EXAMINING THE EFFECTS OF URBANIZATION PROXIMAL TO MUNICIPAL WATER SOURCES: A CASE STUDY OF LAKE THUNDERBIRD OKLAHOMA

ANNA RAE HALL

ABSTRACT

In light of current debate over turnpike expansion, this study strives to discover the connection between urbanization and pollution of Lake Thunderbird and further the overall understanding of how proximal populations affect public surface water sources. It has become increasingly important to preserve and protect existing municipal water reservoirs located near, and presently serving, thriving metropolitan areas as there is a finite amount of accessible, viable, fresh water available.

Lake Thunderbird is an excellent source for research as it reflects the state of the reservoirs nationally. Particularly, the characteristics of the water body are relational to others due to proximal urbanization, municipal water source reliance, and continued elevations of contaminants.

This study was completed via a case study application of available secondary data regarding Lake Thunderbird and the Lake Thunderbird Watershed. The study's hypothesis is, *Lake Thunderbird is prone to pollution via soil erosion from urbanization.* The findings conclude that the declining quality of Lake Thunderbird's water is caused by multifarious, simultaneous factors in a multiphase process initiated and perpetuated by proximal urbanization. Improv-

ing the quality of the water isn't as simple as identifying a specific cause or stress, but a holistic approach to managing urbanization, restricting impervious surfaces, mitigating soil erosion, addressing sedimentation, and decelerating subsequent pollution within a watershed. The long- term implications of creating large, paved surfaces such as a turnpike proximal to Lake Thunderbird are contradictory to other efforts of sustainability. As applied to what effects urbanization may have on municipal surface water supplies, it compounds the problem and creates additional environmental strains. It is prudent, practical, and possible to thoughtfully plan the placement of impervious surfaces.

INTRODUCTION

In 1928 H.W. Streeter, a Sanitary Engineer for The United States Public Health Service, wrote "Present indications, moreover, point to the likelihood that an increasing amount of dependence must be placed, in future years, on surface sources of water supply for public use...to supply increasing populations… pollution of… many surface supplies has increased with such rapidity that questions have arisen to the possibility of a failure of existing safeguards, both natural and artificial, to afford adequate degree of protection to such supplies" (Streeter 1928, p. 1499).

Urbanization is a pernicious force. By the late 19th century, the United States ever- increasing density of industry, housing, and transportation followed by subsequent air, waste, noise, and water pollution established American resources as refuse (Merchant, 2007). History transpired with the unbridled consumption and degradation of the nation. This land use and resource consumption trend in American history continued unabated. By 1972 the federal government created and passed the Federal Water Pollution Control Act, amended to become the Clean Water Act (CWA) of 1977. The document institutes that we must "restore and maintain the chemical, physical, and biological integrity of the Nation's

waters" (Federal Water Pollution Control Act, 2002, p.3). According to the Oklahoma Long Range Transportation growth plan the goal of the CWA, working in conjunction with state agencies, is to regulate discharges of pollutants from both point and non-point sources and "achieve and maintain a high standard of water quality in surface and ground waters" (Oklahoma Department of Transportation, 2010, p. 4-1). It is imperative that the CWA and subsequent municipal freshwater resources protection policies be maintained and soundly regulated. This is paramount as urbanization continues to apply pressure upon the limited resources available.

A considerable amount of freshwater municipal sources is drawn from surface water which is defined as any water that is on Earth's surface comprised of both "fresh and salt water such as but not limited to the oceans, streams, lakes, rivers, wetlands, creeks and reservoirs" (National Geographic Society, 2022, p. 1). Surface water is highly impacted by man-made activities such as urbanization. According to the Environmental Protection Agency (EPA), Urbanization is the "concentration of human populations into discrete areas. This concentration leads to the transformation of land for residential, commercial, industrial, and transportation purposes. It can include densely populated centers, as well as their adjacent peri-urban or suburban fringes" (2022, n.p.). Conspicuously, man-made activities such as urbanization have direct negative impacts on freshwater bodies. Specifically, freshwater bodies suffer from severe pollution due to the encroachment of urban development on rural lands.

Freshwater pollution levels of municipal sources must be considered future capital as they are finite, and many are approaching the natural end of their life cycle. Some states have a pronounced number of reservoirs. It is not clear whether this is prudent water management or mere luck. However, it is inferred this insulates them from the pressures of an expanding population that is American urbanization.

Lake Thunderbird, located in Central Oklahoma, serves as a prime example of the interactions between urbanization and surface water. Originally created for flood control, the reservoir has become vital to the residents of Norman as their main source of municipal water. The impounded water also supplements water supplies for four other metropolitan populations. Worth noting is that Lake Thunderbird additionally serves as a State Park, is a designated Warm Water Aquatic Community, and is acknowledged as providing fish for human consumption (Enviroshield, 2021).

Regardless of several unavoidable factors, such as the propensity of local soils to be highly mobile, Lake Thunderbird continues to struggle to sustain clean, clear water. However, its main recorded issues today are nutrient overloading and sedimentation credited to anthropological activities such as population growth, urbanization, and impervious surfaces (Martin-Mikle et al., 2015).

