MOTORBOAT USE DENSITY AND NATURAL FORCES AS FACTORS IN WATER QUALITY

By

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NOMENCLATURE

ANOVA	one-way analysis of variance
^oC	degrees Celsius
cm	centimeters
EPA	Environmental Protection Agency
^oF	degrees Fahrenheit
G.I.S.	geographical information systems
ha	hectares
HP	horsepower
hr	hours
km	kilometer
km^2	square kilometers
m	meter
mg/L	milligram per liter
mi^2	square miles
ml	milliliter
mm	millimeter
mph	miles per hour
nm	nanometer

NMMA	National Marine Manufacturers Association
NTUs	nephelometric turbidity units
ppm	parts per million
p.s.i.	pounds per square inch
SPSS	Statistical Package for the Social Sciences
USDA	United States Department of Agriculture
USDI	United States Department of Interior
UV-VIS	ultraviolet and visible wavelengths combined

CHAPTER I

INTRODUCTION

Background

Environmental degradation in aquatic ecosystems is not a recent phenomenon. Even before human arrival on planet earth, aquatic ecosystems were undergoing shifts in physical, chemical and biological structure and composition. These shifts were both gradual and rapid, depending on direct or indirect effects from natural events (e. g., drought, flooding, the fluctuating ice age, etc.). Since the invention of water-oriented recreational pursuits (e. g., boating, personal watercraft, etc.), some of these aquatic succession changes have accelerated beyond nature's ability to adjust over the short term, according to many research reports.

Human society has realized the recreational importance of attractive, aquatic ecosystems dating back to 2000 B. C. Although environmental impacts to these areas have always been controversial to some extent, no one major contributor, other than industry, has been targeted as a possible cause to accelerated degradation, at least until 1945. It has only been since the end of the World War II that motorboat-induced water disturbance has become a major environmental issue. Since the late 1970s, there has been a substantial increase in the holistic awareness of environmental fragility of freshwater lake systems that includes not only land, motorboats, sediments and water issues, but also the living plant and animal communities (Hutchison, 1957; Mele, 1993; Nelson, 1994; Imboden and Wuest, 1995).

Lighthill (1978) stressed that in a contemporary world greatly concerned with the consequences of all aspects of global change, lakes make up a small percentage of the total land mass, and are very important components of the overall global environment. For example, human societies living near lakes depend on a great variety of factors associated with them, ranging from aesthetic and recreational demands, to economic infrastructures, and the reliance on lakes as sources of drinking water and ameliorators of local climate (Imboden and Wuest, 1995; Lighthill, 1978).

Cross (1992) emphasized that people seek unspoiled, natural areas for recreation. Due to this, one of the biggest disappointments that aquatic recreationists encounter at a lake is the presence of water turbidity, which reduces the optical property (i. e., clarity) of water. Once the water becomes turbid, there can be far-reaching consequences on the biological (e. g., fauna, flora, food chains, etc.); chemical (e. g., dissolved oxygen, pH levels, etc.); and physical (e. g., color, odor, taste, temperature, etc.) lake properties.

Statement of the Problem

Much has already been determined by researchers regarding the detrimental effects that various non-point and point sources of pollution have on water quality. At the same time, very little research has been conducted on the possible harmful effects that motorboats may be having to the water quality. This is because personal use of motorboats was very limited before 1945. As more and more contemporary, aquatic recreational areas are being transformed into motorboat zones, it is hoped that this study will demonstrate the usefulness and need for water quality monitoring to ensure environmental preservation for future generations.

Purpose of the Study

This study was conceived to establish a comparative pattern of water quality relationships based on the time frame before, during and after peak motorboat season (May 15 through September 15, 1996) at Lake McMurtry, which is located in north central Oklahoma. The study was intended to discover whether effects, if proven conclusive, could be measured through limnological observations, and to ascertain if these effects are indeed detrimental.

The specific purposes of this study are:

1. To determine if various levels of motorboat use have any physical or chemical effects (e. g., creating more or less similar water parameter readings within and/or between measuring sites at Lake McMurtry) or whether meteorological conditions are the principal cause of variation in water parameter measurements.
2. To identify which, if any, of the physical and/or chemical parameters (e. g., dissolved oxygen concentrations, water temperature and water turbidity) were most altered during the study period.
3. To determine if motorboat use in the littoral zone causes higher water turbidity levels at the measuring site containing the heaviest motorboat traffic.

Objectives of the Study

Hilton and Phillips (1982) and Yousef (1974) recommended more research aimed at investigating the nature and significance of water turbidity, resulting from agitation due to motorboat use in the littoral (i. e., shallow) zone. Therefore, this study was intended to further determine what, if any, relationships exist between motorboat use and water turbidity. Further, it was intended to compare the limnological characteristics of three separate locations in an attempt to segregate motorboat-induced water turbidity from water turbidity caused by meteorological conditions (e. g., air temperature fluctuations, heavy precipitation periods, wind fetch-induced wave action resulting from prevailing winds, etc.). This information is valuable in assessing the impact of motorboat turbulence upon fragile aquatic ecosystems, and is intended to aid in management decision processes governing rules and regulations involving motorboat use.

Significance of the Study

Adverse environmental effects due to human activity is not a recently discovered problem. Although there has been a substantial increase in the awareness of environmental fragility of aquatic ecosystems since the 1970s, recreationists continue to seek these freshwater lake systems for family, group and personal usage, thus creating possible physical impacts both to the water quality and to the surrounding area. In some areas, increased lake usage is creating greater water turbidity levels, and is damaging the attractive water quality that brings visitors to these areas. The result could be a decrease in recreational use of lakes in the future, which would be undesirable to both recreationists and local economics associated with aquatic recreation. Both *in situ* and *ex situ* water quality instruments will be employed, in this research, to answer the following questions:

1. Is water turbidity in a recreational lake related to natural forces, motorboat activity, or a combination of both?
2. Does motorboat use density affect water quality in shoreline areas?

