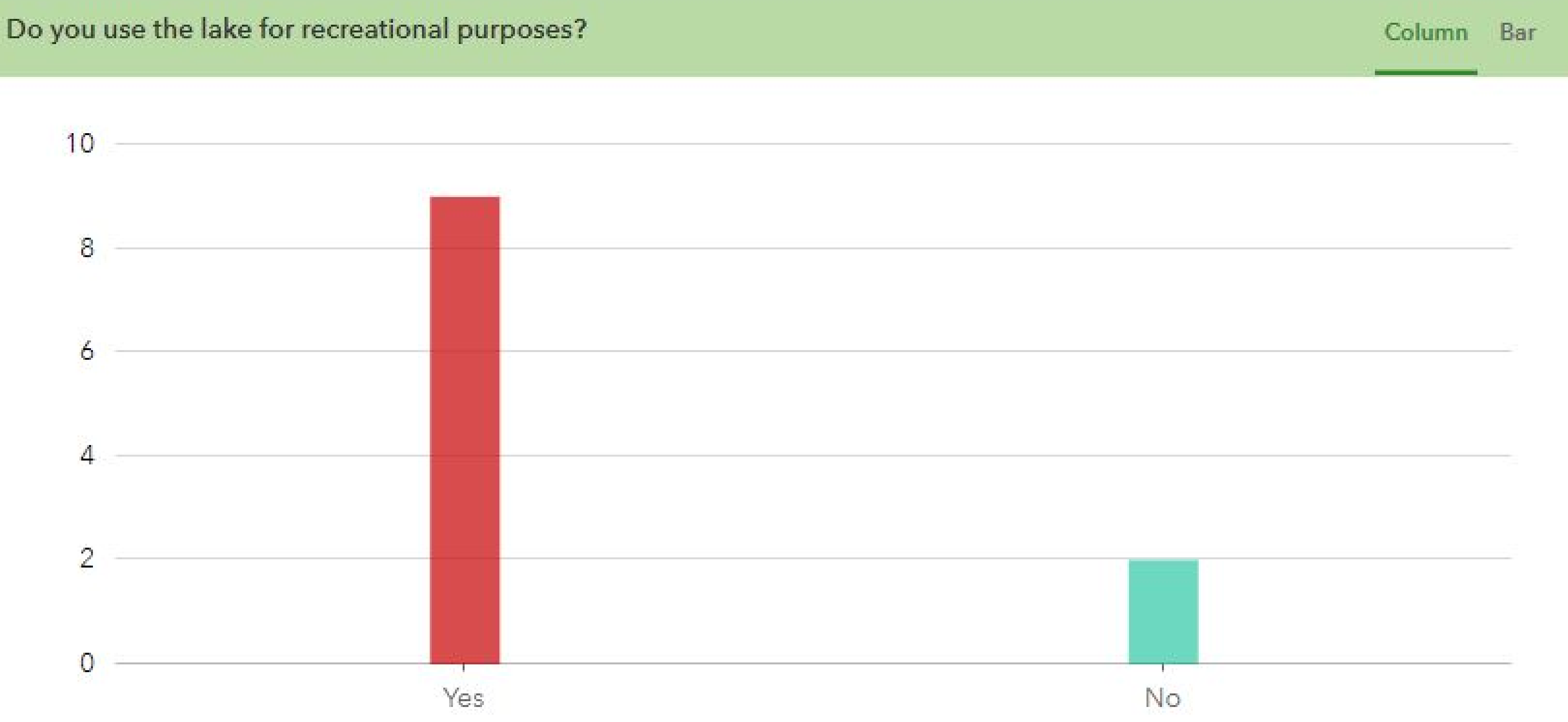
Answers	Count	Percentage
Yes	6	54.55%
No	3	27.27%
I'm not sure	2	18.18%

Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 5

Do you use the lake for recreational purposes?



Hide table

Empty categories Sort

Answers	Count	Percentage
Yes	9	81.82%
No	2	18.18%

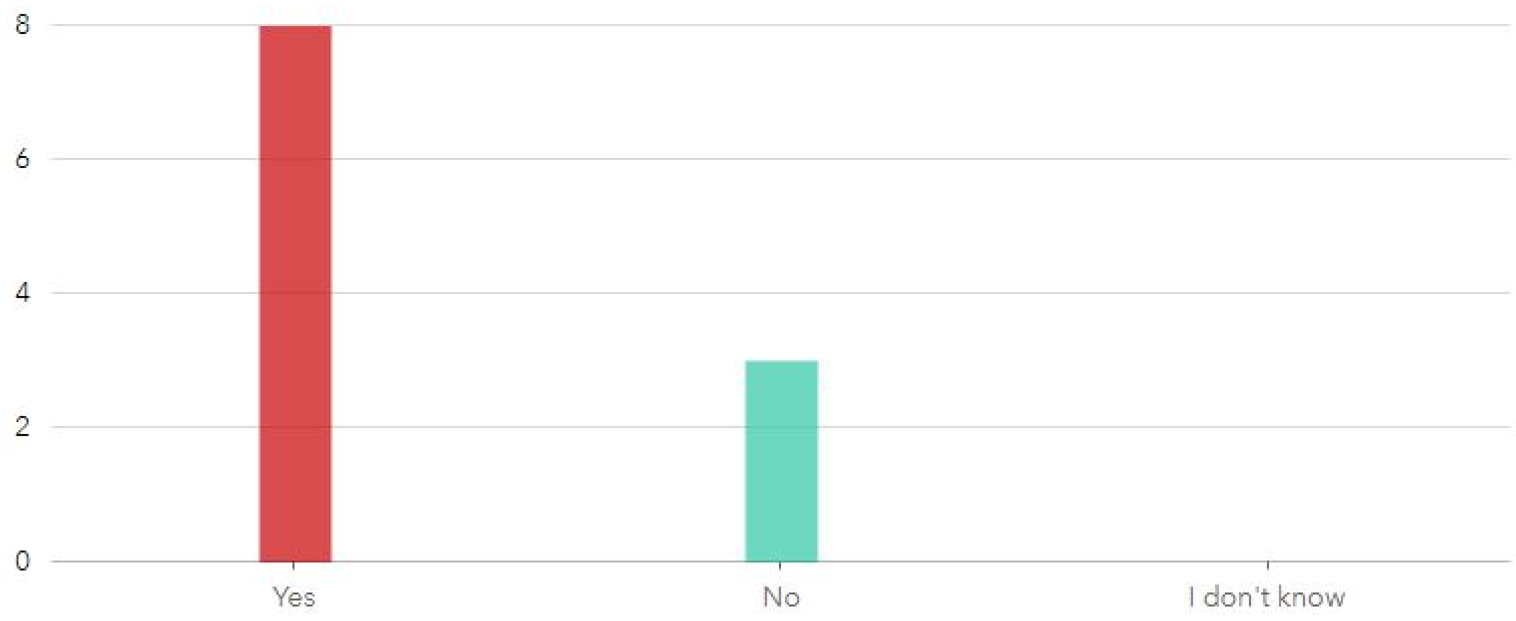
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 6

Do you get your drinking water from the lake?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Yes	8	72.73%
No	3	27.27%
I don't know	0	0%

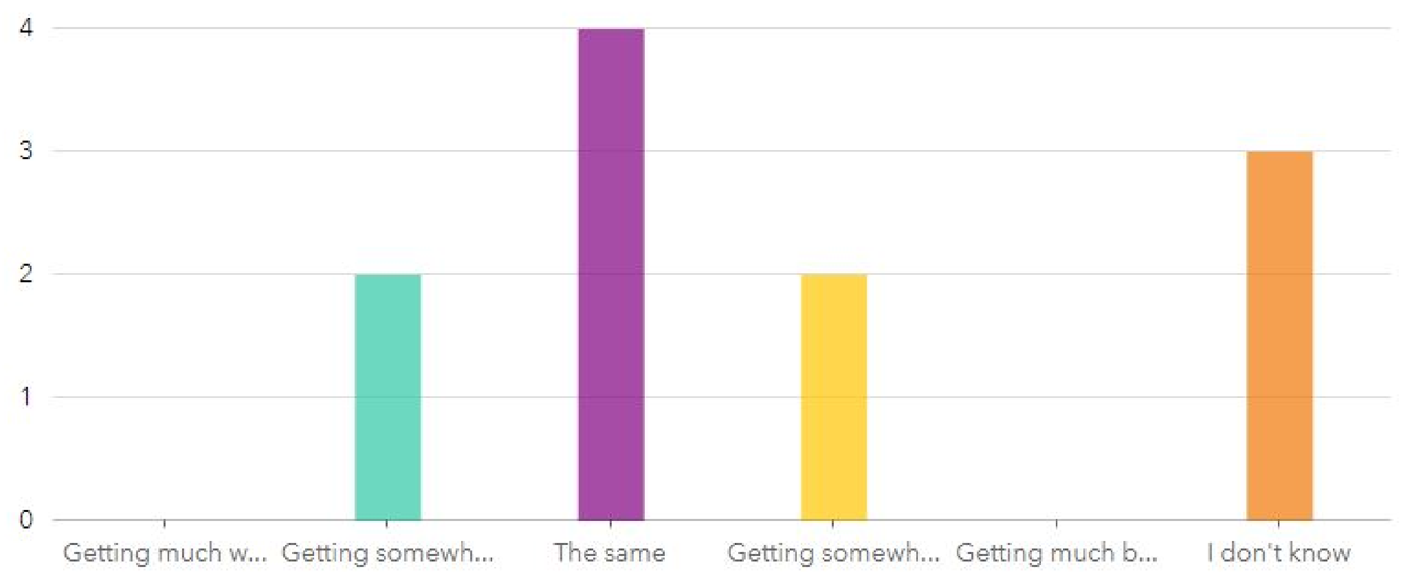
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 7

Do you think the water quality in Lake Thunderbird is

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Getting much worse	0	0%
Getting somewhat worse	2	18.18%
The same	4	36.36%
Getting somewhat better	2	18.18%
Getting much better	0	0%
I don't know	3	27.27%

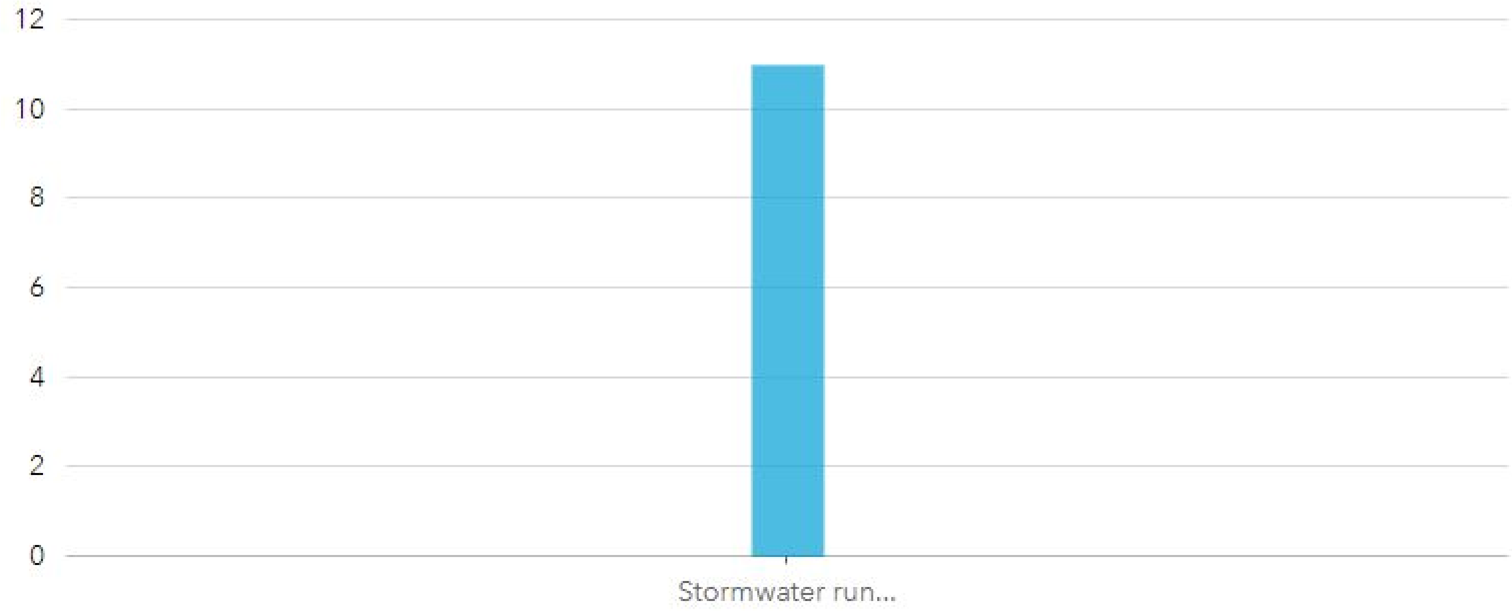
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 8

Which ONE of the following do you think has the biggest impact on Lake Thunderbird?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Stormwater runoff	11	100%

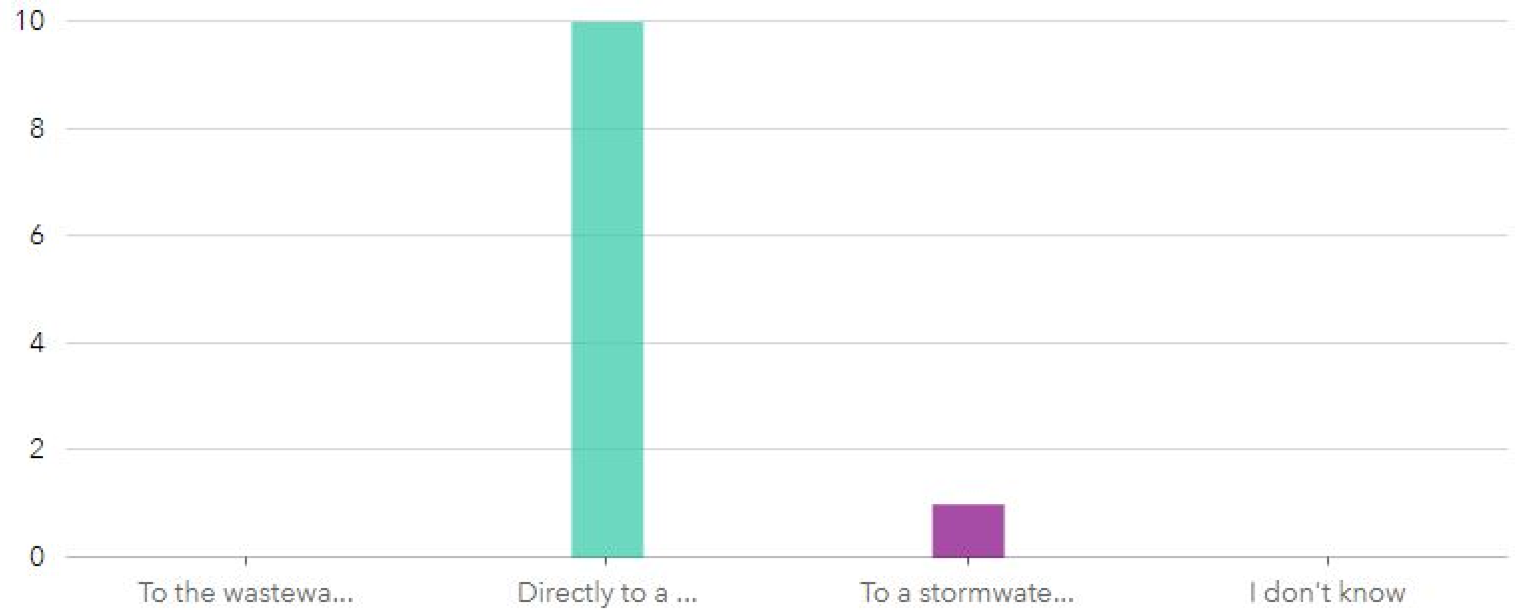
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 9