This study strives to discover the connection between urbanization and pollution of Lake Thunderbird and further the overall understanding of how proximal populations affect surface water sources. Non-point pollution of waterbodies is a complex multiphase phenomenon that combines multiple natural variables simultaneously affected by various anthropogenetic co- occurring activities creating biological impairment of water bodies.

The research technique employed in this study was a case study analysis. This study will exclude differentiation between sedimentation, pollution, and siltation. Sedimentation is an ambiguous term. It includes siltation, sediment both organic and inorganic in nature, and all other manners of small-suspended pollutants; thus, the terminology is often interchangeable and is not delineated within this study.

The research's hypothesis is 1) Lake Thunderbird is prone to pollution via soil erosion from urbanization. This thesis contains six chapters including the introductory chapter, the literature review,

methodology, analysis, discussion and policy recommendation, and applications and conclusion.

LITERATURE REVIEW AND RESEARCH

LINEAR PROCESS OF WATER POLLUTION VIA URBANIZATION

It is important to understand that reservoirs are man-made catchments and part of greater systems known as watersheds. All water bodies have areas of land that drain or channel precipitation into them, these areas are known as watersheds. Watersheds can be very large, such as the Mississippi River Watershed which covers roughly one-third of the United States. That means that events, such as the growth of an urban area, or a new highway miles away from a water body can affect the water quality of a downstream lake or reservoir within the watershed.

There is a distinct correlation between static bodies of water and the anthropogenic activities within a watershed measurable in the quality of the water contained in a catchment. The process by which pollutants arrive in the catchment is a linear multi-staged process.

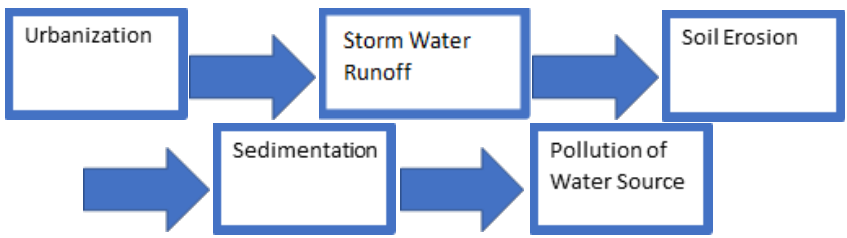


Figure 1: Linear Process of Pollution to Waterbodies via Urbanization

The cumulative effect of these linear processes of pollution to municipal water body sources is increased pollution. Sedimentation via urbanization increases cost and ultimately dictates the

mortality of the reservoir. The study clearly defines sedimentation, acknowledges its quantification (in relation to urbanization), and discusses its links to water quality as it relates to Lake Thunderbird in Norman, Oklahoma.

LAKE THUNDERBIRD: A CASE STUDY

Lake Thunderbird is a man-made 6, 070-acre reservoir located in Norman, Oklahoma (Longitude: -97° 13' 3.1 Latitude: 35° 13' 24.25) (USGS Water Data, 2023). It is in an area of Oklahoma known as Cross Timbers, a patchwork belt of low rolling hills comprised of pastureland, rangeland, and woodlands including some of the least disturbed forest land in theU.S. (Oklahoma Biological Survey, 2015). It is part of the Little River watershed and has a 256- square-mile watershed area (Water Quality Division, 2019).

The land surrounding Lake Thunderbird was previously known for flooding and was the subject of study by the Army Corps of Engineers, specifically in 1936 and 1947 (COMCD, 2023). In 1953 experts in the nearby municipalities of Norman, Moore, Del City, Midwest City, and Tinker Airforce Base, voiced concerns regarding population growth in the area and the eventuality that water supplies would cease being adequate by 1970 (COMCD, 2023). A report in 1954 led to a Plan Report in 1961; construction began on Norman Dam in 1962 (COMCD, 2023). The dam and subsequent Lake Thunderbird were completed in 1965 by the U.S. Bureau of Reclamation. Norman Dam measures 144 feet in height and sequesters 171, 400 acre-feet of water, owned by the Bureau of Reclamation, and operated by the local Central Oklahoma Master Conservancy District (COMCD, 2023). The dam henceforth has been the municipal water source for five municipalities with The City of Norman dependent on the reservoir for the majority of supplied water (COMCD, 2023).

Historically pollution of Lake Thunderbird has been chronic. Reports show that Lake Thunderbird was a little behind the criteria

for clean water (as set forth by the Clean Water Act of 1972) in 1983, and very far behind expectations set for 1985. As such the lake was listed as impaired and deemed a "Sensitive Water Supply" in 2002 and placed on a 303(d) list by the EPA consequently, the Oklahoma Department of Environmental Quality (OKDEQ) established Total Maximum Daily Load (TMDL) parameters in 2010 (OCC, 2008). However, rising contamination levels continued. In 2013 the lake's management came under scrutiny and serious management restructuring was mandated due to federal pressures. A five-year development plan to tackle the major contributors to Lake Thunderbird's woes was established. The major problems were designated as; pet waste, nitrogen, phosphorus, and suspended sediment from construction runoff (OWRB, 2009). By October 2016, the 5-year Plan was implemented (*History*, 2023). It is imperative to note that Lake Thunderbird receives all recharging water from rainfall, precipitation, and inflow from the tributaries, which includes all surface runoff in the watershed (OWRB, 2008).