Hypotheses

These questions will be evaluated at the $\alpha = .05$ level for the following hypotheses.

1. H_O There is no significant difference in dissolved oxygen concentrations, between the three locations or within each location, as a result of natural forces and/or motorboat use.

   H_1 There is a significant difference in dissolved oxygen concentrations, between the three locations or within each location, as a result of natural forces and/or motorboat use.

2. H_O There is no significant difference in water turbidity levels, between the three locations or within each location, as a result of natural forces and/or motorboat use.

   H_1 There is a significant difference in water turbidity levels, between the three locations, as a result of natural forces and/or motorboat use.

Delimitations

This study was designed to study the recreational water quality of Lake McMurtry, which is a recreational lake owned and managed by the City of Stillwater, Oklahoma. The focus was targeted at segregating possible causes of water turbidity into two categories: motorboat use and meteorological forces. Lake McMurtry allows for a viable study due to its shallow morphology (i. e., less than 40 feet in depth), located in a geographical region that experiences, on average, higher prevailing wind speeds, and adequate amount of motorboat traffic (refer to Figure 9) for research purposes involving motorboat use density. The conclusions are therefore applicable to public resource managers, particularly those associated with aquatic lake environments.

Limitations

Limitations of the study include:

1. As Cross (1992) recommended, in order to obtain the most valid limnological readings possible, an average hot and dry summer is best, preceded by a cooler and wetter spring. This is because a hot and dry summer allows maximum settling of a reservoir in the absence of flushing and significant erosion from heavy precipitation periods. This increases the possibility of depicting water turbidity induced by meteorological forces from possible water turbidity created by motorboats. There was no guarantee that 1996 would provide these ideal conditions, as was the case with Cross' 1992 study.

2. Physical and chemical conditions are to be measured in equal proportions between the three locations; however, the amount of motorboat traffic could vary during each measuring period and may not reflect the actual motorboat use density for the entire day.

3. Long-term versus short-term weather concerns could affect the water parameter readings. Bad weather, especially high winds, precipitation and thunderstorms, could influence the conditions that yield the readings (e. g., by creating high waves, rapid inflow and changes in water temperatures), thus creating short-term anomalies that could influence long-term (i. e., four month) research results.

4. Red clay soils, located at Lake McMurtry, have a tendency to provoke a certain degree of water turbidity, outside of being induced by meteorological forces or possible motorboat-induced turbulence, due to their ferris iron content. Bahnick et. al. (1979) demonstrated this as part of their Lake Superior study. This could contribute to turbid conditions as a third or extraneous source, and will not be monitored in this study as a possible contributing source.

4. Although motorboat use and meteorological conditions are the primary independent variables in the study, there are several other variables, in terms of visitor use, that could affect the validity of limnological readings on the dependent variables associated with this study. These include possible off-road vehicle use, soil compaction, swimmers, etc.

Assumptions

1. It was assumed that Lake McMurtry is adequate in terms of both size and amounts of recreational usage, so use density of motorboat traffic would be sufficient to make the study viable. Yousef (1974) conducted his study on Florida lakes similar to Lake McMurtry in terms of size and use density.
2. The assumption was made that the study period (i. e., May 15 through September 15, 1996) would be of sufficient length to observe limnological fluctuations associated with the period before, during and after peak motorboat use dates. This assumption was based upon the highest national average use density, as well as previous research aimed at motorboat usage (Hilton and Phillips, 1982; Moss, 1977).
3. It was assumed that characteristics between the three sampling locations (e. g., amount of motorboat traffic, depth of the water column, shoreline erosion, surface area of water and wave fetch) would provide a generalized comparison for limnological measurements.
4. The assumption was made that all limnological measurements taken, at any of the three sites, would not be disturbing to the local wildlife, visitors, or the environment in general.

Definition of Terms

Autochthonous Sediments - sediments resting on the lake bottom that were formed by physical and chemical means within the lake (*in situ*), and not transported into the lake from outside sources (Cole, 1994).

Benthic Region - the lower or deeper in a water body portion directly above the lake bottom. This region receives the least solar radiation, and usually contains much lower dissolved oxygen concentrations (Martin, 1977).

Boundary Layer - the location (i. e., from the surface to the sediment-water interface) where mixing occurs in the water column. The energy driving this mixing zone is provided by turbidity currents, internal and surface waves, and by river inflow (Imboden and Wuest, 1995).

Convective Storms - thunderstorms that usually occur during the summer months, and on an isolated to scattered basis. They are usually short in duration, but can produce considerable amounts of rainfall over small geographical areas (Cole, 1994).

Direct Contact - the dissipating action of kinetic energy created by motorboat engines through direct collision with the bank surrounding a water body (Goldman and Horne, 1983).

Diurnal Variation - the temperature change (e. g., increase or decrease) occurring in a water body over a 24-hour period, encompassing both day and nighttime fluctuation. This temperature change is much less varied compared to air temperatures for the same period (Cole, 1994).

Epilimnion - the region in a water body extending from the surface to the thermocline. This region does not display a permanent, water temperature stratification. It is referred to as the mixed layer (Goldman and Horne, 1983).

Euphotic Zone – the surface layer of a water body extending down to the depth of light penetration at which photosynthesis balances respiration. In transparent lakes, the euphotic zone may extend below the region of thermal stratification (Goldman and Horne, 1983).