Where does stormwater go after it enters a storm drain or roadside ditch?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
To the wastewater treatment plant	0	0%
Directly to a stream or river without treatment	10	90.91%
To a stormwater treatment facility	1	9.09%
I don't know	0	0%

Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 10

Do you think the things you do on your yard, driveway or other areas have any impact on the quality of wat... Column Bar

Hide table

Empty categories Sort

Answers	Count	Percentage
Yes	11	100%
No	0	0%
I don't know	0	0%

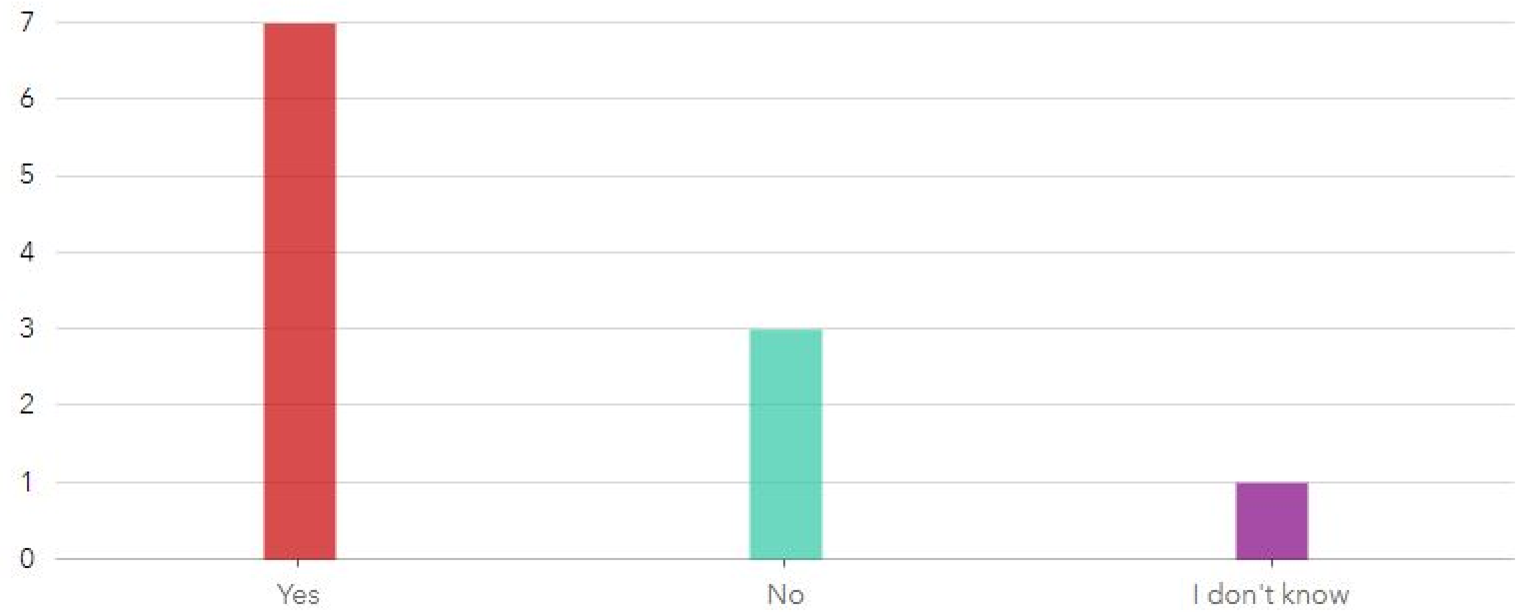
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 11

Do you or other household members pick up pet waste out of your yard or when you walk your dog?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Yes	7	63.64%
No	3	27.27%
I don't know	1	9.09%

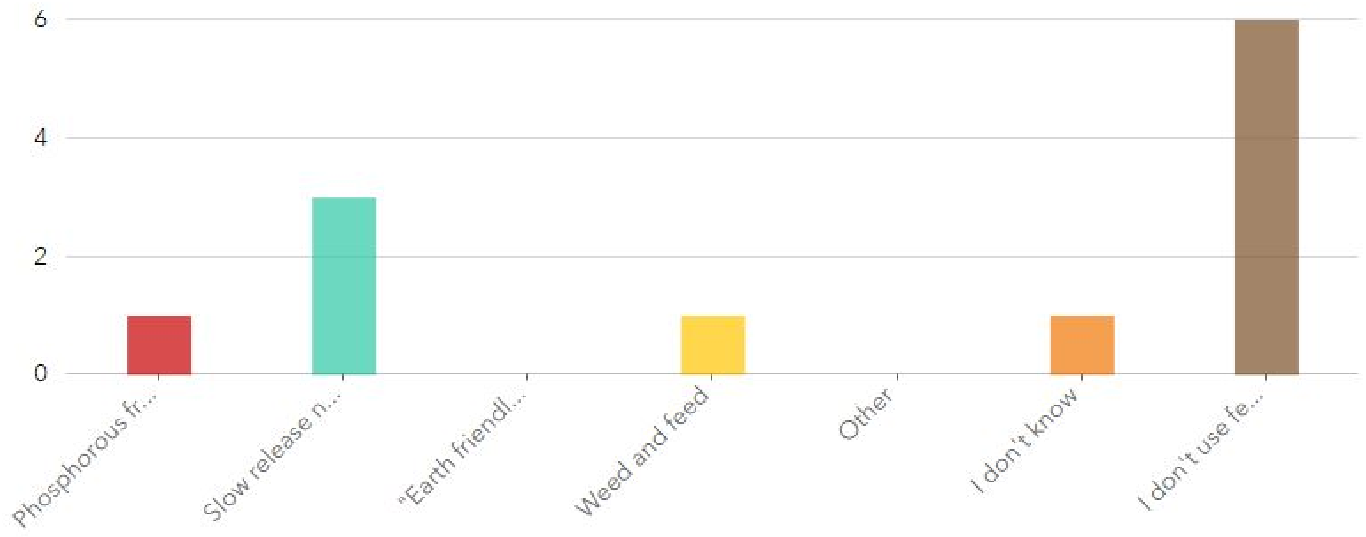
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 12

If you use fertilizers, what type do you use?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Phosphorous free	1	9.09%
Slow release nitrogen	3	27.27%
"Earth friendly" or organic	0	0%
Weed and feed	1	9.09%
Other	0	0%
I don't know	1	9.09%
I don't use fertilizer	6	54.55%

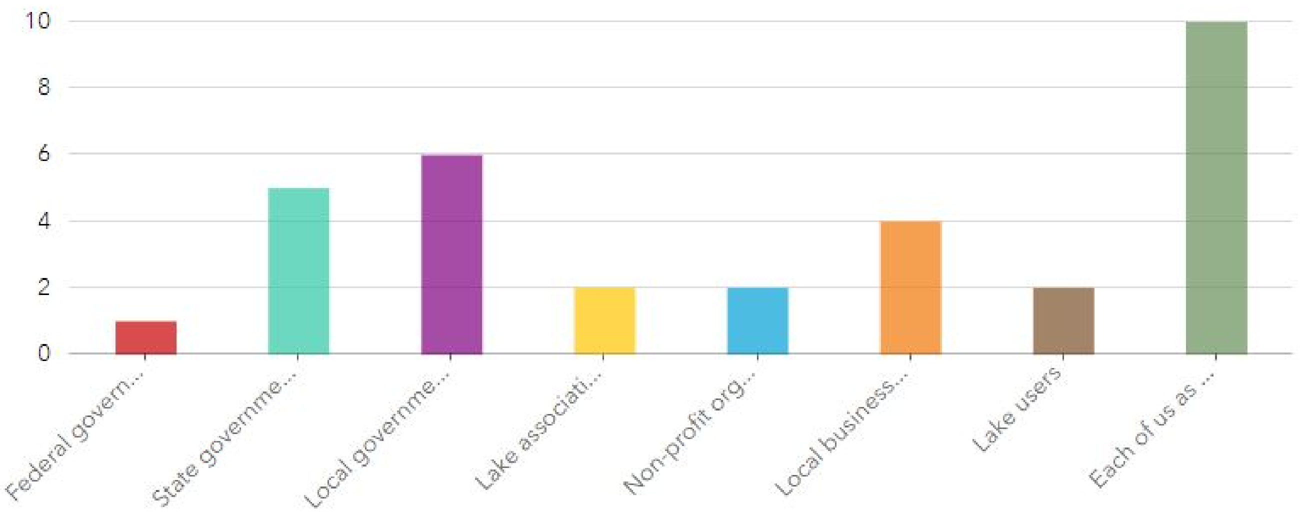
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 13

In your opinion, who should be responsible for protecting water quality in Lake Thunderbird watershed?

Column Bar



Hide table

Empty categories Sort

Answers	Count	Percentage
Federal government	1	9.09%
State government	5	45.45%
Local government (city/county)	6	54.55%
Lake associations	2	18.18%
Non-profit organizations	2	18.18%
Local businesses	4	36.36%
Lake users	2	18.18%
Each of us as individuals	10	90.91%

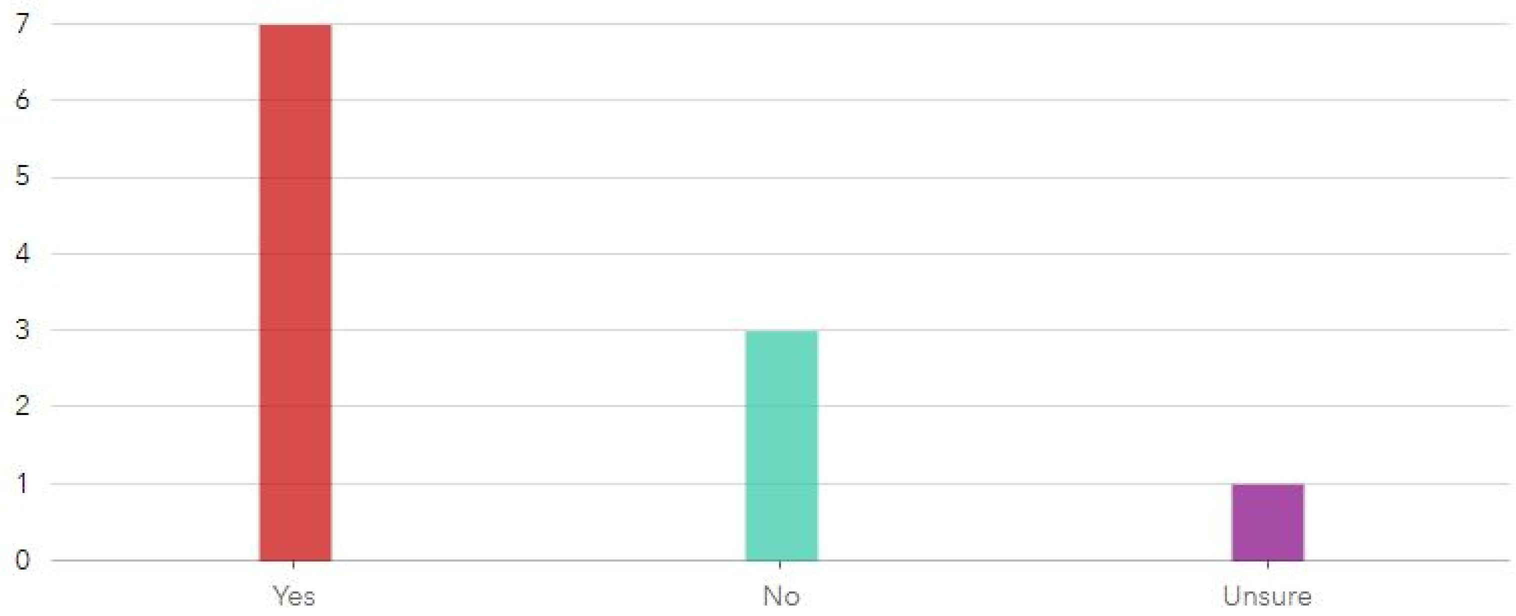
Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 14

Have you ever attended, or do you plan to attend a Lake Thunderbird clean up or community event?

Column Bar



Hide table

Empty categories Sort

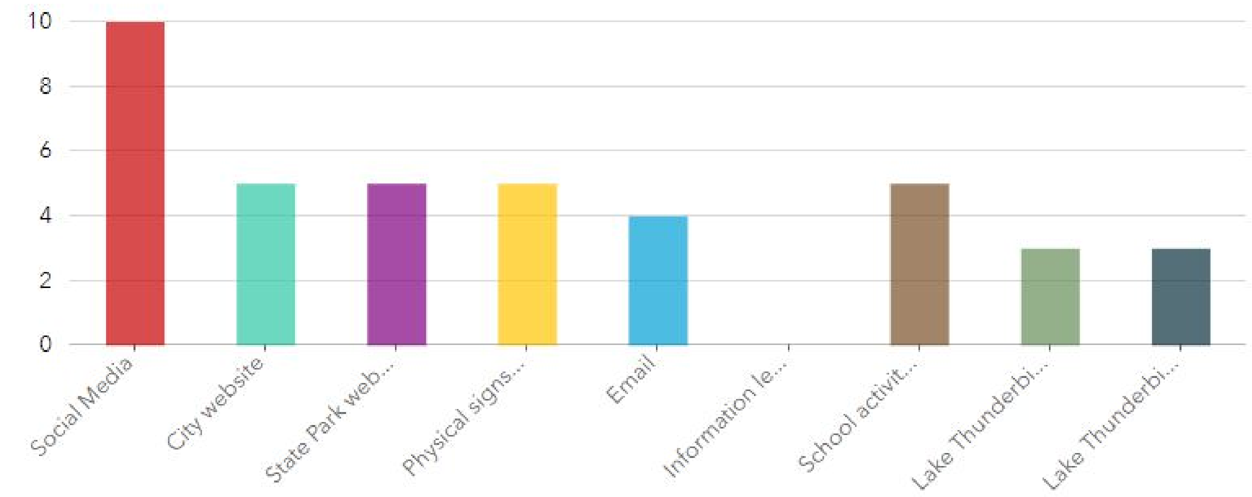
Answers	Count	Percentage
Yes	7	63.64%
No	3	27.27%
Unsure	1	9.09%

Answered: 11 Skipped: 0

LTWA GENERAL SURVEY RESULTS

Question 15

What is the best way to communicate information about the watershed and what you can do to protect Lak... Column Bar



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Empty categories Sort

Answers	Count	Percentage
Social Media	10	90.91%
City website	5	45.45%
State Park website	5	45.45%
Physical signs around the lake	5	45.45%
Email	4	36.36%
Information left at door	0	0%
School activities	5	45.45%
Lake Thunderbird community events	3	27.27%
Lake Thunderbird recreation groups	3	27.27%

Interactive Map Comments

Interactive Map Comments

1. “Soil erosion is occurring on both sides of Sooner Road between SE 134th and approximately S Osborne Way.”