METHODOLOGY

The value of the case study approach is that it allows for extensive examination of complex, multiphase subjects in a real-world application by use of an actual data set from a real place (Crowe et al., 2011). Furthermore, a case study approach is especially appropriate to provide an applicative understanding of complex interlaced occurrences and appropriate to attain a deep understanding of the sum of a case (Crowe et al., 2011).

This application is highly applicable to the exploratory facet of this study as Lake Thunderbird is an entity whereby applications (management of the resource) are examined, and results are presented regarding urbanization and its linkages to the pollution of the water body. This study was conducted via the collection whereby utilization of Google Scholar with keywords included but not limited to the terms "Lake Thunderbird," "urbanization,"

"stormwater," "runoff," "soil erosion," and "sedimentation"; reports (both historic and contemporary) submitted to or published by credible government agencies such as the Environmental Protection Agency, the Oklahoma Water Resource Board, the City of Norman, and academic articles. As an expeditious study secondary data was utilized. The academic literature provides the bulk of materials while local Norman City municipalities, Central Oklahoma Master Conservancy District (COMCD), and other notable stakeholders' accurate data substantiate the information within this study. Lake Thunderbird has recognized federal attention, as such data has been abundantly generated. This statistical information provides a wealthy collection for assessment. The study strives to evaluate past implementations to avoid future failure but is not bound by these historical documents. Attention will be prioritized to relevance.

FINDINGS

The hypothesis: Lake Thunderbird is prone to pollution via soil erosion from urbanization is supported.

The following review of variables leading up to the pollution level increase in Lake Thunderbird via urbanization is expounded upon. Specifically, the elements are polluted by urbanization and collectively accrue more pollution than their natural processes upon the Earth. Furthermore, human activities exacerbate pollution levels and the evolution of natural processes of stormwater runoff, soil erosion, and sedimentation/pollution.

Table 1: Lake Thunderbird Plans

Date	Title of Plan/Action	Issuing Agency
2002	Sensitive Water Supply-Added to 303(d) list	Oklahoma Dept. Of Environmental Quality
2008	Watershed Based Plan for the Lake Thunderbird Watershed	Oklahoma Conservation Commission

2009	Lake Thunderbird/ Norman Project Resource Management Plan	Bureau of Reclamation
2009	Lake Thunderbird/Norman Project RMP (Reclamation Resource Management Plan)	U.S. Dept of Interior-Bureau of Reclamation & OK Tourism and Recreation Dept
2013	TMDL Rates Established	Ok Dept of Environmental Quality
2015	Lake Thunderbird Compliance and Monitoring Plan	City of Norman
2015	Final MS4 and Lake Thunderbird TMDL Compliance Plan	City of Moore
2016	City of Moore Stormwater Management Plan	City of Moore
2016	City of Norman Stormwater Management Plan	City of Norman
2016	City of Norman TMDL Compliance and Monitoring Plan	City of Norman
2016	Norman Compliance and Monitoring Plan-Resolution No. R-1617-41	Norman City Council
2017	City of Oklahoma City Water Conservation Plan	City of Oklahoma City
2018	City of Oklahoma City Stormwater Quality Management Plan	City of Oklahoma City

HOW IS LAKE THUNDERBIRD PRONE TO POLLUTION?

Lake Thunderbird has been steadily plagued by pollution problems almost from conception. The Clean Water Act was passed by Congress in 1972. The Act set forth specific expectations and defined the goals as: restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The interim goals of the Clean Water Act were to achieve "fishable and swimmable" (Cleans Water Act Fact Sheet, 2016) waters by 1983, and eliminate all discharges of pollutants into navigable waters by 1985. Noted is a geological attribute indicative of the Great Plains Region: the composition of the earth below the topsoil layer easily disperses when the topsoil is disturbed as it did during the Dust Bowl.

By 2008, Lake Thunderbird's condition had become dire. By 2013, significant action was required immediately. To its credit, the City of Norman swung into action. They commenced a 5- year plan to tackle the major contributors to Lake Thunderbirds' woes. The major problems are pet waste, an elevated presence of nitrogen and phosphorus leading to prolific algae blooms and in turn causing a separate environmental air quality issue, and suspended sediment in the water from construction run off. By October of 2016, the 5-year Plan was implemented. In the following years an aggressive course of action was enacted. There were partnerships formed, community alliances established, new rules and regulations governing construction sites launched, educational outreach instituted, and an impressive Basin Monitoring Plan executed.

Argumentatively, all action is good. However, deep inside the Enviro-Shield Solutions Water Quality 2021 report (p. 64) is this statement, "Although much has been done to address problems at Lake Thunderbird, continually poor water quality and the rising demand for freshwater for multiple beneficial uses makes it critical to continue working on the future health of the reservoir..."