Eutrophication - a process, in a lake or river, creating lower dissolved oxygen concentrations, resulting from a high accumulation of nutrient loads and a high rate of primary productivity. This results in a lowering of dissolved oxygen concentrations and a higher biological oxygen demand. Eutrophication occurs mainly in older and/or shallow lakes with a well-developed littoral and sublittoral vegetative zone. The process can be artificially increased by the addition of agricultural fertilizers, animal excrement, etc. to the water body (Martin, 1977).

Hypolimnion - the region in a water body extending from the thermocline to the lake bottom. This region is removed from surface influence (Goldman and Horne, 1983).

Internal Waves - the most important type of wave for mixing the stratified water column below the energetic surface layer. Most importantly, internal waves precipitate cycling of important nutrients between the hypolimnion and epilimnion. Internal waves are mostly generated by wind (Imboden and Wuest, 1995).

Leeward - referring to lake morphology, the leeward end is the downwind side where internal waves (e. g., acting from wind stress) pile up surface water. This causes water from greater depth to rise closer to the surface at the windward (e. g., opposite) end, thus initiating nutrient cycling (Imboden and Wuest, 1995).

Littoral Zone - the area both above and beneath the shallow water zone (e. g., bank, shelf) extending from the shore to a depth where light is barely sufficient for rooted aquatic plants to grow (Goldman and Horne, 1983).

Low-Pressure Zone - a broad area of anticyclonic (e. g., counterclockwise) rotation of air, in the Northern Hemisphere, that lowers surrounding air pressure and creates higher surface wind velocities. This weather pattern enhances various physical processes of lake water such as internal and surface waves, wind fetch, etc. (Imboden and Wuest, 1995).

Marena – the name given to a specific Oklahoma Mesonet site near Lake Carl Blackwell.

Thermal Stratification - the horizontal layering of different water temperature zones. Three different, vertical water temperature zones are formed; (1) the upper warmer water in the epilimnion; (2) the middle or thermocline portion where the rate of water temperature change with depth is greatest; and (3) the coldest water found in the deepest portion, which is located in the hypolimnion (Goldman and Horne, 1983).

Thermocline - the water layer displaying the most rapid changes in water temperature in lakes during summer, above which is the epilimnion and below is the hypolimnion (Holmes, 1979).

Upwelling - a vertical movement that develops in the water column of a lake during a seasonal mixing event (e. g., spring and fall overturn), by some other natural event such as internal Secchies, or during major meteorological events. This upwelling causes nutrients and chemicals to become more uniformly distributed throughout the lake (Cole, 1994).

Wash – the forces generated by motorboats. The power required to drive a motorboat must be dissipated in the surrounding water, thus creating bank erosion. This energy depends on the speed and power of the motorboat, the shape of its hull, and its displacement (Liddle and Scorgie, 1980; Yousef, 1974).

Water Column - the total vertical depth of lake water, at any given location from the air-water interface down to the water-sediment interface (Imboden and Wuest, 1995).

Water-Sediment Interface - the region or zone where the bottom of water column makes contact with sediment material. This region is in the profundal or benthic zone (Imboden and Wuest, 1995).

Wave Fetch - the shoreline or bay area receiving the most pronounced and successive wave events at any single time. This phenomena occurs 180° downwind of the prevailing wind direction, and is rapidly enhanced during stronger wind events (e. g., frontal passages, low pressure zones, thunderstorms, etc.). Water is piled up on the leeward side located downwind (Imboden and Wuest, 1995).

Windward - referring to lake systems, the windward end is the wind-facing side displaying vertical upwelling, as internal waves pile water up at the leeward (e. g., opposite) end, thus creating downwelling opposite of the windward side (Imboden and Wuest, 1995).

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

This chapter is a literature review pertaining to water quality patterns in recreational lakes. This review includes literature covering (1) summary of mixing phenomena involved with freshwater lakes; (2) description and characteristics of dissolved oxygen and water temperature; (3) inorganic sources of water turbidity in freshwater ecosystems; (4) possible effects on freshwater, lake ecology resulting from motorboat use; (5) controversy over motorboat engine design; (6) past field research involving motorboat use, and (7) a concluding segment discussing the significance of the literature to the current study.

Summary of Mixing Phenomena Applied to Freshwater Lakes

According to Imboden and Wuest (1995) and Lighthill (1978), all mixing and transport phenomena in lakes are driven by external forces. Mixing patterns are the result of both external forces (e. g., geothermal heat flux, river inflow and outflow, surface heat flux, turbidity currents, underwater springs, wind, etc.) and internal properties of the system (e. g., lake morphometry, stability of the water column, etc.). Therefore, water in a lake is never at rest.

In natural lakes such as Lake Carl Blackwell and Lake McMurtry, three layers eventually form. The upper layer (i. e., epilimnion) represents the warm, freely circulating region of near uniform water temperature level. The middle layer (i. e., thermocline) is the region of rapid change in temperature. The lower layer (i. e., hypolimnion) is the coldest region, also of near uniform water temperature level. This layer is cut off from circulation with upper waters, and does not receive oxygen from the atmosphere during stratification. Autumn causes the water body to cool by increasing the thickness of the epilimnion. This condition lasts until the lake is frozen over, depending on geographic location (Goldman and Horne, 1983).

In spring, water temperatures may be homogeneous from top to bottom. Vertical water density may also be homogeneous, thus allowing wind to mix the lake water and distributing nutrients and bottom solids from deeper waters. At this point, oxygen is mixed throughout the water. Summer then warms the surface waters, thus forming an annual thermal stratification (Goldman and Horne, 1983; Hall and Morrison, 1978; Mackenthun et al. 1964; Powell, 1985; Simpson, 1991; Yousef, 1974).