2. “The construction project on the southwest side of south 34th and Broadway around Central Park Drive, which I believe may be part of The Apples subdivision, has silt fences knocked over, dirt tracking, and erosion off the site.”

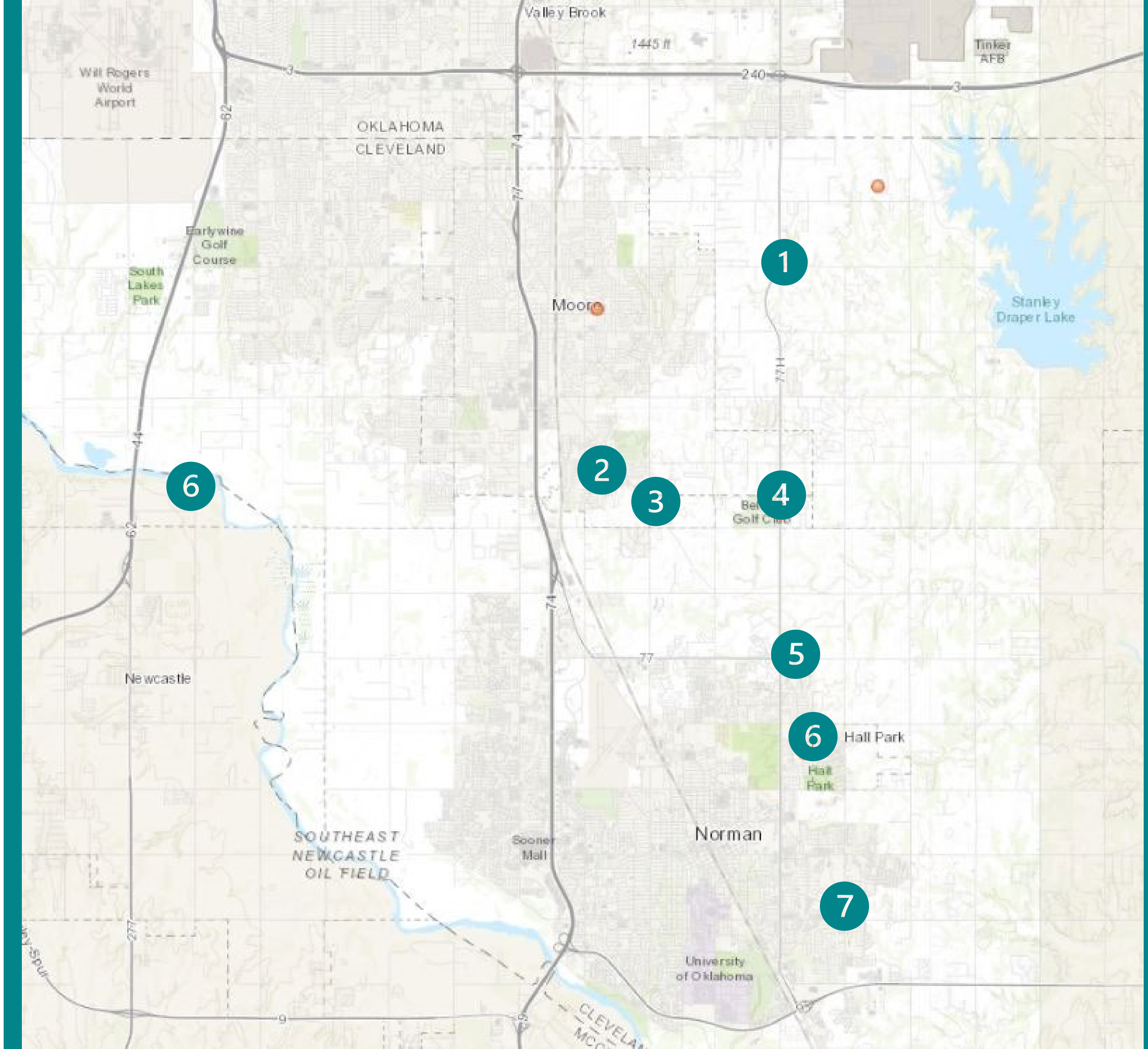
3. “The construction project (maybe a new subdivision?) on the west side of the Bryant and Broadway intersection has silt fences knocked over, and dirt tracking off the site.”

4. “The unincoporated area east of Belmar Golf Club experiences frequent gravel and dirt washouts from the businesses and homes into the roadways and surrounding areas each time it rains.”

5. “The hillsides along both Tecumseh Road and 12th Ave NE are eroding. It is not uncommon to find dirt washing into the road after rain.”

6. “There is a lot of soil erosion taking place in Northeast Lions Park in Norman, especially around the pond area.”

7. “Creekside Bike Park is experiencing a significant amount of trash and tire dumping.”