Despite aggressive proactive actions and countermeasures, Lake Thunderbird's water quality remains poor. Derichsweiler, manager of the Oklahoma Department of Environmental Quality decisively stated in 2013, "We have over a thousand impairments in this state. Lake Thunderbird is one of the priorities" (Terry-Cobo, 2014, par. 4).

Not only does Lake Thunderbird serve as a drinking water source for five municipalities, but it also serves as an example of issues plaguing many of Oklahoma's reservoirs. The consistent population growth, and subsequent construction that follows growth is known to be attributed to the rapid motility of this layer of earth.

URBANIZATION

The population of Cleveland County, where Norman serves as the county seat, has continually grown at a higher rate than the overall state of Oklahoma (Kaplan, 2023). Lake Thunderbird is Norman's primary source of water. Norman has grown 33% since 2000, adding 10, 400 single-family homes and 6,120 multifamily homes (Kaplan, 2023). A comprehensive 2019 growth report for Norman recorded a 26% uptick in new construction in Ward 5, which surrounds Lake Thunderbird (City of Norman, 2020). Worth noting is that the parameters of Lake Thunderbirds watershed extend beyond surrounding municipalities; however, building permits are not required outside of city limits, ergo there would not be any way to ascertain the number of impervious surfaces added outside of city limits without layering data from multiple sources. The addition of so many impervious surfaces increase the likeliness of pollution of Lake Thunderbird via storm water run-off given that Central Oklahoma is experiencing regular intense heavy rainfall events that encourage runoff leading to the primary cause of pollution to the lake (Oklahoma Conservation Commission, 2008). Consider the figure below which displays (as of 2006) Lake Thunderbird's watershed which is approximately 40% residential and dominated by hard surfaces (Fry et al., 2011).

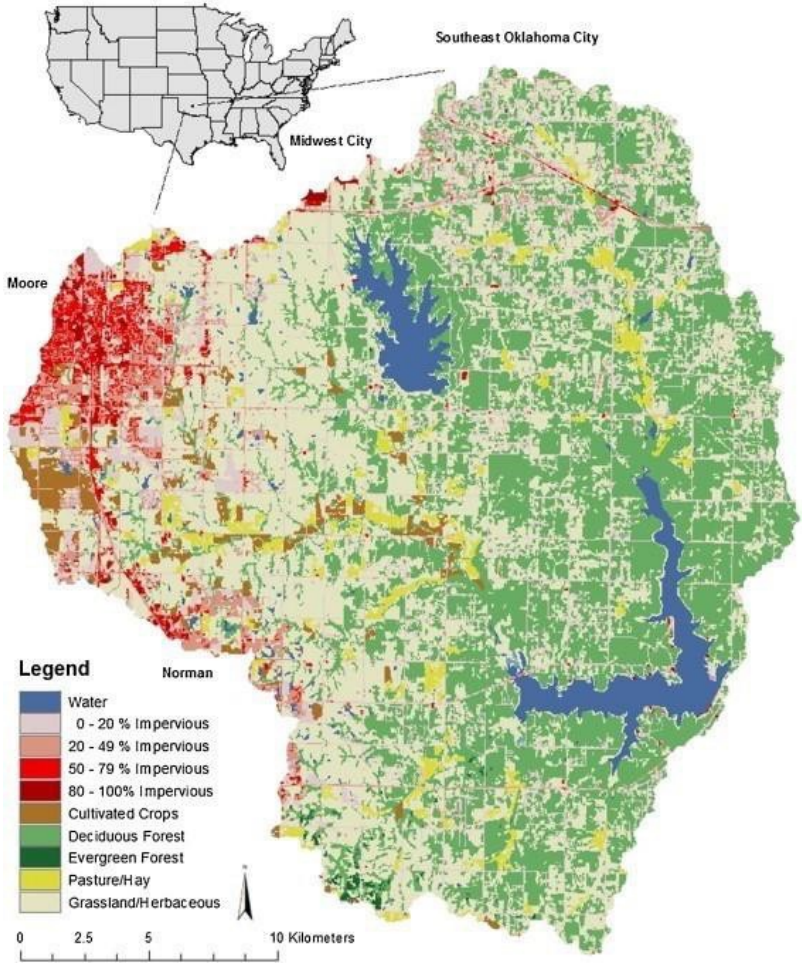
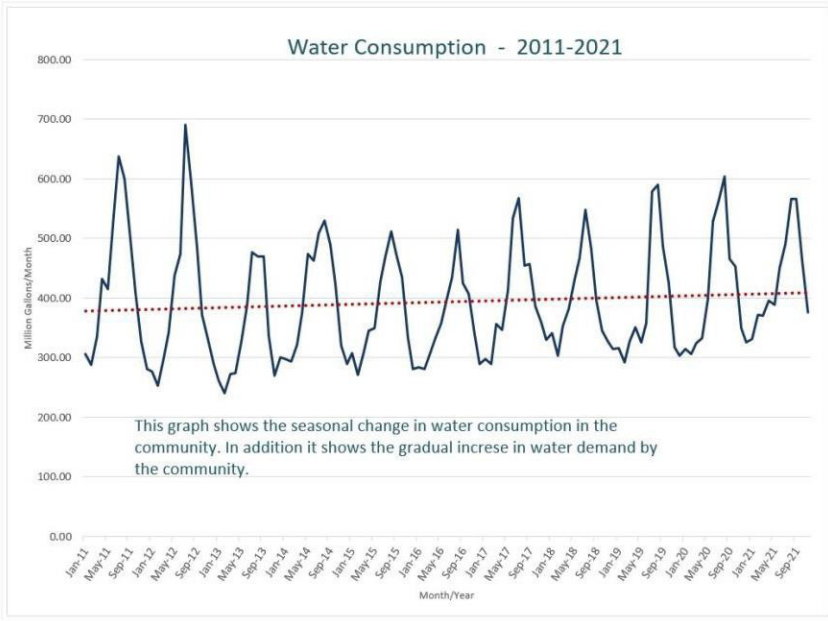