In the epilimnion, intrusions result from differential heating and cooling patterns, especially in the shallow parts of a lake. Due to limited depth, the daily (i. e., diurnal) variation of water surface temperature levels is larger in shallow, side arms than in the open lake. In contrast, during cooling, surface water sinks to the bottom of the side arms, creeps downslope, and finally merges into the lake interior (Lighthill, 1978).

Lighthill (1978) emphasized that two forces are required for wave motion to exist, one tending to initiate wave motion and the other tending to restore equilibrium. Waves in lakes are generated mostly by wind stress, and to a lesser degree by atmospheric pressure changes and tidal forces. Restoring forces include change of Corealis force (e. g., inertial waves), gravity (e. g., gravity waves), potential vorticity (e. g., Rossby waves), and surface tension (e. g., capillary waves). With regard to mixing, gravity waves are the most important type of wave (Lighthill, 1978).

Currents are induced by wind acting at the water's surface, by inflows, and by density gradients caused by differential heating and cooling. Imboden and Wuest (1995) demonstrated that strong winds during storm events account for the largest source of kinetic energy. Rivers entering a lake are another, but less substantial compared with storms, source of kinetic energy. After drainage into a lake, a river's kinetic energy undergoes a great degree of dissipation (Imboden and Wuest, 1995).

Lake size also brings about increasing sensitivity to meteorological and even climatic gradients. For example, a small lake tends to react instantaneously and as a whole to a passing zone of low-pressure (e. g., a thunderstorm creating large waves and lower water temperatures over the entire water surface area), while an air-pressure gradient moving across a larger lake usually affects only a portion of the total water surface area (Imboden and Wuest, 1995).

Internal waves are crucial for mixing the stratified water column, below the surface layer. Lighthill (1978) concluded that internal waves induce shear both in the interior of the water column (e. g., between the hypolimnion and epilimnion) and at the sediment boundary. Liddle and Scorgie (1980) claim that wake produced by motorboat engines can act as artificial mechanisms to produce internal waves, and to a lesser extent capillary and surface waves.

According to Imboden and Wuest (1995), internal waves are created when wind stress piles up surface water at the leeward end of a lake. This phenomena is also known as wave fetch. At the same time water from greater depth rises closer to the surface at the windward end. Thus, surface water is transported downward and upwelling occurs in between. Downwelling velocities generally increase with wind speed (Imboden and Wuest, 1995). When turbulence is nearly absent, energy dissipation is low and internal waves may persist for weeks (Lighthill, 1978).

Aquatic sediments, which are accumulated deposits of settled clay and colloidal organic solids, are permanently water logged and continuously regenerated by deposition. In shallow, small lakes these sediments form largely from material brought in from the shoreline, surrounding swamps, and from drainage basins. Bahnick et al. (1979) noted that sediments, as a pollutant and transporting agent, are found to play a predominant role in determining surface water quality.

Settled or suspended sediments may serve both as a sink and source for nutrients and other contaminants. However, Yousef (1974) claims that the influence of bottom sediments, on overlying surface water quality, becomes significant only when dissolved oxygen concentrations at the water-sediment interface fall below 1 or 2 mg/L. This concentration is very low compared to most freshwater lakes, which average between 5 and 10 mg/L in dissolved oxygen concentration (Simpson, 1991).

Descriptive Characteristics of Dissolved Oxygen

According to Berner and Berner (1987), Kurklin (1990), Liddle and Scorgie (1980) and Yousef (1974), dissolved oxygen is the best indicator for determining the quality of natural waters. It is supplied to a lake naturally by the diffusion of atmospheric oxygen into the water. Dissolved oxygen is also highly correlated with respiration rates of aquatic life, and as a variable which manipulates trends in algae growth, carbon concentrations, eutrophication processes, as well as nitrogen and phosphorus cycles in freshwater lakes. For nitrogen, dissolved oxygen is required for the biochemical oxidation of ammonia, which is ultimately converted to nitrate in natural waters.

Concentrations of dissolved oxygen are dependent on several factors including degree of photosynthesis, light penetration, water depth, water temperature, etc. In most lakes, phytoplankton contributes the majority of dissolved oxygen concentration. Agitation of surface water surface by wind and waves enhances this process. In addition, waves attributed from wake agitation due to motorboat engines have been documented to increase dissolved oxygen concentrations, depending on operation time of motorboats, engine size and lake conditions (Goldman and Horne, 1983; Hall and Morrison, 1978; Hammitt and Cole, 1987; Mackenthun et al. 1964; Powell, 1985; Simpson, 1991; Yousef, 1974).

Decreases in dissolved oxygen concentrations are due mostly to respiration of plants, animals, and aerobic bacteria involved in the decay of organic matter. Physical warming of the epilimnion, during summer months, can account for a decrease in dissolved oxygen concentrations because the solubility of oxygen decreases as water temperatures increase. Deeper portions of a lake may be anaerobic if light fails to penetrate the lake. As a result, decomposition and respiration would prevail in the deep strata, as dissolved oxygen is depleted faster than it is produced (Kurklin, 1990).

Descriptive Characteristics of Water Temperature

The chemistry of freshwater lakes also depends upon circulation driven by changes in water temperature levels. As water temperature changes so does density. When less dense water becomes overlain by water of greater density, convection, or lake overturn takes place. Warming of lake water, due to higher air temperatures, creates greater acceleration of circulation patterns. Berner and Berner (1987) emphasized that the depth of heating, in the water column, depends on wind stirring and extends down to where wind effects die out.