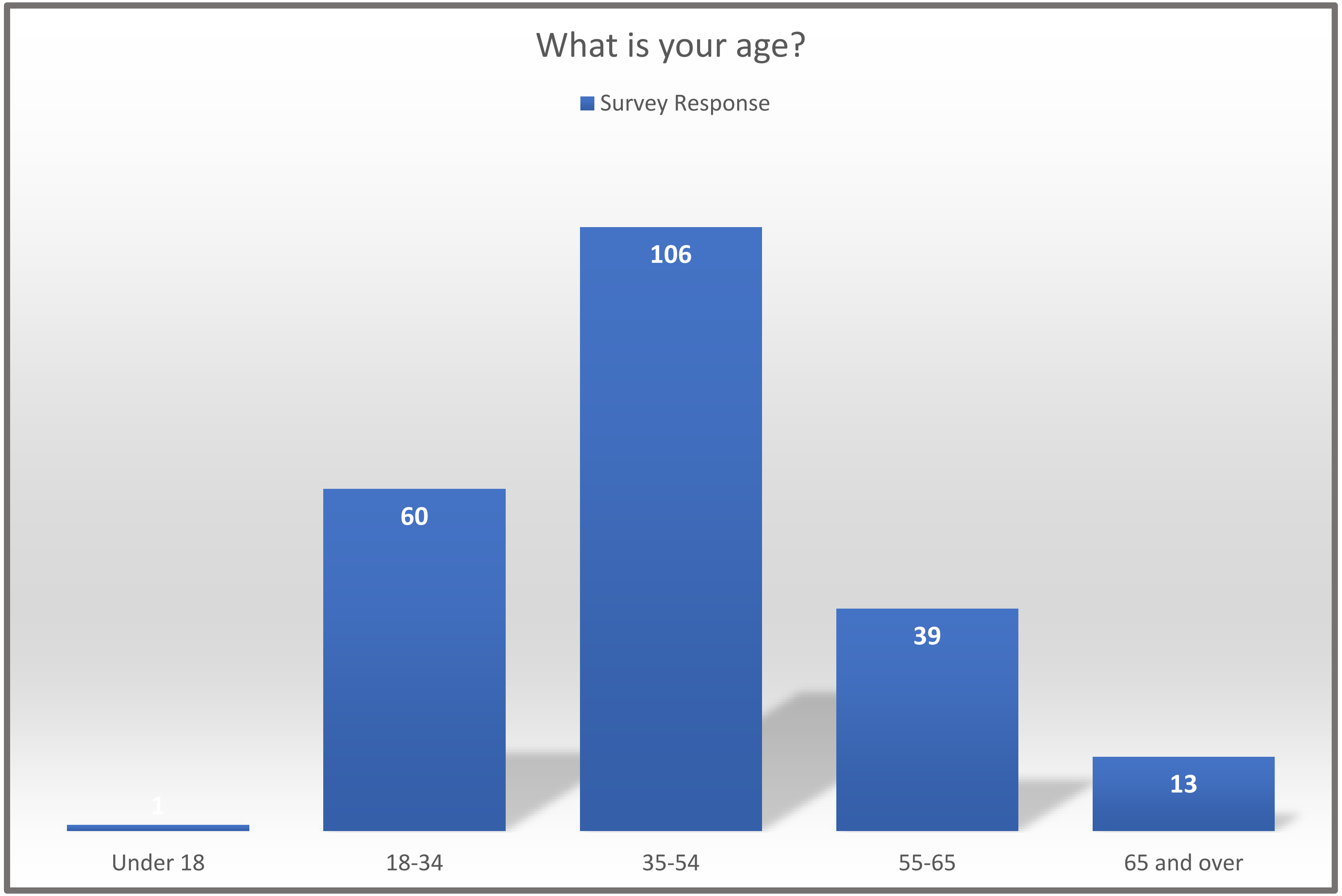


LTWA GENERAL SURVEY RESULTS

FROM SURVEY MONKEY

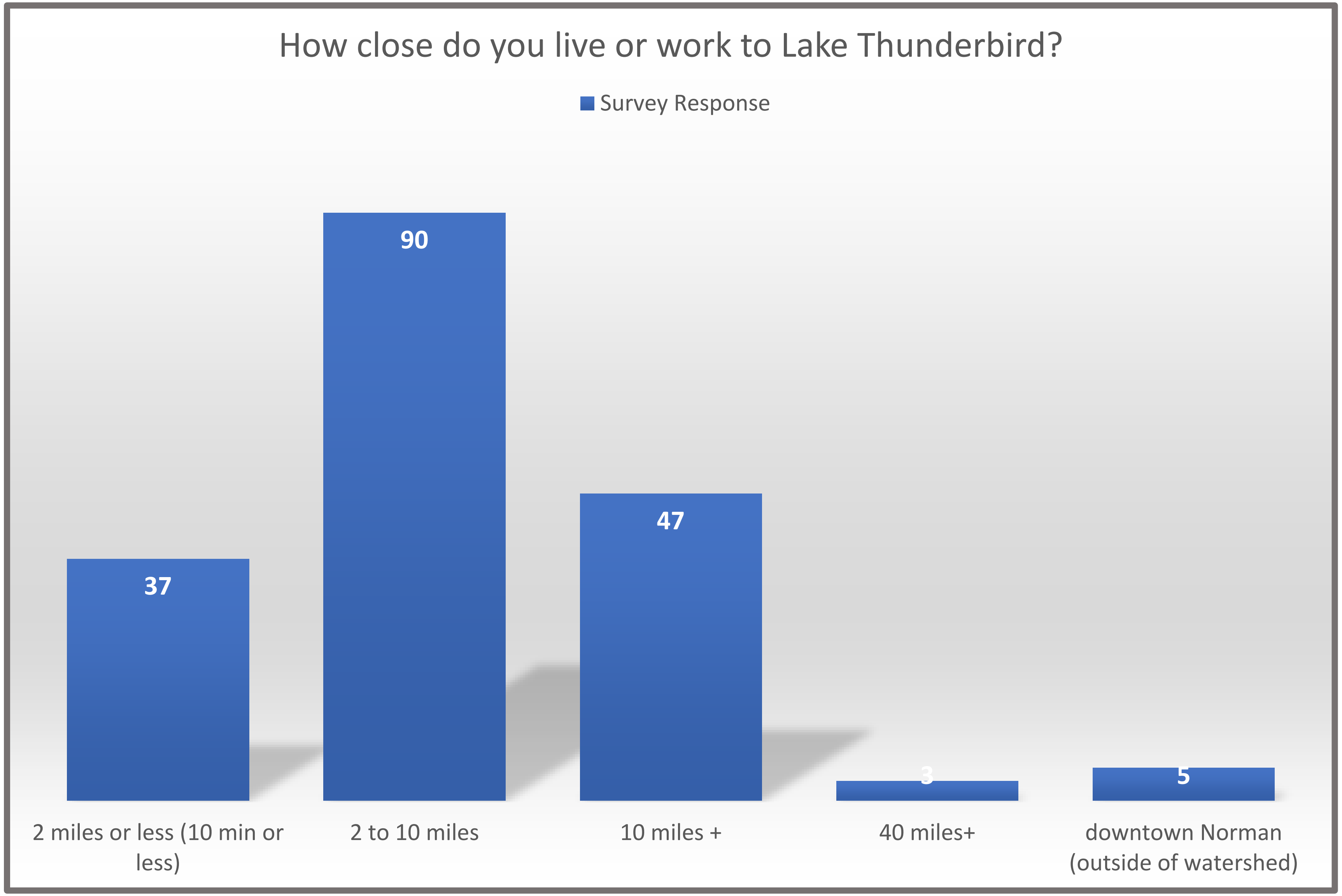
LTWA GENERAL SURVEY RESULTS

Question 1



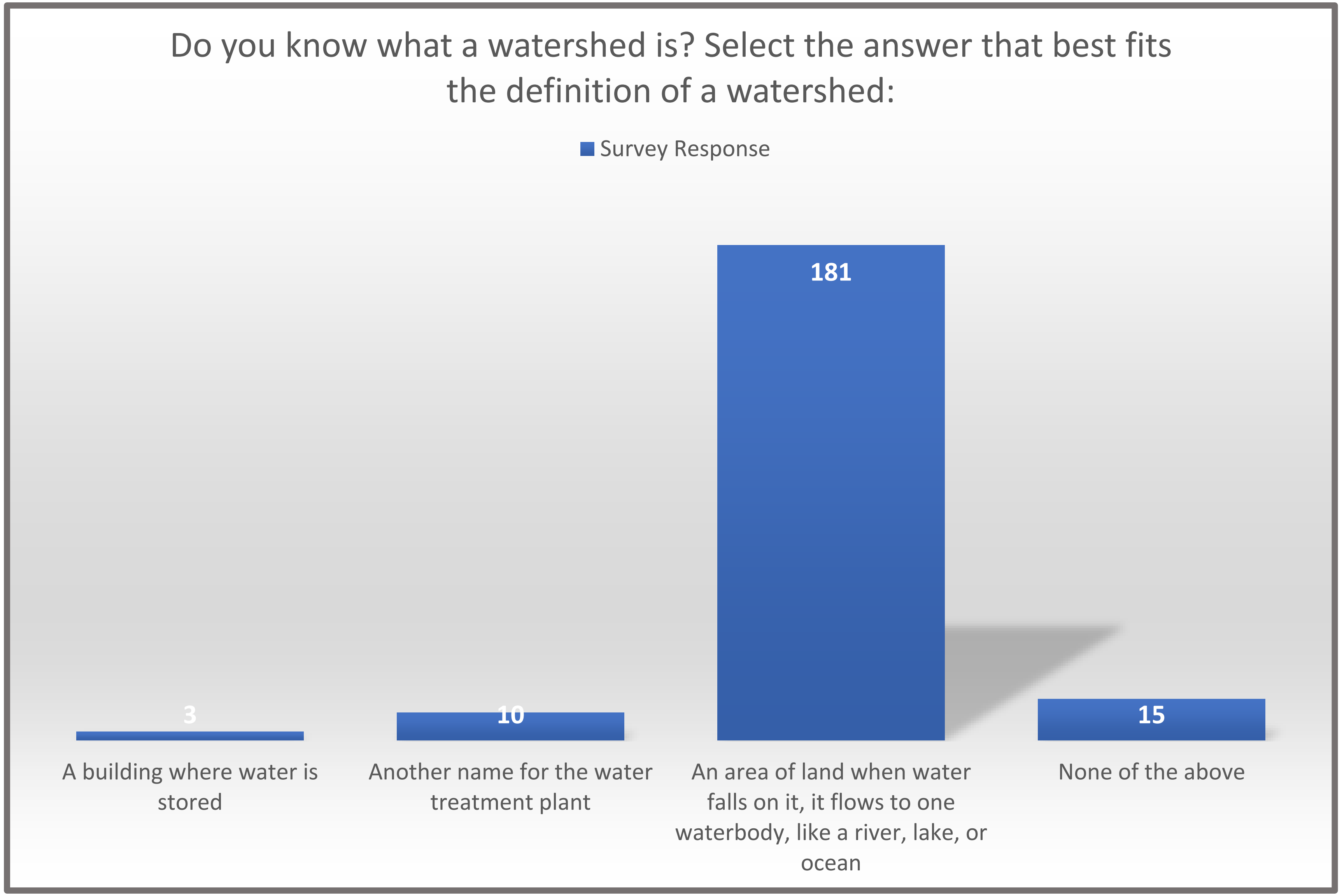
LTWA GENERAL SURVEY RESULTS

Question 2



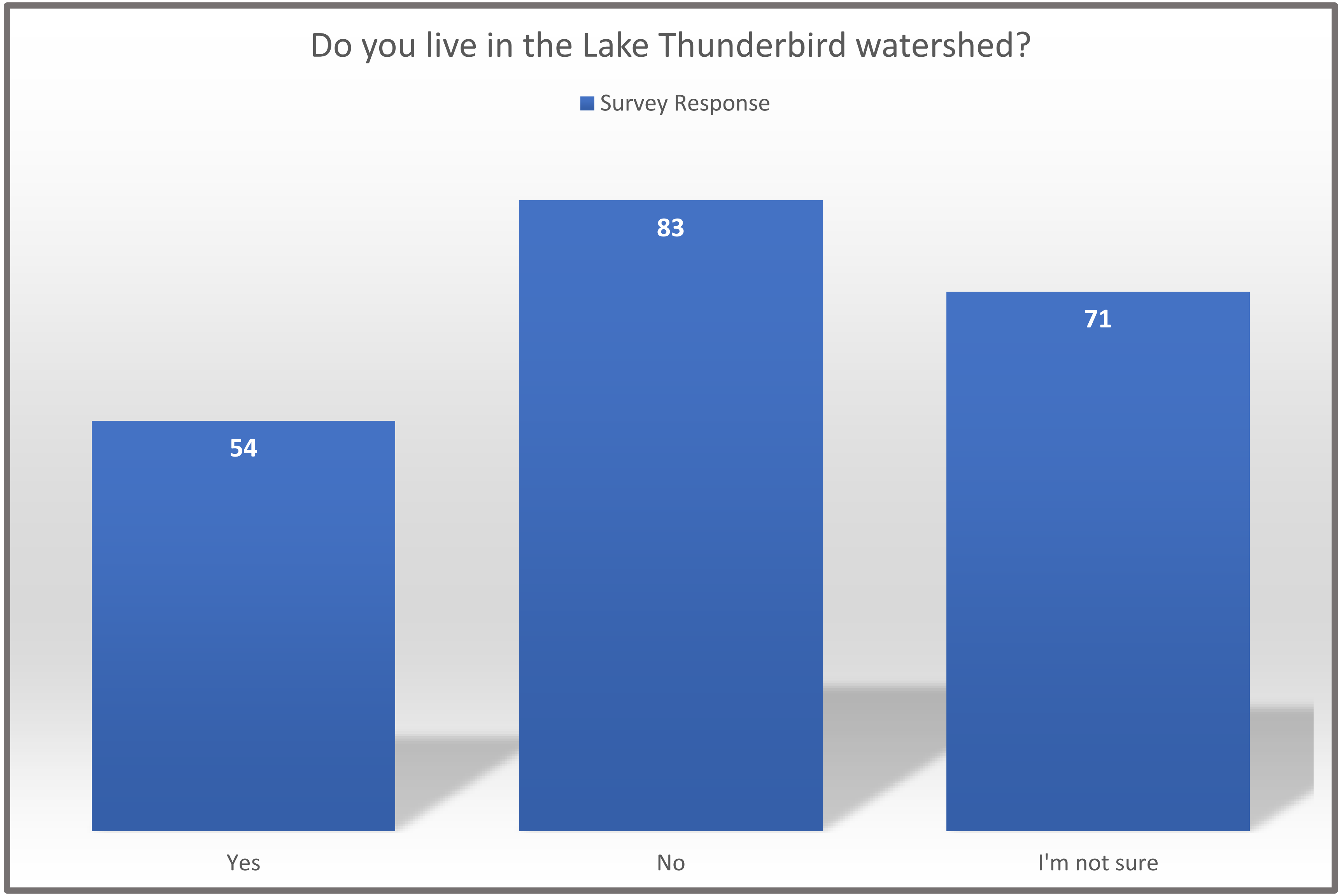
LTWA GENERAL SURVEY RESULTS

Question 3



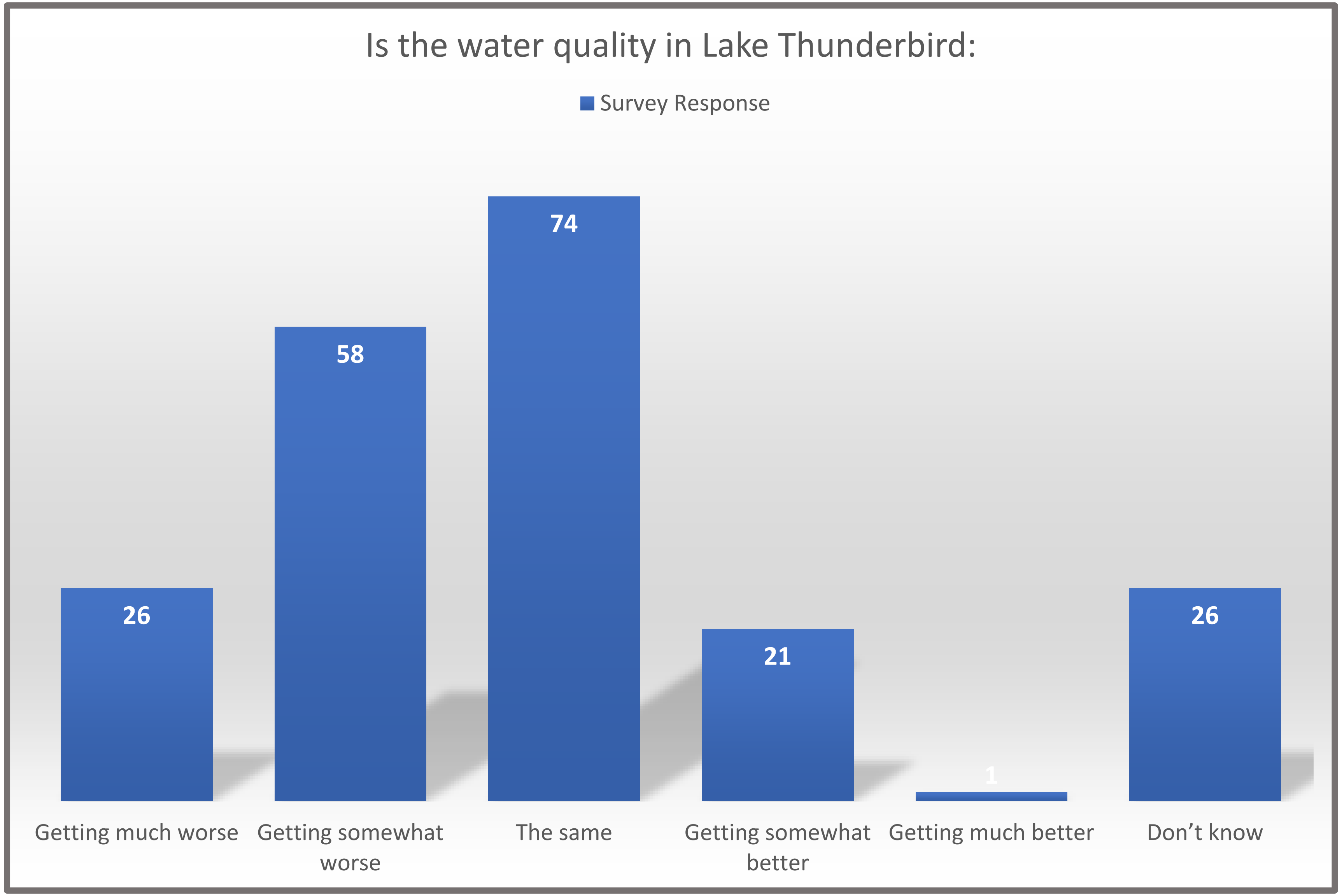
LTWA GENERAL SURVEY RESULTS

Question 4



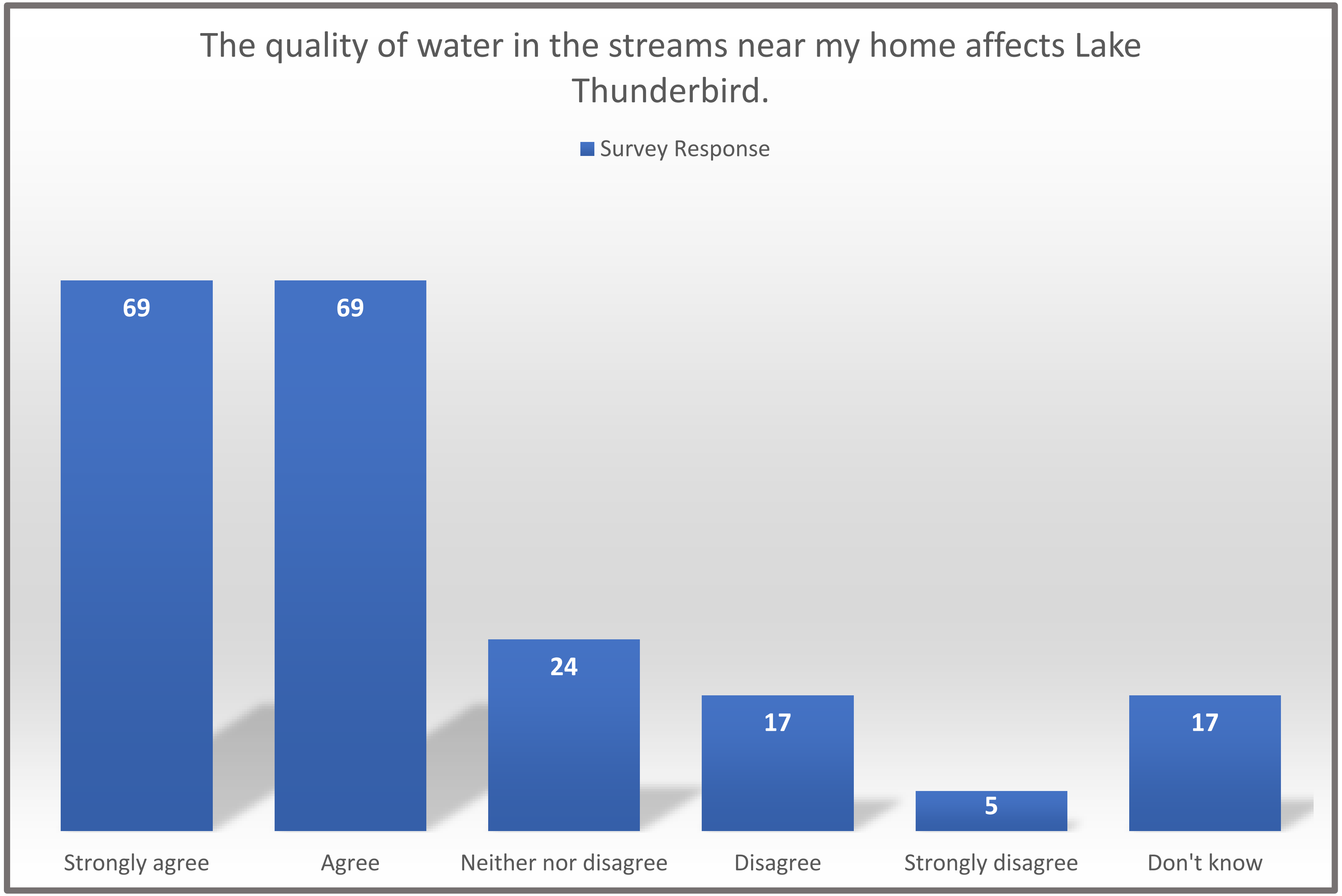
LTWA GENERAL SURVEY RESULTS

Question 5



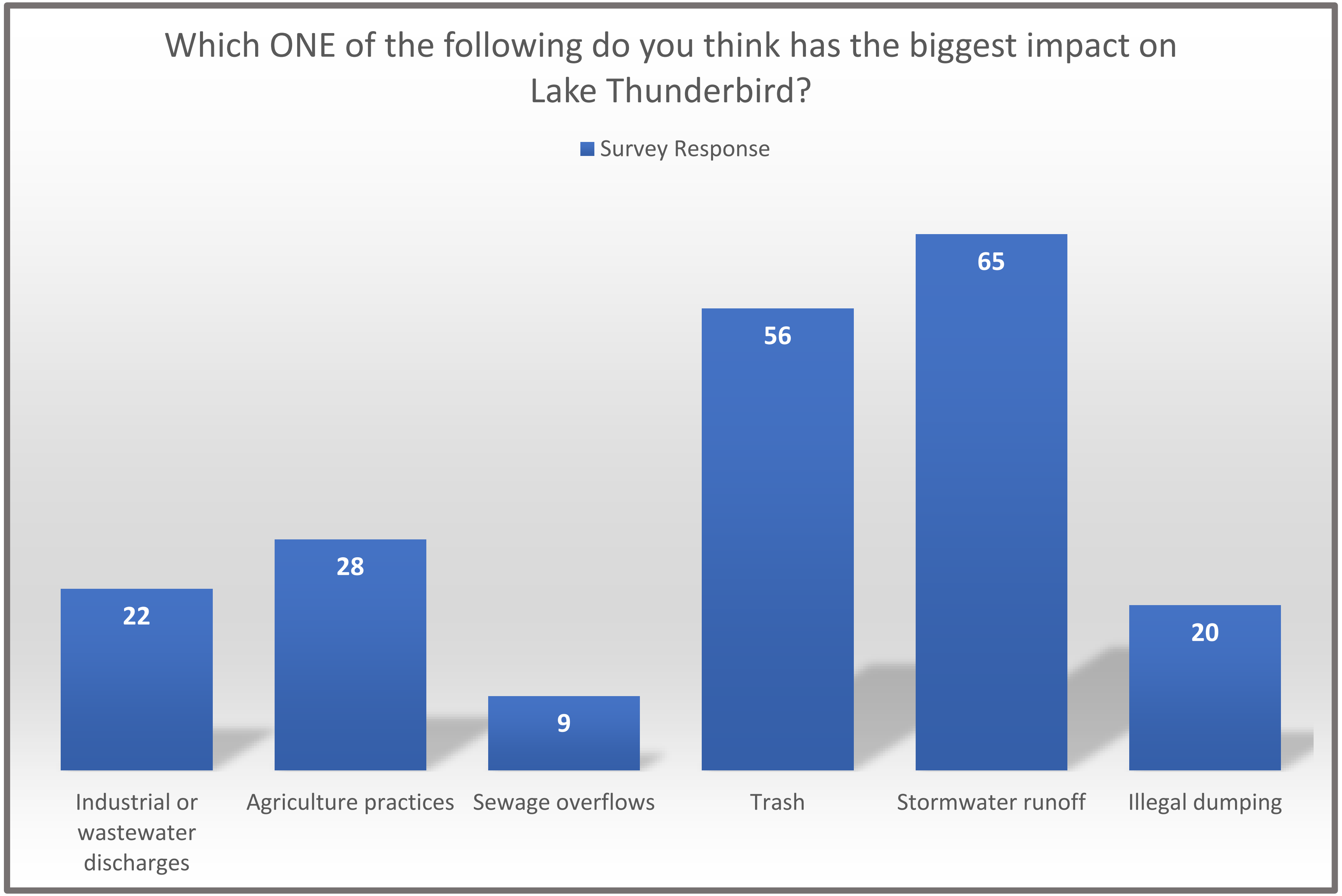
LTWA GENERAL SURVEY RESULTS

Question 6



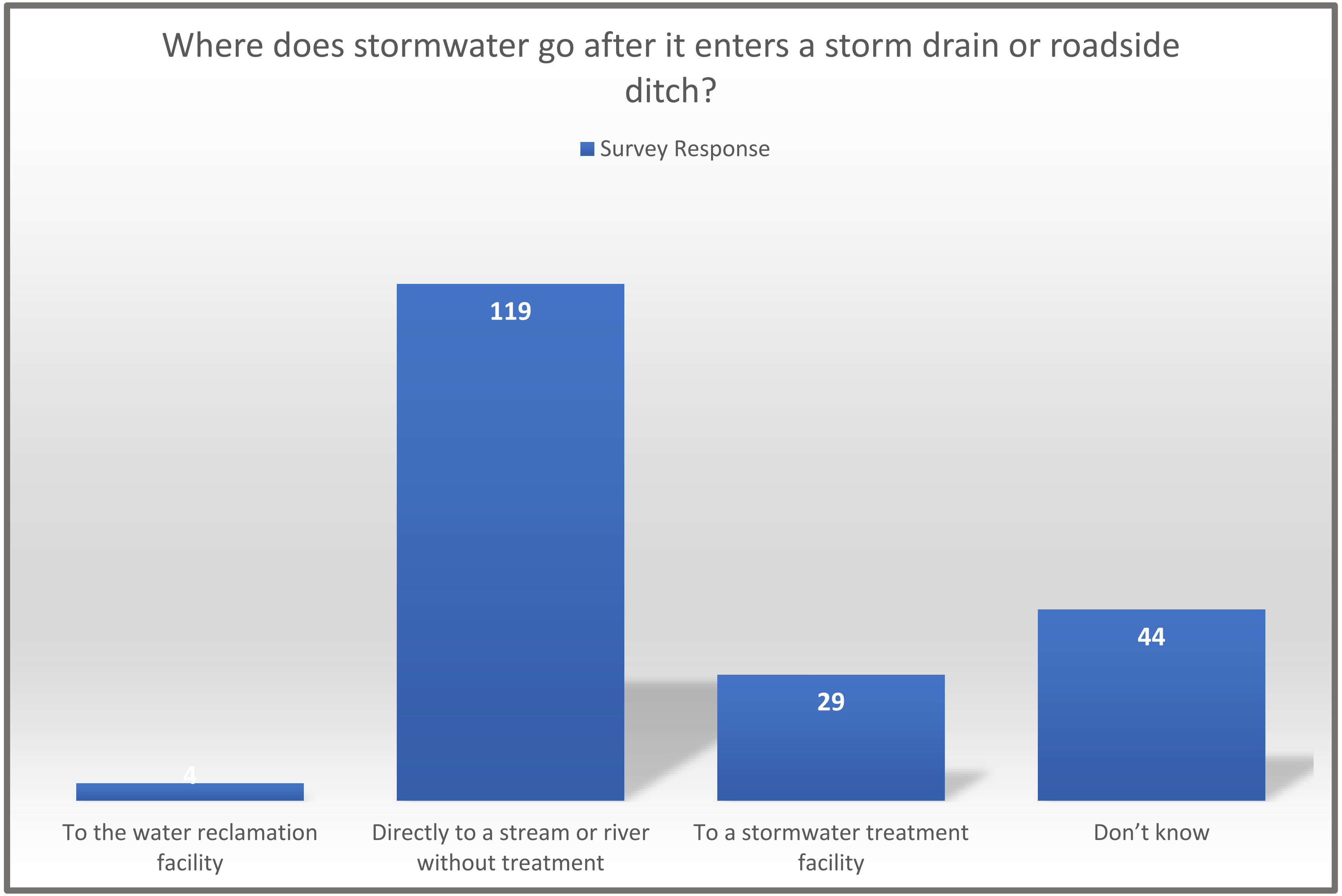
LTWA GENERAL SURVEY RESULTS

Question 7



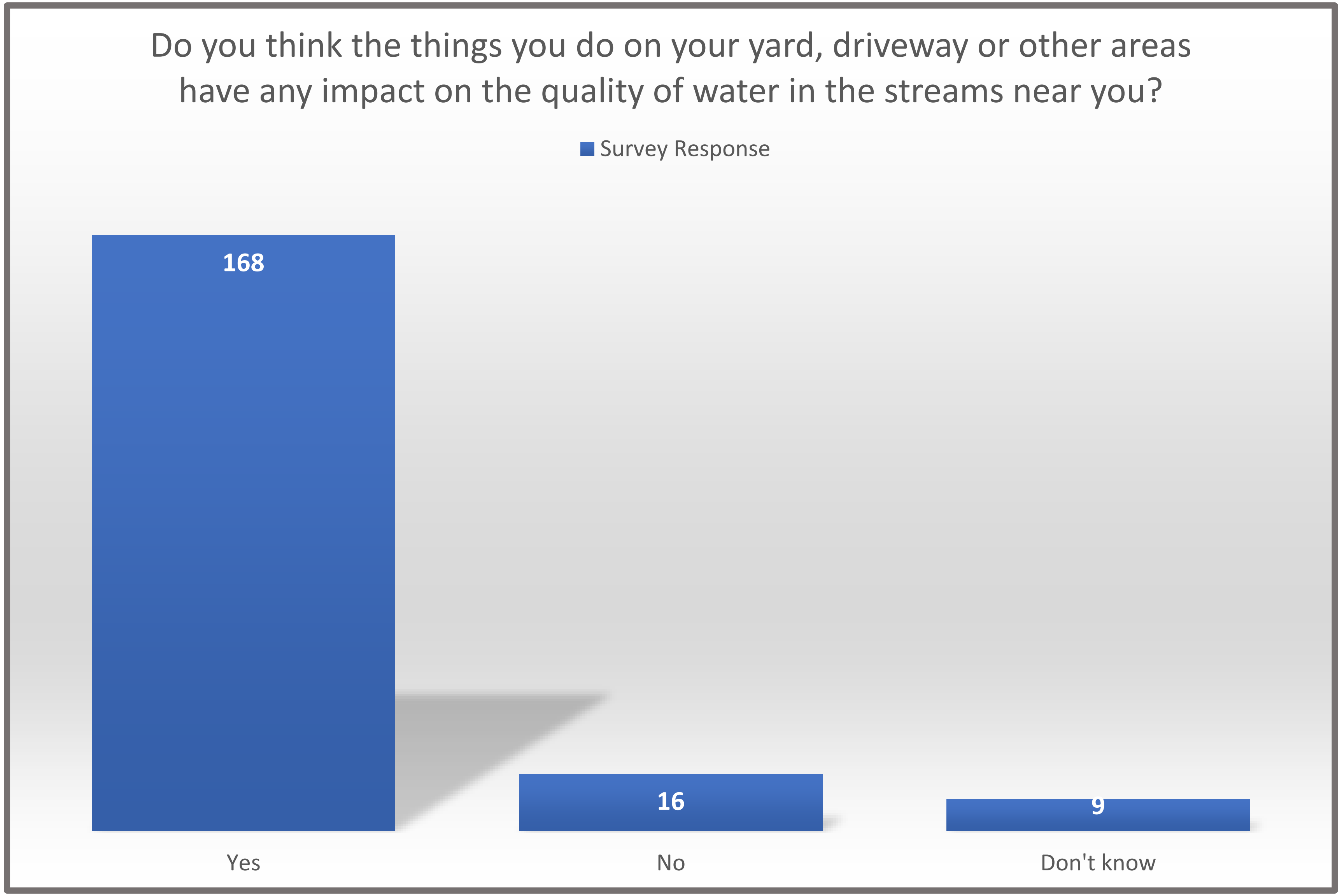
LTWA GENERAL SURVEY RESULTS

Question 8



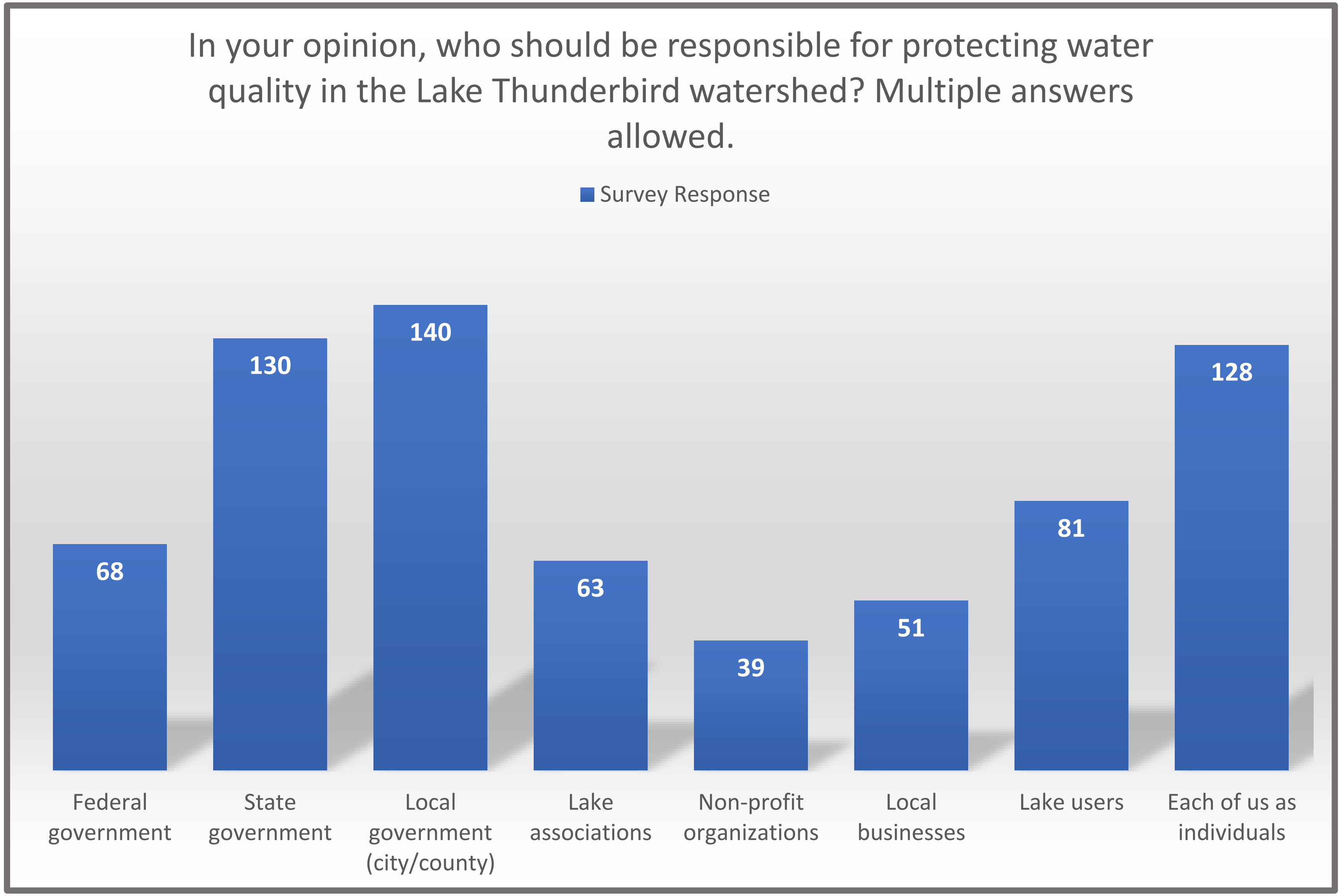
LTWA GENERAL SURVEY RESULTS

Question 9



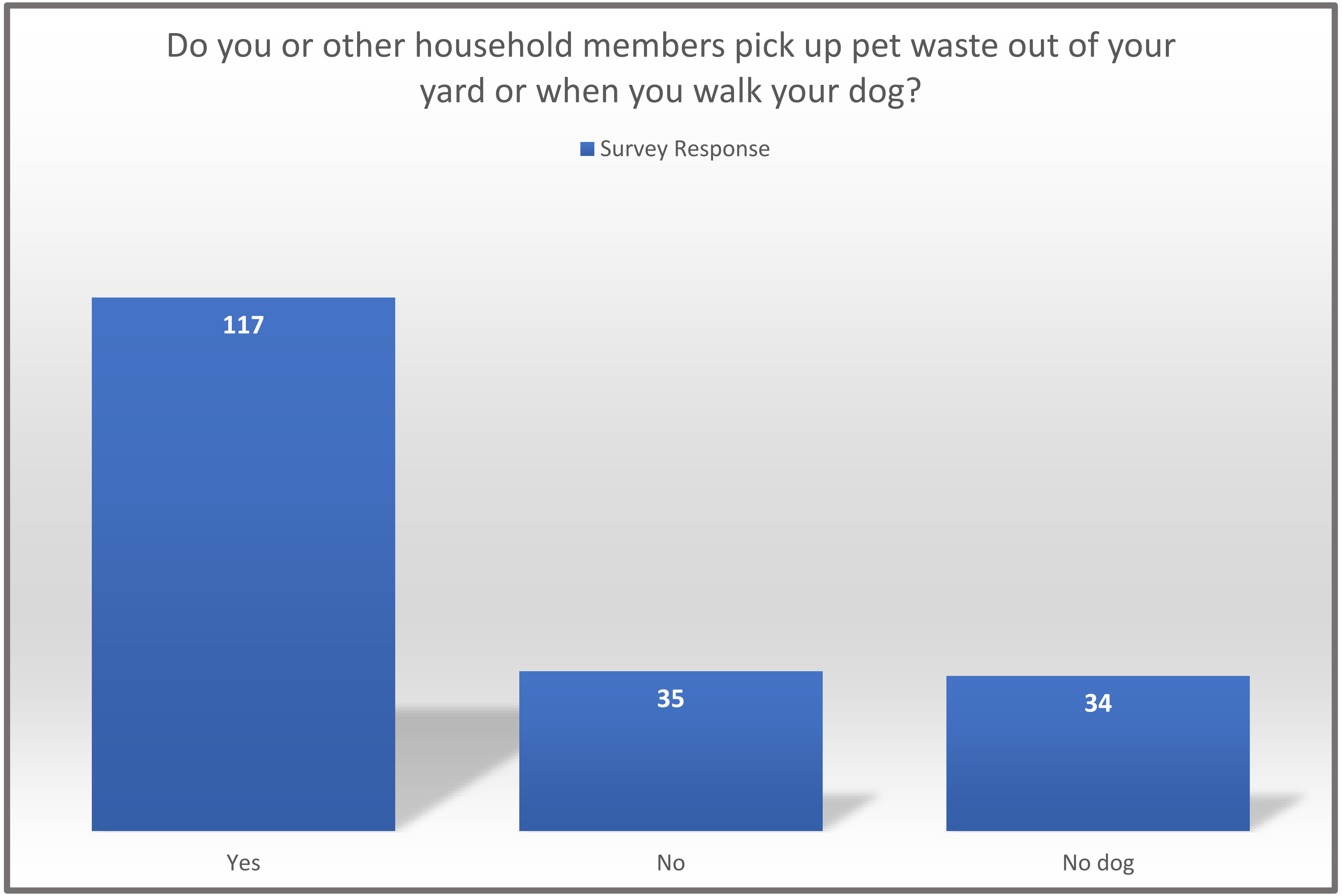
LTWA GENERAL SURVEY RESULTS

Question 10



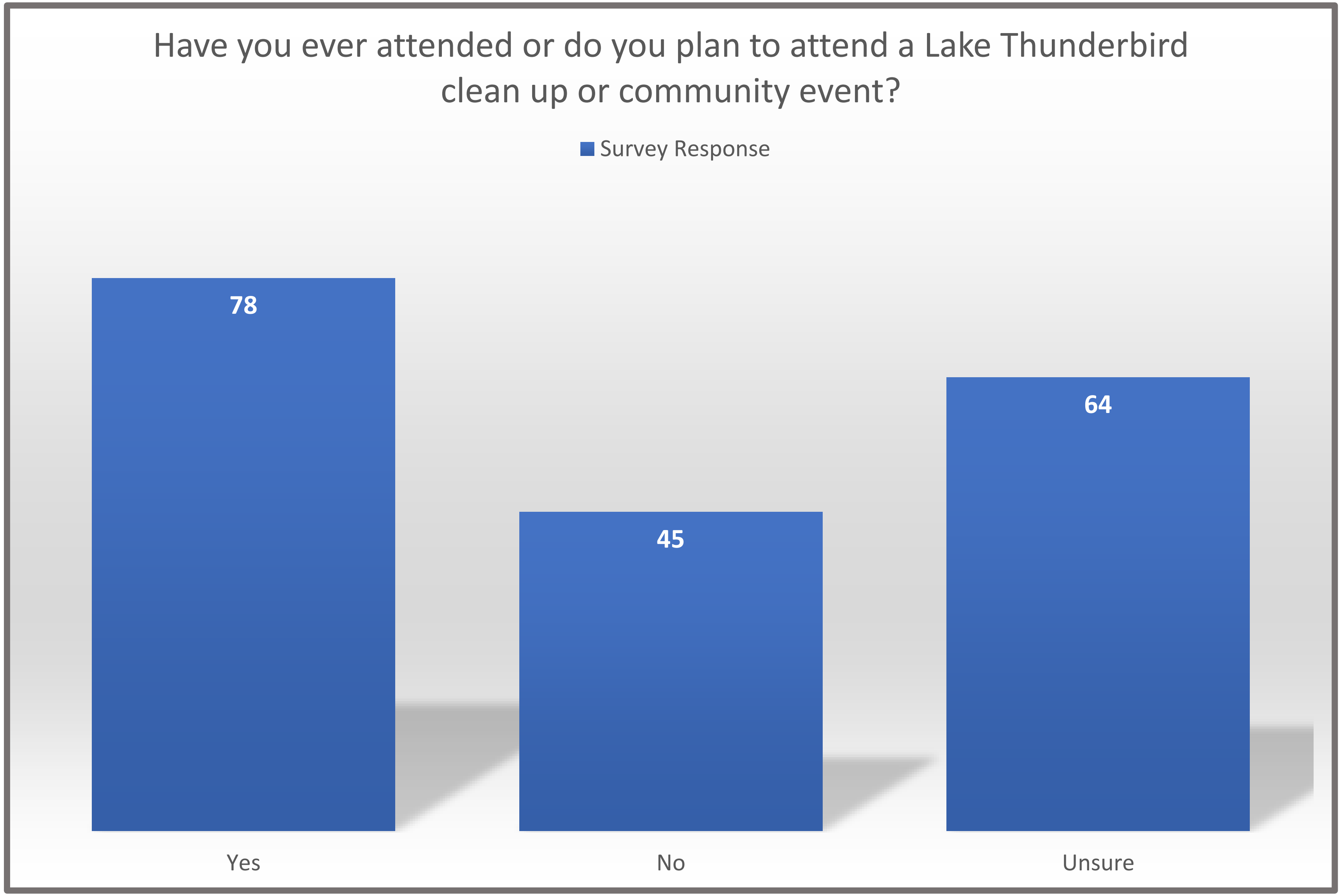