Figure 2: Lake Thunderbird Watershed Surfaces 2006 (Fry et al., 2011)

A subsequent consequence of new construction is the removal of natural surfaces as they are replaced with homes, roads, and businesses. The removal of vegetative plants, brush, and trees will increase water pollution (Bae, 2020). According to the H2OU, "in the past 30 years, the agricultural regions have decreased" and "since 2016, there is a decreased percentage of open spaces, evergreen forests, grasslands, and cultivated regions" (2021, n.p.).

Pavement and hard surfaces reduce the ability of nature to act as a natural filtration system. This means that runoff stormwater collects pollutants and disperses directly into collective water basins such as Lake Thunderbird. Not only does urbanization pollute Lake Thunderbird but the significant population increase adds pressure to the limited resource. Municipal water consumption has shown a marked escalation, while the overall average water consumption by Norman residents has increased by half a million gallons a year (City of Norman, 2023). Peak water consumption months, such as September, illustrate a variance of a one-million-gallon increase from 2011 to 2021(City of Norman, 2023).



A look at 10 year of Water Consumption by the Norman community.

Figure 3: Water Consumption- 2011-2021
(City of Norman, 2023)

Table 2: Population Growth in Cities Contributing Runoff to Lake Thunderbird, 2000 and 2019

City	Year 2000	Year 2019
Norman	95,694	124,880
Oklahoma City	506,671	643,692
Moore	41,138	60,943

(USCB, 2020)

STORM RUN OFF / SOIL EROSION

"Stormwater runoff to Lake Thunderbird has increased in both quantity and velocity as the populations of the nearby cities that deliver the vast majority of the stormwater runoff to the Lake have grown" (Evenson, 2019, p. 5). It is recognized pollutants can be directly discharged into waterways and subsequently to the lake via stormwater runoff (Lake Thunderbird Watershed Partnership, 2019). Oklahoma does not treat its stormwater (Lake Thunderbird Watershed Partnership, 2019). This means that contaminants are not removed or even reduced before entering catchment areas. According to studies compiled from Oklahoma's DEQ, "a TMDL was established in 2013 which identified stormwater runoff from urbanized areas as the primary contributors to the Lake's water quality impairment" (Evenson, 2019, n.p.).

Stormwater runoff and sedimentation become very convoluted when discussing pollution levels. Recognition is given that according to a cumulative study published in 2016, stormwater runoff is responsible for specific contaminants within Lake Thunderbird, they include, natural sediments, nitrogen, and phosphorus (Chen et al.).Consider studies that compile OWRB data that identifies marked increases in phosphorous and nitrogen which is evidence of direct correlations to "residential areas, road construction, and agricultural areas, and leakage from septic systems, and other non-point sources" (H2OU Engineering, 2021, n.p.). Regard the table below which displays the total nutrient loading of phosphorous and nitrogen per city.

Table 3: Total Nutrient Loading Contribution by City

City	Total Phosphorous (%)	Total Nitrogen (%)
Norman	38.0	39.5
Oklahoma City	31.1	32.4
Moore	28.1	25.4
Other	2.80	2.60

(OWRB, 2020)

Highly urbanized areas within the Lake Thunderbird Watershed (Chen et al. 2016), have intensified water pollution in Lake Thunderbird due to storm runoff (OCC, 2008). Storm runoff is particularly injurious when it is the product of intense rainfall events. Lake Thunderbird watershed regularly experiences intense rainfall events mathematically described as 24/h 2/y=87mm/h (Martin-Mikle, 2015). Intense rain events combined with impervious surfaces (a consequence of urbanization), create destructive runoff leading to soil erosion. Additionally, the influx of abundant, swift-moving water into small tributaries contributes to bank erosion and channeling rapidly delivering overabundant sediments and disproportionate amounts of nutrients to Lake Thunderbird (Julian et al., 2015).