Ecologically, the thermal properties of lake water are the most important factors in determining both the suitability of water as a natural environment and in regulating activities of aquatic organisms (Kurklin, 1990). For example, warmer water temperature levels affect aquatic organisms by increasing the growth of aquatic plants and bacteria, thus increasing algae and eutrophication rates. Blooms of algae can give the water an unpleasant taste and odor, reduce clarity, and color the lake a vivid brown, green, or yellow. Due to the dependency of algae and eutrophication on both water temperature levels and dissolved oxygen concentrations, water temperature can be closely correlated to the amount of dissolved oxygen present in a water body (Cross, 1992; Kurklin, 1990; Mackenthun et al. 1964; Powell, 1985; Simpson, 1991; Yousef, 1974).

Sources of Inorganic Turbidity in Freshwater Ecosystems

Turbidity, an expression of the optical property of water, causes light rays to be scattered and absorbed within the water column, rather than transmitted in straight lines. Hammitt and Cole (1987) claim that inorganic turbidity originates from direct sources occurring on or in the water (e. g., disturbance and resuspension of bottom sediments, erosion of shorelines and adjacent banks) as a result of wind-induced waves, water inflow from precipitation, as well as possible agitation due to motorboat use.

Research reports conducted by Leonard (1950), Schreiber (1959), Norton (1968), Hysmith (1975), Entz (1980), Howick et al. (1982), and Johnson (1991) have yielded conclusive results indicating that pH, meteorological conditions (e. g., precipitation, wind speed and direction), and motorboat-induced agitation within the water column are major variables that create inorganic turbidity in freshwater lakes. These specific variables perform either independently or in combination to produce this aesthetically degrading effect in aquatic ecosystems.

Leonard (1950) conducted a trend study at Lake Carl Blackwell, separated by nine years (1940-1949), that focused on general limnological conditions (e. g., carbon dioxide, dissolved oxygen concentrations, nutrients, pH, water temperature and water turbidity). Leonard (1950) claimed that water turbidity showed an increase, over the nine-year period, that was a result of increased silt by run-off due to heavier precipitation in the late 1940's.

Water temperatures ranged from 3.5° C to 28.5° C. Thermal stratification occurred only from May through September 1941, and from June through August 1949.

Dissolved oxygen concentrations showed greatest fluctuation near the surface. pH levels also showed long-term increases with only minor fluctuation. According to Leonard (1950) the lake was highly alkaline by 1949. Leonard (1950) concluded that, overall, meteorological conditions (e. g., increase in rains) were directly associated with increased silt loads, which promoted fluctuations of water turbidity through excessive runoff.

The distribution and particle size of sediments in Lake Carl Blackwell were studied by Schreiber (1959) and Norton (1968). Particle sizes recorded in the sediments ranged from less than 0.005 to 0.1 mm in diameter. Both researchers concluded that average particle size was greater near the shore, and less in hypolimnion areas, which was indicative of resuspension, transport of smaller particles to the quiescent profundal waters, and wave action. These conditions were associated with substantially increased water turbidity levels (Schreiber, 1959; Norton, 1968).

Although shoreline erosion had been substantial, Schreiber (1959) felt that Stillwater Creek, which enters Lake Carl Blackwell from the west, was the main source of sediments. Schreiber (1959) found that greater sediment depths occurred near Highway 86 along the western end of the lake. However, Norton (1968) claimed that greater sediment depths were located near the dam, on the east end of Lake Carl Blackwell.

Hysmith (1975) attempted to relate effects of sediment resuspension and resulting increase in water turbidity to primary productivity in Lake Carl Blackwell. Measurements included longitudinal variation in chlorophyll, dissolved oxygen concentrations, primary productivity, sediment depth, water temperature and water turbidity, all at three transects.

Results indicated that the relationship between wind velocity and sediment depth in Lake Carl Blackwell was non-significant. Also, water turbidity was not correlated with sediment depth. However, water turbidity was highly correlated with wind speed. Primary productivity was not limited by water turbidity. Longitudinal variation of dissolved oxygen concentrations in the hypolimnion, water temperature levels and water turbidity levels were significant, suggesting nonuniformity in Lake Carl Blackwell (Hysmith, 1975).

Entz (1980) conducted a study at Lake Balaton, Germany, on the temporary light and heat-induced stratification (e. g., sun-energy induced), together with its physical, chemical and biological aspects. Lake Balaton contains a surface area of 600 km^2 and is one of the largest recreational lakes in central Europe. Its length stretches 77 km and its width spans between 1.5 and 16 km. Lake Balaton is very shallow with a mean depth of 3.3 m.

Results indicated several discoveries. First, when wind speeds exceeded four miles per hour, soft bottom sediments were stirred up over the entire lake due to wave action, thus reducing water transparency within a few minutes. During calm weather there was significant spatial differences in water transparency, ranging from low in the northeast to high in the southwest. Entz (1980) concluded that the attenuation of light gradually increased from northeast toward the southwest, as increased numbers of phytoplankton produced a self-shading effect. Water turbidity levels showed the most dramatic increases during heavy storms. However, most water turbidity levels quickly resettled within 24 to 48 hours, as transparency once again increased (Entz, 1980).

Entz (1980) emphasized that even a very shallow lake can show significant differences in water temperature levels between the surface and bottom during long, calm and sunny periods. Lower water surface temperature levels were accompanied by higher dissolved oxygen concentrations and high pH, but with low redox values (Entz, 1980).

Howick et al. (1982) conducted a two-pronged study in the Lake Carl Blackwell watershed, located in north-central Oklahoma, which encompasses both Lake Carl Blackwell itself and Stillwater Creek to the west. The study spanned a total length of nine months. Sampling was conducted at a depth of 0.5 m and included nine sampling stations. Overall, they found water temperature and water turbidity at higher levels in Stillwater Creek, located west of Lake Carl Blackwell. Dissolved oxygen concentrations, nitrates, pH and Secchi depth were higher in Lake Carl Blackwell.