LTWA GENERAL SURVEY RESULTS

Question 11



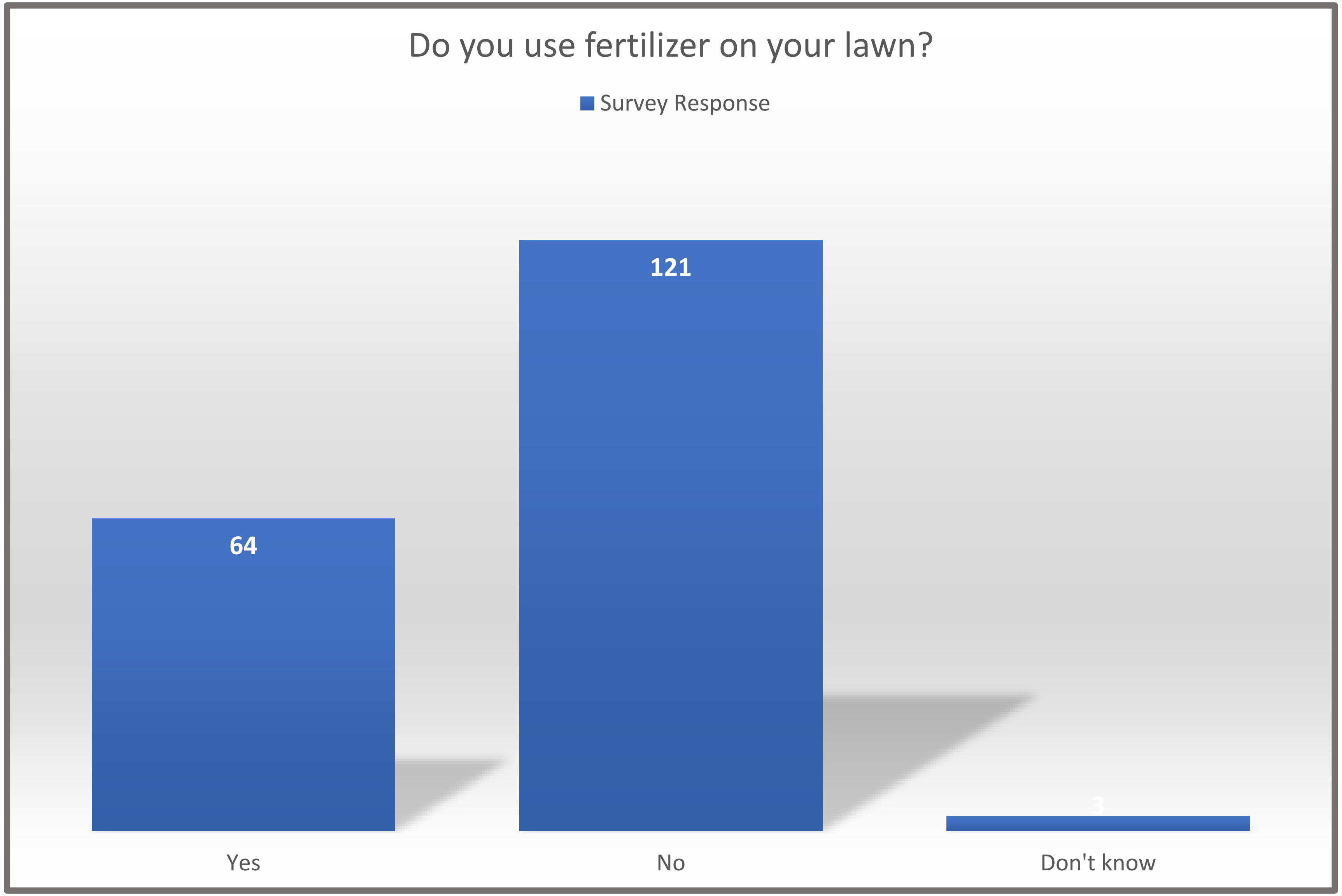
LTWA GENERAL SURVEY RESULTS

Question 12



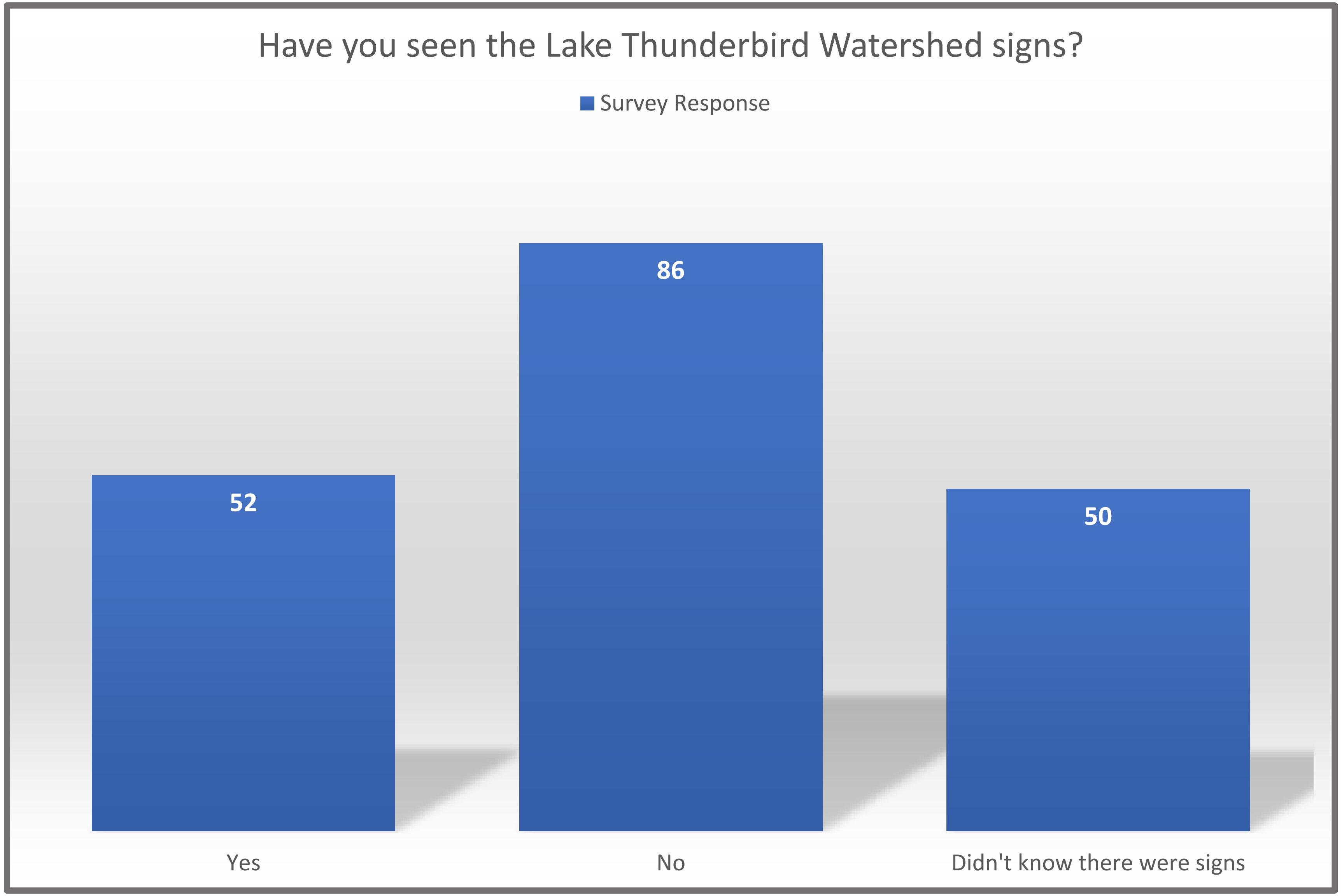
LTWA GENERAL SURVEY RESULTS

Question 13



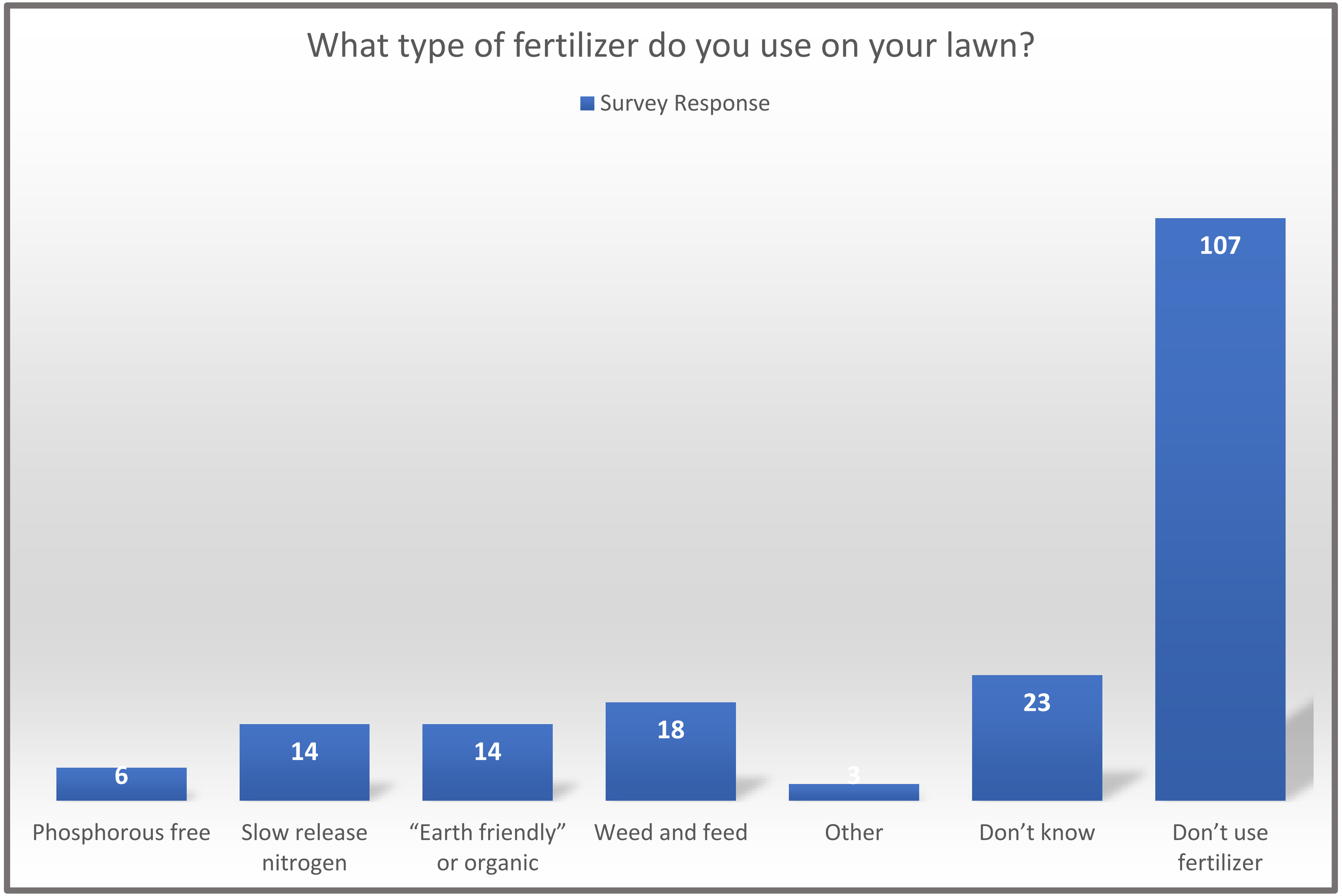
LTWA GENERAL SURVEY RESULTS

Question 14



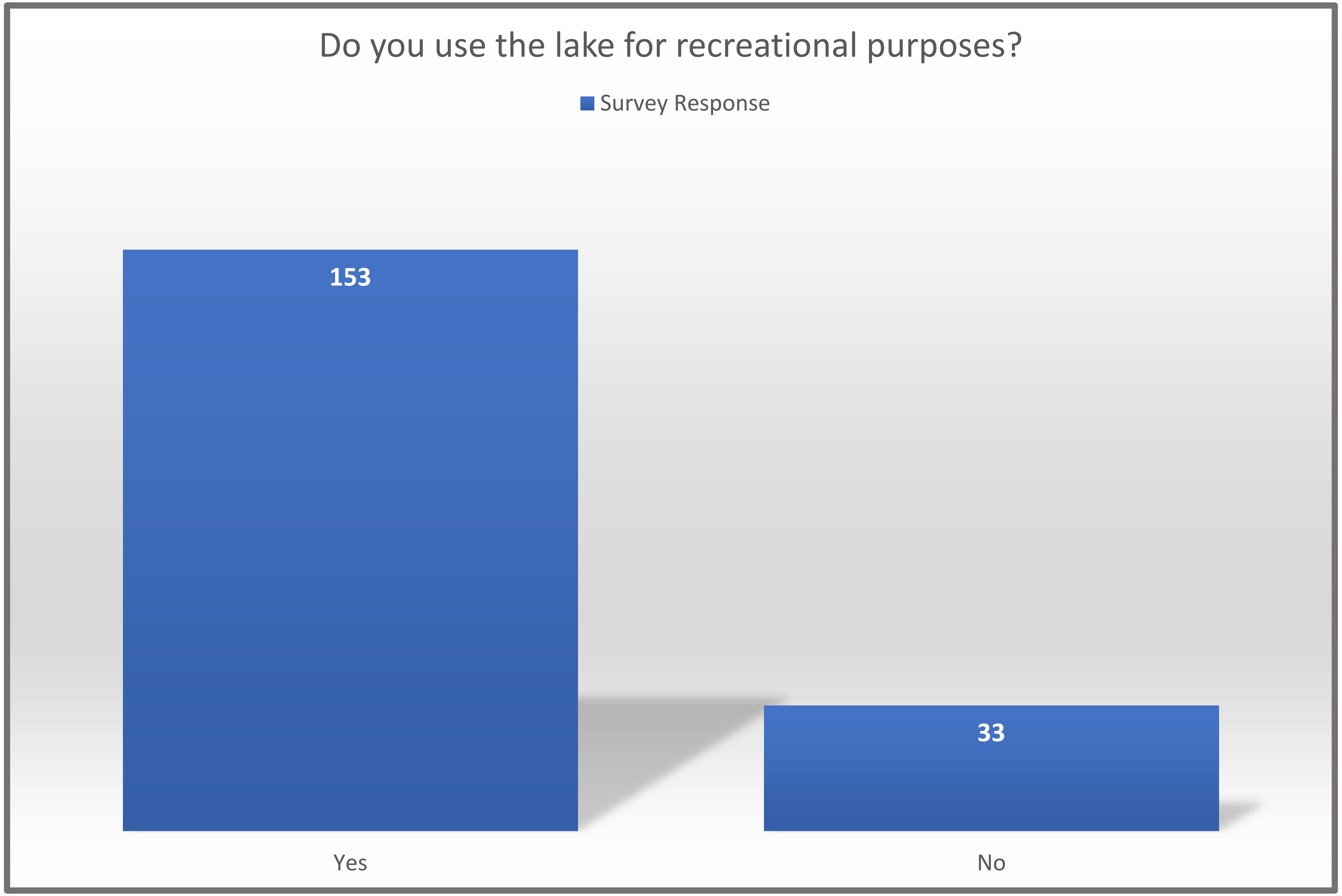
LTWA GENERAL SURVEY RESULTS

Question 15



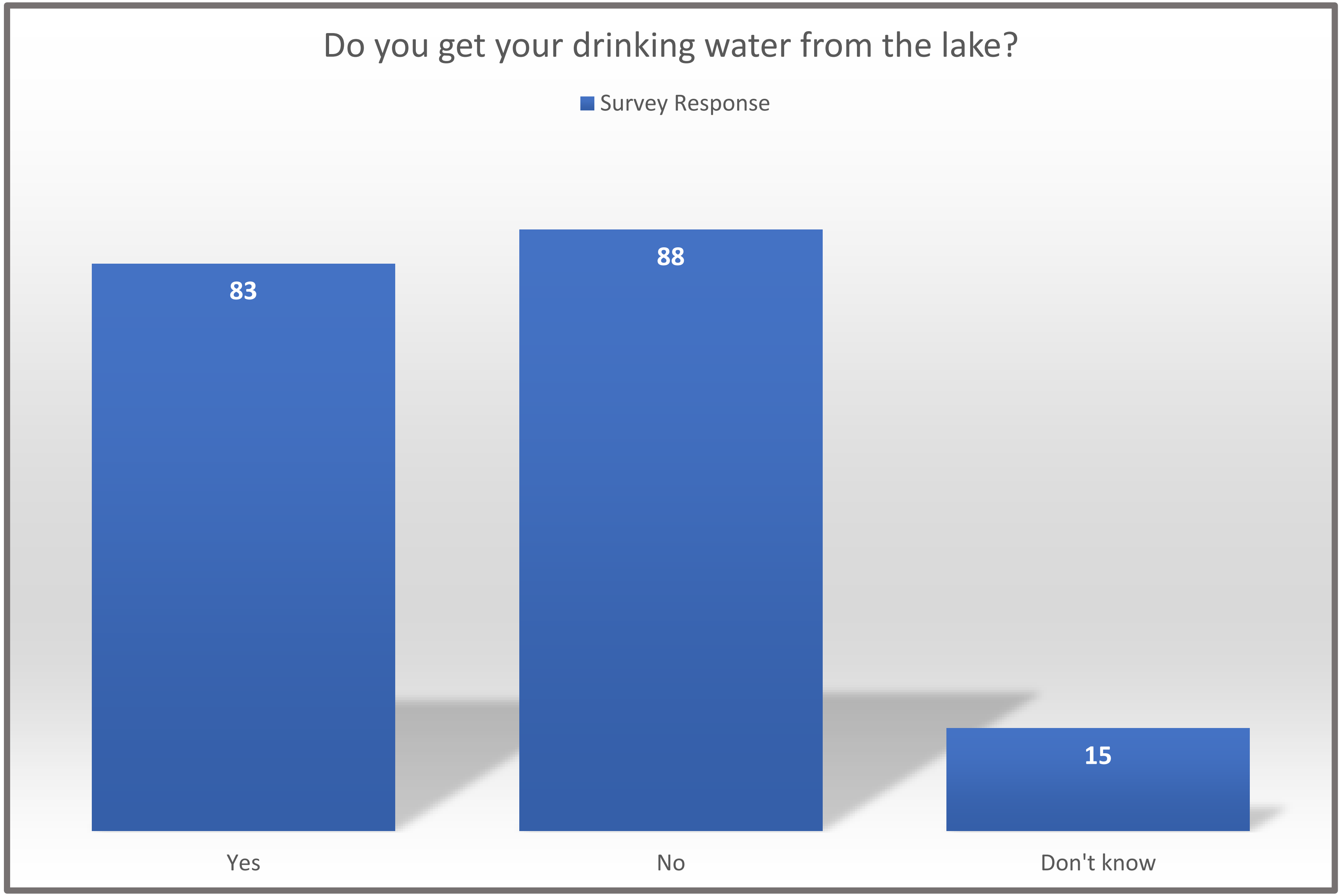
LTWA GENERAL SURVEY RESULTS

Question 16



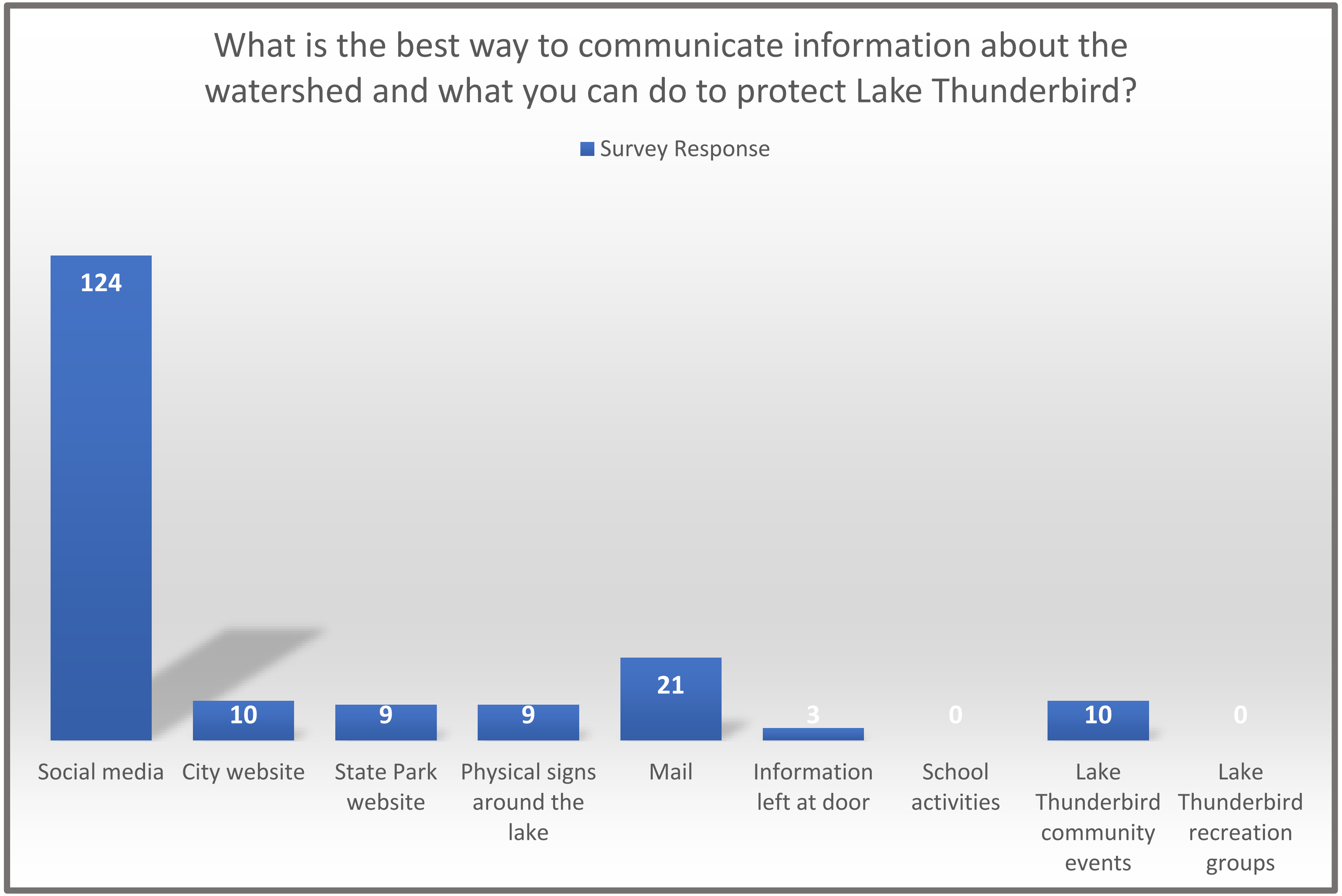
LTWA GENERAL SURVEY RESULTS

Question 17



LTWA GENERAL SURVEY RESULTS

Question 18



Appendix D

Useful Links

Oklahoma Boat Safety and Life Jacket Information—http://204.61.10.226/lp/lps.htm

Boating Safety Classes—https://www.boatus.org/oklahoma/

Thunderbird Sailing Club—https://thunderbirdsailingclub.org/