Soil erosion is a worldwide concern, a national concern, a concern indicative of the Great Plains region, and a concern to those in the Lake Thunderbird Watershed. Oklahoma has a long tumultuous history with soil erosion (as does Kansas, Texas, Colorado, and New Mexico). In 1934 alone, it is approximated that 300 tons of soil were dislodged from the region and transported to portions of the eastern United States (Cummins, 2021). It is estimated by the Oklahoma Cooperative Extension that "50 million tons of soil are washed away from the state's land every year by water erosion" (Cummins, 2021, p. 1).

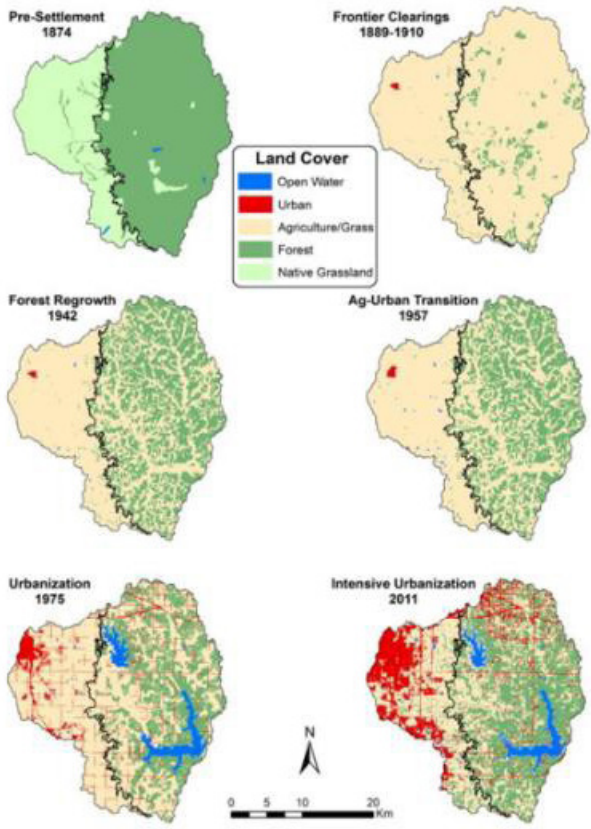


Figure 4: Chronological Land Use in Lake Thunderbird Watershed
(Julian et al.,2015)

Although soil erosion occurs naturally, the activities of humans have contributed greatly to the rate at which soil erosion occurs. Urbanization has been associated with soil erosion via storm run-off in the Lake Thunderbird watershed in several ways, however, none are impactful as construction activities that expose bare land to the elements (Kamara, 2019). Exposed land is subject to soil erosion, subsequent soil loss, eventual sedimentation of water bodies, and (if not addressed) water quality impairments, property damage, habitat loss, and potential loss of biodiversity (Kamara,

2019). It has been determined that solutions to sediment control and improved water quality of Lake Thunderbird, as offered by the Oklahoma Cooperative Extension Service, begin with the prevention of soil erosion via stormwater management (Kamara, 2019). This is proposed because it is acknowledged that soil erosion becomes sedimentation which is pollution. Regarding stormwater and its impact on pollution levels of Lake Thunderbird depicts that as the elements are fluid within a segmented linear process they must be managed from the beginning of their lifecycle on the earth's surface, which is stormwater management.

SEDIMENTATION / POLLUTION OF WATER SOURCE

All flowing waters contain sediments naturally. When flowing water is delayed behind a dam, the sediments settle to the bottom of the reservoir (McCully, 2001) such as the Norman Dam of Lake Thunderbird. Despite ever-evolving research, sedimentation is the most perilous issue confronting dam management (McCully, 2001). In an effort to better understand the relationship between sedimentation and reservoirs, various studies have emerged. One such assessment revealed Lake Thunderbird received large volumes of sediment-laden runoff (Ross, 1991).

The Bureau of Reclamation completed a thorough evaluation in 2015 and concluded that Lake Thunderbird has lost roughly 12% of its original storage capacity since 1965 due to sedimentation (OWRB, 2020). Further evaluations display the annual sediment yield, or amount of sediment entering the lake from the watershed, at 1.93 acre-feet per square mile annually; this data highly exceeds acceptable amounts of sedimentation for the lake (U.S. Department of the Interior-Bureau of Reclamation, 2006).

Aside from sediments filling in the reservoir and rendering it useless, sedimentation presents a number of problems in Lake Thunderbird. The smallest of particles stay suspended causing cloudiness making Lake Thunderbird appear dirty. This is called turbidity- aside from aesthetics, turbidity harms the natural biota