Mean water surface temperature levels ranged from 3.2° C in February 1981 to 28.9° C in July 1981. Surface dissolved oxygen concentrations ranged from 6.2 mg/L in July 1981 to 15.1 mg/L in January 1981. According to the researchers, higher dissolved oxygen concentrations in January 1981 represent a supersaturated condition caused by wave action (Howick et al. 1982).

Secchi disc transparency ranged from 23 to 130 cm. These values were higher in winter and summer, and lower in spring and fall. Water transparency showed significant variation among different depths and stations (Howick et al. 1982).

Johnson (1991) conducted a study on the effects of pH change to the physicochemical water quality of two east Texas ponds. The two ponds were naturally acidified due to underlying geological formations consisting of gypsum and pyrite. A total of four artificial liners were placed in each pond, over a four-year period, and acidified or neutralized to specific pH ranges using chemicals. One enclosure from each pond was left in its natural water quality condition for use as a control site (Johnson, 1991).

Results indicated that significant differences occurred to water turbidity levels both between the control site and the manipulated ponds. The general trend associated with increases in acidity, or lowering of pH ranges, was inversely related to the parameters that define water turbidity, which included turbidity, iron, true and apparent color. Johnson (1991) claims that, overall, lower water turbidity levels (i. e., 2-10 nephelometric turbidity units or NTU's, which is an international measuring scale for water turbidity) resulted from sampling sites containing a mean pH between 5.1 and 6.0 units, while higher water turbidity levels were noticed in alkaline zones between 7.0 and 8.7 units.

Johnson (1991) also claimed that statistical analysis revealed some of the water turbidity parameters (e. g., true and apparent color) displayed significant seasonal and sample site variations. For example, greater fluctuations in water turbidity levels were noted both during summer periods and at sampling sites located along wind fetch or leeward shorelines, that included the northeast sampling sites (Johnson, 1991).

Possible Effects on Freshwater Lake Ecology Resulting from Motorboat Use

For many centuries boating has been a major source of transportation for both people and nations. Throughout history, emphasis on the art and science of boating has been focused on the construction, design, mechanics, military value and navigation of these vessels. According to Hutchinson (1957), the objective was to build a boat that was easier to operate, faster, larger and more powerful than the previous generation of boats.

Although these are still major focuses, another important topic has emerged that is now challenging the integrity of the boating industry. This topic is centered on the environmental destruction that boats may be carrying out upon aquatic ecosystems. It is a highly controversial topic for two reasons: (1) although most research now points to conclusive impacts, other sources are not conclusive; and (2) conclusive data could have great repercussion on the boating industry.

Hutchinson (1957) stressed that World War II was the major turning point at which environmental degradation to aquatic ecosystems was significantly accelerated as a result of motorboat use. Before World War II, outboard motors were unimportant pieces of equipment for boating enthusiasts. Engineering of that era resulted in unreliable motors. Outboard motors frequently stalled, leaving boaters adrift. In that era, inboard engines contained the most power and were operated by the military, private industries and others who were forced to obey strict rules and regulations governing their use (Hutchinson, 1957).

Beginning in the 1950s, newly designed and more dependable outboard motors ushered in the era of fast-paced pleasure boating. Today, outboards are in the most demand due to variety of engine sizes, ease of maintenance, high maneuverability (e. g., especially in shallow water), ease of transport method (e. g., trailers) and low operational costs (Hutchinson, 1957; Nelson, 1994).

Andre Mele (1993), in her book Polluting for Pleasure, set off a firestorm of controversy by targeting two-stroke outboard engines as the biggest unregulated source of marine pollution. Based on gathered facts, as well as interviews conducted by Mele (1993), she blamed the Environmental Protection Agency (EPA), National Marine Manufacturers Association (NMMA) and others for withholding evidence of ecological destruction due to two-stroke engine use. According to her published interview with NMMA, over 98% of all outboard motors currently in use are of the two-stroke cycle type.

Liddle and Scorgie (1980) claim that physical forces resulting from two-stroke cycle motorboat engines originate mainly from direct contact, propeller action, turbulence and wash. The height of wash from a boat declines as it spreads out over a large body of water, thus lake size has a strong influence on the effect of wash on macrophytes.

Impacts from wash also depend upon seasonal influence (e. g., time of year) in relation to the phenology of plants. Erosion of aquatic plant roots in littoral zone areas can be a serious problem, especially during the spring and summer months. The edges of propellers, depending upon their design, position and size in relation to the hull and motor, can act as a set of rotating knives (Liddle and Scorgie, 1980). Water turbidity can be increased from the eddy-like currents produced by propellers, especially in very shallow littoral zones (Yousef, 1974).

The wave of future outboard engines will probably be four-stroke outboard motors. Nelson (1994) noted that these engines produce less than 20% of the total pollution compared with two-stroke outboard motors. Some four-stroke outboards are based on highway-engine designs, and produce relatively small amounts of air and water pollution. The choice will be limited in the near future because, according to Nelson

(1994) and Parshall (1994), sales of conventional two-stroke outboard engines in the U.S. will be terminated shortly after the year 2000, thus gradually phasing out existing ones.

Field Research Involving Motorboat Use

Yousef (1974), Moss (1977) and Hilton and Phillips (1982) conducted field research on the potential of motorboats to produce higher water turbidity levels, as well as overall ecological damage to aquatic ecosystems. This research has resulted in conflicting conclusions. Nonconclusive results indicating a weak correlation between motorboat use density and inorganic water turbidity levels were confirmed by Hilton and Phillips (1982) and Moss (1977), while strong conclusive results were obtained by Yousef (1974).