The Lake Thunderbird Watershed Alliance was formed in 2020 to work collaboratively with residents, communities and other stakeholders to protect the water quality of Lake Thunderbird. The LTWA also serves as a clearinghouse for Lake Thunderbird watershed-related implementation projects, research and outreach.

For more information about the LTWA visit the website at https://LTWA.org

Lake Thunderbird
Watershed Alliance, Inc.
PO Box ....
Norman, OK

Publication adapted from the Grand River Dam Authority's Guard the Grand program in cooperation with the Oklahoma Water Survey.

Understanding Boat and Dock Maintenance

Every weekend, hundreds of people load up their boats or personal watercrafts and head to Lake Thunderbird to enjoy some fun on the water. But, they may not stop to think about the impact they are having on the water quality of the lake. With so many people on the lake and its tributaries, recreational boating can leave pollutants and invasive species both in the water and on the land surrounding it.

How you maintain and care for your boat can reduce any impact you might have on the lake. Turn the page and learn how to properly maintain your boat or watercraft to help protect Lake Thunderbird.

LAKE THUNDERBIRD
WATERSHED ALLIANCE

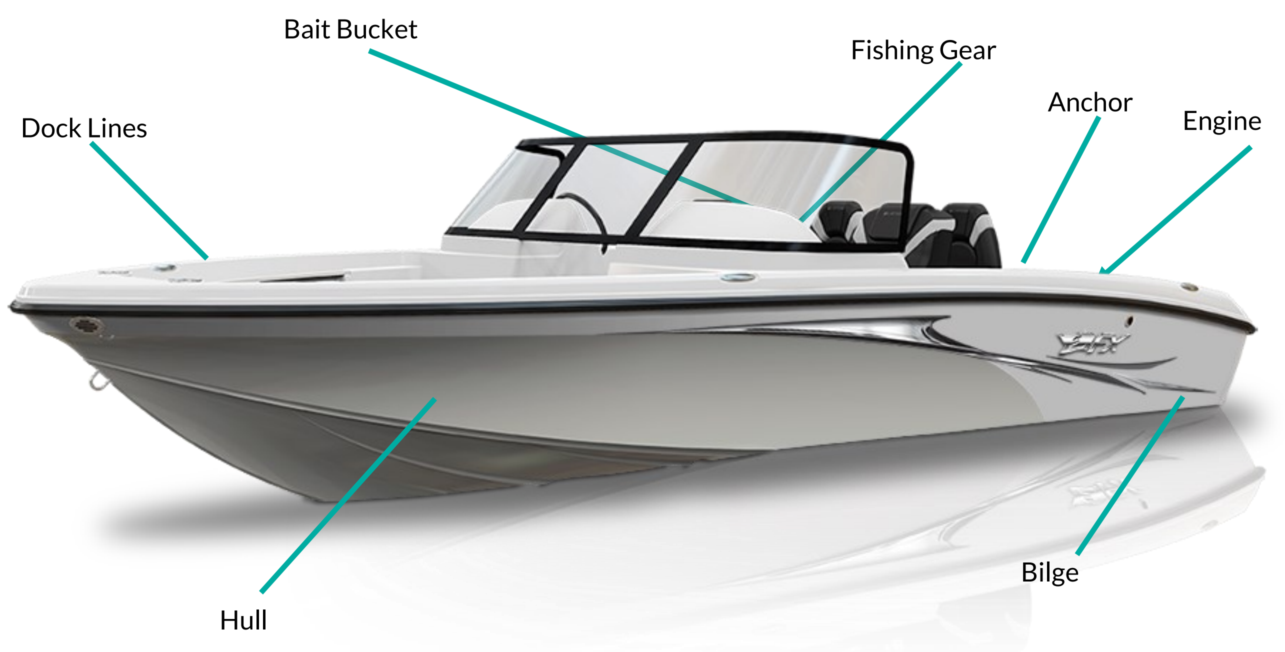
Simple Boat Maintenance Tips for Cleaner Water

Boat Cleaning

While we might not think that cleaning our boat would cause any problems, some of the cleaning materials used on boats can contain chemicals that are hazardous to humans and aquatic life. To help protect water quality and reduce the number of invasive plants and animals that might result from cleaning or rinsing your boat, think about doing these things:

1. Clean your boat away from bodies of water or locations that flow directly into a body of water.
2. Rely on water as your primary cleaning agent.
3. Find cleaning materials that are phosphate-free and biodegradeable while avoiding cleaning agents that use chlorinated solvents, petroleum distillates, or lye.