of the lake. In 2008, Lake Thunderbird exceeded criteria levels of turbidity put forth for the protection of the beneficial use of Fish and Wildlife thus designating compromised (OWRB, 2008). These facts were again reiterated in 2020; specifically, regarding the lake's inability to support fish and wildlife due to turbidity (OWRB, 2020). Furthermore, turbidity creates water treatment issues and plays a significant role in the thermal dynamics of the lake establishing an occurrence known as turning over. Heavy sediment entraps pollutants and sinks to the bottom of reservoirs. Specifically in Lake Thunderbird phosphorous (JAY Engineering, 2021), nitrogen, metals (such as iron and manganese) (OWRB, 2008), and ammonia (OWRB, 2020) all attach to heavy sediment and create detrimental pollution levels within the lake. Shallow lakes (20 ft or less) are subject to a phenomenon known as turning over whereby the contents of the bottom of the lake (heavy sediments) cycle back toward the surface and vis-a-versa this releases bound pollution and continues to exacerbate contamination levels experienced by Lake Thunderbird (OWRB, 2008). The excess nutrients in Lake Thunderbird cause the prolific growth of algae. "This process of elevated algal growth and ensuing consequences is known as cultural eutrophication, where anthropogenic point and non- point sources are always the cause of excess nutrients in aquatic environments, where in-lake dynamics will exacerbate associated problems. Consequences of cultural eutrophication were observed in Lake Thunderbird in 2008" (OWRB, 2008 p. 40).

Where does the overabundance of sedimentation come from? Lake Thunderbird receives all recharging water from rainfall, precipitation, and inflow from tributaries, which includes all surface runoff in the watershed (OWRB, 2008). Furthermore, the lake has water pollution levels specifically from urban stormwater specifically in relation to intense rainfall (OCC, 2008). The nutrient-overloaded sediment was coming in from the watershed at various lake inlets. "Larger- grained sediment washed in from the watershed seems to account for the bulk of the accumulated sediment" (OWRB, 2002, p.13).

In 2020 Lake Thunderbird's nonalgal turbidity was scrutinized and was found to be predominately allochthonous, meaning the suspended sediment particles were originating from elsewhere and being transported to Lake Thunderbird (OWRB, 2020). Excessive amounts of sediment, as well as problematic phosphorus and nitrogen, are transported to Lake Thunderbird via headwater streams subsequently resulting in excessive turbidity (and algal blooms) that exceed regulations prescribed by the Oklahoma Department of Environmental Quality (ODEQ, 2008). Lake Thunderbird is a victim of pollution via sedimentation originating from stormwater runoff from urban areas. Studies firmly establish, "stormwater runoff from urbanized areas as the primary contributors to the Lake's water quality impairment" (Evenson, 2019, p. 5).

DISCUSSION AND POLICY RECOMMENDATION

Lake Thunderbird is currently transcribed on Oklahoma's 303(d) list as Priority 1, in Category 5a (OWRB, 2021) such categorization indicates that a water body is impaired, water quality is diminished, and the waterbody has failed to meet its designated uses (ODEQ, 2013). Reasons for Lake Thunderbird's impairment include high turbidity as well as elevated concentrations of nitrogen and phosphorus (OWRB, 2020). The Oklahoma Department of Environmental Quality has further classified the lake as a Sensitive Water Supply because it continues to fail to meet requirements for Fish & Wildlife Propagation for a Warm Water Aquatic Community and Public Water Supply uses (OCC, 2008). Included academic and community concerns manifested in contemporary research include deteriorating aesthetic values (H2OU, 2020) and rising water treatment costs (OWRB, 2011).

RECOMMENDATIONS FOR BETTER POLICY MANAGEMENT

Worth mentioning is the concept of Low Impact Development where thoughtful implementation watershed-wide of comprehensive planning could potentially mitigate the impacts of urbaniza-

tion (Martin-Mikle et al., 2008). Low Impact Development is used in agricultural practices often, it is rarely seen in an urban setting due to the mixed-use complexities of urban settings (Martin-Mikle et al., 2015).

Furthermore, an understanding that Oklahoma's regional options for freshwater are dwindling and new management and paradigms are required. Acceptable geographic places to build and store water in the form of reservoirs (that haven't already been used for such purposes) near metropolitan areas are few and far between. John Harrington a registered professional geologist and Director of the Oklahoma Water Resource Division, is quoted as saying, "The bottom line is, we're going to have to start investing in building lakes in places that we didn't think were great 40 years ago because now we have an expanding population" (Minty, 2023, n.p.). Harrington warns against apathy in times of favorable precipitation as easy solutions to water availability are diminishing. Dams, such as Norman Dam, are temporary in nature.

Ultimately, all reservoirs fill with sediment (McCully, 2001), and are returned to land either by natural disaster or intentional removal (Glen Canyon Institute, 2018). It is not enough to address pollution at the lake, it must be mitigated at a watershed level and holistically addressed in order to preserve the reservoir as a viable source of municipal water for as long as possible.

APPLICATIONS AND CONCLUSION

This study proposes that water must be managed from the beginning of its life cycle.

Specifically, management must begin at the onset of precipitation with stormwater runoff. This study discussed linear subsections of the element's transactions after reaching the Earth: stormwater runoff, erosion, sedimentation, and pollution. Of these several scientific gaps were discovered. For example, studies regarding Lake

Thunderbird's pollutants (specifically microplastics) were nonexistent, indicating a necessity for further research. Furthermore, few if any connections are made to urbanization and pollution. Simply put, scientific linkages displaying correlations between urbanization and pollution of Lake Thunderbird are absent.