Yousef (1974) compared water quality versus motorboat use in four shallow, Florida lakes. These lakes included Lake Claire, Lake Maitland, Lake Mizell and Lake Osceola. Motorboats equipped with different engine sizes ran for limited periods of time, and at speeds of 15 to 30 miles/hr. Water parameters including carbon dioxide, dissolved oxygen, nitrogen, pH, phosphorus, specific conductance, water temperature and water turbidity were tested (Yousef, 1974). Lake Claire is oligotrophic (i. e., nutrient poor) with low pH (e. g., about 5.0 units) and limited aquatic plants. Attempts were also made to evaluate characteristics of resuspended particles, as well as the effect of depth, elapsed time of operation and motor horsepower (Yousef, 1974).

During the first test, a 10 HP motorboat ran across Lakes Mizell, Osceola and Maitland for less than one hour, as water samples were collected from both shallow, shoreline areas and deeper areas at mid-width. A visible increase in water turbidity levels was observed in shoreline areas less than five feet deep after a period of less than five minutes. Water turbidity levels then increased at greater depth by increasing motor power. Yousef (1974) concluded that Lake Claire displayed little or no changes in surface water turbidity levels when the motorboat was equipped with a 28 HP motor. However, changes in water turbidity levels throughout the epilimnion was noticed at depths of six to seven feet (Yousef, 1974).

As part of another experiment, a 100 HP outboard motorboat ran for approximately 20 miles at Lake Mizell, Osceola and Maitland. Dissolved oxygen concentrations, nutrients, pH, water temperature and water turbidity levels were measured. Results indicated changes in dissolved oxygen concentrations; however, no apparent changes in water turbidity levels and nutrient concentrations were noted (Yousef, 1974).

At Lake Claire, a 50 HP motorboat was tied to a tree and held stationary in the lake at distances of 10 to 100 feet from the shore. The motor was allowed to run, and water samples were collected at different time intervals. Results indicated that water turbidity levels increased in the vicinity of the motorboat within first five minutes of operation. However, within 30 minutes the resuspended solids were transported away from the area by propeller wash currents, which lowered water turbidity levels (Yousef, 1974).

Yousef (1974) concluded that increases in nutrient concentrations were associated with increases in suspended solid concentrations. Lake Mizell has a very shallow photic zone and a noticeable decline in dissolved oxygen concentrations with depth. However, after agitation, mixing between layers did occur, and dissolved oxygen concentrations were homogenized (Yousef, 1974).

According to Yousef (1974), dissolved oxygen concentrations were the best indicator of water column mixing due to motorboat use. Conductivity, pH, nitrogen and water temperature levels were not as conclusive. Yousef (1974) concluded that in shallow eutrophic lakes, motorboats seem to resuspend sediments previously deposited on aquatic plant leaves, stems and on bottom sediments. Areas close to shoreline displayed the most rapid changes in water turbidity levels due to motorboat use (Yousef, 1974).

Moss (1977) carried out synoptic surveys of water turbidity levels and phytoplankton in navigable waterways, located in the Norfolk Broads and rivers area of eastern England. The study was conducted from July through December 1973. According to the researcher, the Norfolk Broads are small, shallow lakes excavated for peat until the 13th century. They support an annual population of at least 10,000 motorboats. Increased nutrient loading from human activity (i. e., nitrate and phosphorus) has been associated with macrophyte decline (Moss, 1977).

Moss (1977) concluded that significant correlations were confirmed between phytoplankton numbers and water turbidity levels, while only very weak correlations between motorboat activity and sustained water turbidity levels existed. Bank erosion was attributed to the effects of wash (e. g., from motor cruisers and agitation by propellers). Moss (1977) emphasized that sediment sinks back rapidly unless maintained in suspension by a continual passage of motorboats. In general, the lakes were more transparent in December, when both motorboat activity and phytoplankton numbers were minimal (Moss, 1977).

Hilton and Phillips (1982) conducted measurements of water turbidity levels and motorboat movements on the shallow Broadland River, the River Ant, located in England. The river flows through Barton Broad, which is a shallow lake 70 ha in area, where high summer concentrations of phytoplankton exist due to nitrate and phosphorus levels. Hilton and Phillips (1982) claimed that as many as 100 motorboats per hour have been known to navigate this lake. Water turbidity measurements were conducted both nephelometrically, and in conjunction with a chart recorder to provide continuous monitoring (Hilton and Phillips, 1982).

Hilton and Phillips (1982) indicated long-term build-up of motorboat-induced, water turbidity levels through summer peak-use seasons was unlikely. Most of the water turbidity was due to creation of algae mats from excess phosphorus. However, Hilton and Phillips (1982) claimed that motorboat traffic did have some effect on water turbidity levels. For example, although water turbidity levels increased throughout the summer, as phytoplankton crops increased, water turbidity levels during the holiday season also peaked during the same period, thus indicating periods of isolated motorboat-induced turbidity (Hilton and Phillips, 1982).

Significance of Literature to the Current Study

The literature review involved with motorboats was limited to experimental designs encompassing the manipulation of boat design, engine size, operating times, etc. It was not the intent to only rely on conclusions drawn from these types of studies in order to build a foundation for this study, which did not involve manipulation (e. g., cause and affect observational research in natural surroundings) of motorboat use density. Rather, an extensive literature search did not reveal non-manipulating research concerning motorboat use density. In addition, many of these studies were conducted on lakes located in varying climatic and geologic zones (i. e., England, Germany, Florida). No freshwater lake studies involving the effects of motorboat use on water turbidity levels were found within similar settings of Lake McMurtry.