Cleaning your boat also prevents the spread of invasive species that can cause harm to your boat, ecosystems, and water infrastructure. Carefully inspect your boat for animal life and aquatic plants and remove them. Drain all water from the boat, hatches, bilge, and wells before leaving the launch site and make sure your boat is completely dry before entering another waterway.



Inspect everything that touched water!

Engine Maintenance

Regular engine maintenance helps avoid problems such as oil and gas leaks that can end up in the water. Follow these simple steps to avoid unnecessary pollution:

1. Pre-clean your engine with a wire brush to avoid using solvents.
2. Properly dispose of hazardous waste, such as oil filters, batteries, etc.
3. Use an identified non-toxic antifreeze, instead of the highly toxic blue-green ethylene glycol.
4. Do not completely fill fuel tanks.
5. Inspect fuel lines for deterioration and replace when necessary.
6. Avoid performing engine maintenance, such as changing oil, near or in water and do not dispose of any waste into water.
7. Follow your boat manufacturer's recommended maintenance regime.

Painting, Staining and Sanding

When painting and staining your boat always pull your boat out of the water before painting, staining, or sanding. The paint and other chemicals you might use can be harmful to the bugs and fish that live around your dock. Pick the proper type of paint based on if the portion of the boat needing paint - above or below water.

Parking and Storage

1. Park your boat or trailer over grass or other permeable areas to allow potential leaks to be filtered by the soil before it enters the water.
2. Before storing your boat for long periods of time, ensure that you have performed proper engine maintenance. This may include disconnecting your battery or removing drive belts.
3. Use a cover for your boat to protect it from the elements, particularly over exposed wood parts.

Appendix E

Grants and Cost-Share Programs				
Program Name	**Funding Source**	**Eligibility**	**Funding**	**Description**
Conservation Innovation Grants (CIG)/ Environmental Quality Incentives Program (EQIP)	USDA/NRCS	All non Federal entities (state or local governments, federally recognized American Indian Tribes, **non governmental organizations**) and individuals, but all projects must involve EQIP eligible producers.	Maximum award is set annually and is usually between $1M to $2M	"Conservation Innovation Grants (CIG) is a competitive program that supports the development of new tools, approaches, practices, and technologies to further natural resource conservation on private lands. Through creative problem solving and innovation, CIG partners work to address our nation's water quality, air quality, soil health and wildlife habitat challenges, all while improving agricultural operations" (from CIG website)
Regional Conservation Partnership Program (RCPP)	USDA/NRCS	The NRCS first chooses an eligible organization to be its partner on an RCPP project in an area. Agricultural producers wanting to participate in conservation activities can then apply directly to NRCS.	Two funding pools (Critical Conservation Areas and the State/Multistate) with $300M available annually	"Through RCPP, NRCS seeks to co-invest with partners to implement projects that demonstrate innovative solutions to conservation challenges and provide measurable improvements and outcomes tied to the resource concerns they seek to address" (from RCPP website)
Agricultural Conservation Easement Program (ACEP) / Wetlands Reserve Easements	USDA/NRCS	Agricultural Land Easement: landowners, land trusts and other entities with cropland, rangeland, grassland, pastureland and nonindustrial private forest land Wetland Reserve Easement: private landowners and Indian tribes	Under the Agricultural Land Easement component, NRCS may contribute up to 50 % of the fair market value of the agricultural land easement. For Wetland Reserve Easements NRCS pays between 50 to 100 % of easement value for purchasing the easement and between 50 to 75 %t of restoration costs depending on term length and type	"The Agricultural Conservation Easement Program (ACEP) helps landowners, land trusts, and other entities protect, restore, and enhance wetlands, grasslands, and working farms and ranches through conservation easements" (from ACEP website)
Conservation Stewardship Program (CSP)	USDA/NRCS	Individuals, legal entities, joint operations or Indian Tribes (Private agricultural lands, agricultural Indian lands, nonindustrial private forest land, farmstead, associated agricultural lands and public land that is under the control of the applicant and part of their operation. There is no minimum acreage requirement. All land must be in compliance with USDA highly erodible land and wetland conservation provisions to be eligible for CSP)	NRCS will help design a custom CSP plan	"Our Conservation Stewardship Program (CSP) helps you build on your existing conservation efforts while strengthening your operation" (from CSP website)
Working Lands for Wildlife (WLFW) Improving Working Lands for Monarch Butterflies	USDA/NRCS	Farmers, ranchers and forest landowners	Funding comes from The Environmental Quality Incentives Program, Conservation Stewardship Program, and Agricultural Conservation Easement Program	"Through the Farm Bill, NRCS provides technical and financial assistance to participants who voluntarily make improvements to their working lands while the US Fish and Wildlife Service (FWS) provides participants with regulatory predictability for the Endangered Species Act (ESA). This innovative approach empowers landowners with a means to make on-the-ground improvements and provides peace of mind that no matter the legal status of a species, they can keep their working lands working" (from WLFW website)
Conservation Reserve Program (CRP) / Clean Lakes, Estuaries and Rivers (CLEAR)	USDA/Farm Service Agency (FSA)	A producer must have owned or operated the land for at least 12 months prior to submitting the offer for continuous or 12 months before the close of general or grasslands signup	In return for establishing long-term, resource- conserving covers, FSA provides annual rental payments to participants. FSA bases rental rates on the relative productivity of the soils within each county and the average cash rent using data provided by the National Agricultural Statistics Service (NASS)	"The Clean Lakes, Estuaries and Rivers (CLEAR) Initiative of CRP prioritizes water quality practices on the land that, if enrolled, will help reduce sediment loadings, nutrient loadings, and harmful algal blooms. The Conservation Reserve Program (CRP) provides farmers and landowners with different signup types, practices and initiatives like this to achieve many farming and conservation goals" (from CLER website)
Conservation Reserve Program (CRP) / State Acres for Wildlife Enhancement (SAFE) Initiative	USDA/Farm Service Agency (FSA)	Land must be in a SAFE project area and meet basic CRP eligibility requirements. Eligible land is cropland that was planted or considered planted to an agricultural commodity during four of the six years from 1996 to 2001. The land must be physically and legally capable of being planted in a normal manner to an agricultural commodity.	In return for establishing long-term, resource- conserving covers, FSA provides annual rental payments to participants. FSA bases rental rates on the relative productivity of the soils within each county and the average cash rent using data provided by the National Agricultural Statistics Service (NASS)	"USDA has approved SAFE proposals to address state and regional high-priority wildlife objectives. SAFE practices provide the flexibility to meet the specific needs of high-value wildlife species in a participating state or region. Conservation practices currently offered under CRP are fine-tuned through SAFE to improve, connect or create higher-quality habitat to promote healthier ecosystems in areas identified as essential to effective management of high-priority species" (SAFE website)

Section 319 Nonpoint Source Management Program Grants	US EPA	Clean Water Act Section 319(h) funds are provided only to designated state and tribal agencies to implement their approved nonpoint source management programs	Section 319(h) funding decisions are made by the states. States submit their proposed funding plans to EPA. If a state's funding plan is consistent with grant eligibility requirements and procedures, EPA then awards the funds to the state.	"The 1987 amendments to the Clean Water Act (CWA) established the Section 319 Nonpoint Source Management Program Section 319 addresses the need for greater federal leadership to help focus state and local nonpoint source efforts. Under Section 319, states, territories and tribes receive grant money that supports a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects" (319 Grant Program website)
Environmental Education Grants	US EPA	Local education agency, state education or environmental agency, college or university, **non profit organization**, noncommercial educational broadcasting entity, tribal education agency	Since 1992, EPA has distributed between $2 and $3.5 million in grant funding per year, supporting more than 3,800 grants.	"Under the Environmental Education Grants Program, EPA seeks grant applications from eligible applicants to support environmental education projects that promote environmental awareness and stewardship and help provide people with the skills to take responsible actions to protect the environment. This grant program provides financial support for projects that design, demonstrate, and/or disseminate environmental education practices, methods, or techniques" (EE Grant website)
Healthy Watersheds Consortium Grants (HWCG)	US EPA	Examples include development of state, interstate, or tribal healthy watersheds strategies or plans that employ a systems-based, **integrated approach to protection**; environmental flows assessments; and **public outreach and education** on the importance of protecting healthy watersheds.	The total funding of the grant with the required match is $5 million ($3.75M of federal funding, plus 25% match). The number of subawards under this grant depends upon any additional leveraged funds, increasing the total funding beyond $5 million, and the range of funding in proposed subawards. Funding for each sub-award may range from $50,000 to $150,000 per project. .	"Healthy watersheds protection is defined broadly as actions that preserve, enhance or improve aquatic ecosystems and supporting natural landscape and watershed processes such as hydrology in largely healthy watersheds. The grant is intended to support local protection and/or enhancement projects in healthy or primarily healthy watersheds that can be sustained into the future. Local projects must represent strategic priorities from an interstate, state, tribal, basin-scale, or regional-scale plan or strategy intended to protect healthy watersheds, or from some other prioritization scheme based on a healthy watersheds assessment." (HWCG website)
Pollution Prevention (P2) Grant Program	US EPA	State governments, colleges and universities (recognized as instrumentalities of the state), federally-recognized tribes and intertribal consortia	In September 2020, EPA selected 42 organizations to receive $9.3 million in funding for FY2020-FY2021 P2 grants. Award amounts range from $40K to $500K.	The purpose of the grant is to 1. "Make specific technical assistance available to businesses seeking information about source reduction opportunities, including funding for experts to provide onsite technical advice to businesses seeking assistance and to assist in the development of source reduction plans. 2. Target assistance to businesses for whom lack of information is an impediment to source reduction. 3. Provide training in source reduction techniques. Such training may be provided through local engineering schools or any other appropriate means" (from the Pollution Prevention Act of 1990 Section 13104)
Pollution Prevention (P2) Grant Program / Source Reduction Assistance Grant	US EPA	The states, the District of Columbia, the United States Virgin Islands, the Commonwealth of Puerto Rico, any territory or possession of the United States, local governments, city or township governments, independent school district governments, state-controlled institutions of higher education, non-profit organizations (other than institutions of higher education), private institutions of higher education, community-based grassroots organizations, and federally-recognized tribes and intertribal consortia	Award amounts range from $20K to $200K.	The purpose of these grants is similar to the P2 Grant Program but eligibility is broader
Urban Waters Small Grants	US EPA	States, local governments, Indian Tribes, public and private universities and colleges, **public or private nonprofit institutions/organizations**, intertribal consortia, and interstate agencies	The grants are competed and awarded every two years, with individual award amounts of up to $60,000.	"The Urban Waters program strives to make a visible difference by working with a diversity of partners to support community driven solutions that connect the intrinsic value of urban waters with improving the livability and economic health of the community" (Urban Waters Small Grants website)
Office of Land and Emergency Management (OLEM) Grants and Funding	US EPA	These grants are usually related to Waste Management or Brownfield Cleanups but could be a good reference in the future. They are updated each year		
The Land and Water Conservation Fund - The State Side	National Park Service (NPS)	State and local governments	Annual apportionment to Oklahoma is approximately $1.4M based on FY 2016	"The State Side of the LWCF provides matching grants to States and local governments for the acquisition and development of public outdoor recreation areas and facilities" (from NPS website)

Tribal Wildlife Grants	U.S Fish and Wildlife Service (USFWS)	Federally recognized Tribal governments	$10K minimum to $200K maximum award	"Provide a competitive funding opportunity for Federally recognized Tribal governments to develop and implement programs for the benefit of wildlife and their habitat, including species of Native American cultural or traditional importance and species that are not hunted or fished" (from Tribal Wildlife Grants website)
WaterSMART Cooperative Watershed Management Program Grants/ Implementation of Watershed Management Projects	Bureau of Reclamation	Existing watershed groups like the LTWA	Up to $100K per project over a two year period. Applicants must contribute at least 50% of total project costs	"In 2017, Reclamation started to provide cost-shared financial assistance to watershed groups to implement watershed management projects (Phase II). These on-the-ground projects, collaboratively developed by members of a watershed group, address critical water supply needs and water quality concerns, helping water users meet competing demands and avoid conflicts over water" (from WaterSmart website)
Five-Star and Urban Waters Restoration Grant Program	National Fish and Wildlife Foundation (NFWF)	**Non-profit 501(c) organizations**, state government agencies, local governments, municipal governments, Indian tribes and educational institutions	Awards range from $20,000 to $50,000 with an average size of $35,000 and 40-50 grants awarded per year	"The Five Star and Urban Waters Restoration grant program seeks to develop community capacity to sustain local natural resources for future generations by providing modest financial assistance to diverse local partnerships focused on improving water quality, watersheds and the species and habitats they support. Projects include a variety of ecological improvements along with targeted community outreach, education and stewardship. Ecological improvements may include one or more of the following: wetland, riparian, forest and coastal habitat restoration; wildlife conservation, community tree canopy enhancement, water quality monitoring and green infrastructure best management practices for managing run-off. " (from NFWF website)
National Environmental Education Foundation		None of the current funding opportunities are specific to Oklahoma or the LTWA's goals, but available grants are updated frequently		
Conservation Cost-Share Program	OCC (Area 2 District)	Eligibility to apply is based on Land and Production requirements set by your local conservation district	Our Conservation Programs Division oversees the program and allocates funds to conservation districts based on appropriations from the Oklahoma Legislature	"Our Conservation Programs Division oversees the program and allocates funds to conservation districts based on appropriations from the Oklahoma Legislature. The conservation districts then administer the program to meet their local needs by selecting conservation practices to offer to landowners, establishing cost-share rates, overseeing the landowner application process and assisting the landowners throughout their involvement with the program... The USDA Natural Resources Conservation Service (NRCS) also provides free technical assistance to landowners involved in the program as they implement their conservation practices" (from OCC Cost share program website)