Lastly, very few data sets consider the increased cost of treating water that is highly contaminated. Studies are needed to illustrate the cost comparison of stormwater runoff management versus municipal water treatment. It is proposed that if stormwater runoff was treated (via natural processes) the cost of Lake Thunderbird's municipal water treatment would decrease exponentially.

Furthermore, Lake Thunderbird offers itself as a prime example- an exemplary setting by which to serve as a functioning laboratory to advance effective environmental buffering. This lake is an opportunity to negate long-term heartache through reasonable near-future planning. It also provides a significant source of municipal water for a significant amount of people where a population is growing, and a resource is dwindling. Simply put, water resources in Oklahoma are limited and dwindling. This Lake and study herein can be used to improve and connect pollution drivers to their source. Overall, this research is limited in its coverage. It is a foundational step in finding out the effect of urbanization on the pollution of nearby Lake Thunderbird.

THE FUTURE OF LAKE THUNDERBIRD

This study insists that a holistic nexus approach would aid in negating damages. It is recognized that obvious pollution gets all the attention; however, the environmental consequences of rampant urbanization (e.g., housing tracts, strip malls, roadways, etc.) lead to the degradation of water and significantly impact freshwater municipal sources. The omission of spatial planning damages the environment of its placement with significant deterioration of water bodies (Bae, 2019). It is known that "water contamination

is often discovered long after it has occurred… and practices of today may have effects on water quality well into the future, well before we understand the full ramifications of transportation and water issues" (Bae, 2019, n.p.).

It is understood that the addition of new roads in the Lake Thunderbird area will cause further urbanization of the Lake Thunderbird area watershed. While the additions of roads, highways, and turnpikes are meant to relieve traffic in areas that are established and heavily urbanized, the construction of roadways encourages the further urbanization of the area it intended to relieve. This is known as Induced Demand and is included in the Fundamental Law of Road Construction (Duranton, 2011). In 2010 The Oklahoma Department of Transportation stated, "Land use trends are so closely interrelated with transportation systems that it is difficult to determine which has a stronger effect on shaping the other. Since each land use type has specific accessibility requirements and transportation provides the accessibility development will take place along corridors that provide suitable access" (ODOT, 2010 p.10).

While Oklahoma is well acquainted with erosion, a decisive lack of acknowledgment is displayed when discussing large earth-moving, vegetation-clearing projects such as turnpikes. Erosion does not cease after initial construction concludes. Roads, especially very large, formidable roads, change the paradigms of interactions between soil, vegetation, and water. The addition of hard surfaces encourages run-off and additional erosion long after initial construction is completed. It is advisable to avoid building new roads or mass transits proximally close to Lake Thunderbird, or any other municipal water source. Simply put watersheds, ergo water catchments, are directly impacted by transportation (Bae, 2019) we must consider them when authorizing the employment of urbanization. Consider that no studies have been performed on Lake Thunderbird regarding pollution from roadways.

This study is relevant as it demonstrates the negative consequences of irresponsible spatial planning which is overtly displayed in the proposal of the Kickapoo Turnpike. The proposed route of the Kickapoo Turnpike Extension passes directly over two legs of the reservoir. There will be little opportunity for run-off pollution to be filtered out from natural processes. Furthermore, the Cleveland County water treatment plant is not equipped to remove pollutants such as micro-plastics from tire wear particles. Furthermore, voters have denied water cost increases for over 20 years (Wood, 2022). Regarding water pollution and roadways, several credible studies advocate for the removal of existing roads and the avoidance of constructing new roads (Trombulak et al, 2000). Roads, by their very existence, alter natural drainage characteristics, serving as a link between water sources and pollution sources (Ralston, 1997).

To protect our population and create sustainability, our society must shift ideologically from building and construction to maintaining and planning. This paper hopes to contribute one small spoke in the bike wheel of progress toward this sustainable existence. We must protect the resources we have to mitigate future loss and suffering. Arguably, reasons exist for the construction of the Kickapoo Turnpike Extension; however, the benefits would be negated by the loss of clean water. Concisely, present apathy will result in future strife.

CONCLUSION

Pollution of waterbodies is a complex multiphase phenomenon that combines numerous natural variables simultaneously affected by various anthropogenetic co-occurring activities creating biological impairment of water bodies. Distinguishing specific causes of biological impairment of waterbodies, or the specific stressors that should be managed to improve the condition, is difficult (US EPA, 2023). This is substantiated and recognized as challenging.

To reiterate, the declining water quality of Lake Thunderbird is complex. Improving the water quality is not as simple as identifying a specific cause or stress, but a holistic approach to managing urbanization and subsequent soil erosion, sedimentation, and pollution within a watershed. The long-term implications of creating large, paved surfaces proximal to Lake Thunderbird are contradictory to other efforts of sustainability. As applied to what effects urbanization may have on municipal surface water supplies, it compounds it and creates additional environmental strains. It is prudent, practical, and possible to thoughtfully plan the placement of impervious surfaces.

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