Although the primary fact, in this study, involving dependent variables was water turbidity levels, dissolved oxygen concentrations and water temperature levels were included for scientific research purposes. As pointed out earlier, these two dependent variables both directly and indirectly influence the degree of water turbidity levels. Therefore, to better decipher causes of water turbidity (e. g., motorboat-induced versus eutrophication, etc.), these additional water parameters are of great value.

CHAPTER III

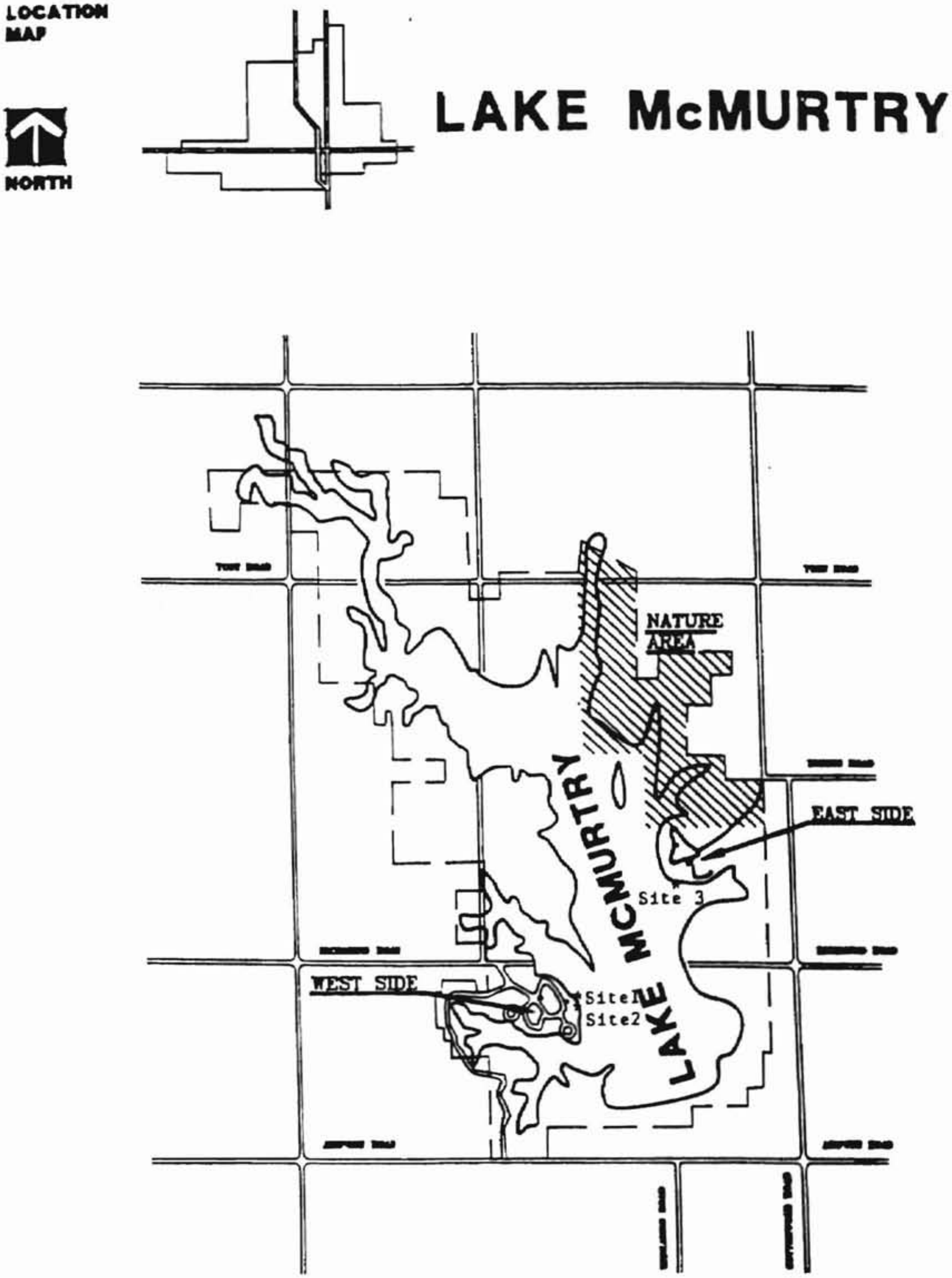
METHODS AND TECHNIQUES OF THE RESEARCH

Introduction

This study was designed to establish a comparative pattern of water quality relationships based on the time frame before, during and after peak motorboat season (i. e., May 15 through September 15, 1996) at Lake McMurtry, which is a freshwater recreational area located in north-central Oklahoma. The specific focus of the study was to determine what physical or chemical changes, if any, were occurring to dissolved oxygen concentrations, water temperature and water turbidity levels. Further, it was intended to correlate any possible changes (e. g., fluctuation or similarity of these limnological readings) to the above water parameters with meteorological conditions (e. g., average air temperatures, precipitation, wind speed and direction, etc.), and/or motorboat-induced agitation within the water column.

The study followed a causal-comparative approach, which allowed for influences on the independent variables to be observed in a natural and unaltered setting. Manipulation of motorboat traffic did not occur. To facilitate the stated research objectives, pre-existing data collection instruments were utilized. Three sites for measuring the water samples were selected. Appropriate statistical procedures (i. e.,

Figure I. Limnological Sampling Locations
(Source: Stillwater Parks and Recreation Dept.,1996)



ANOVA, Tukey's Honestly Significant Difference, Kolmogorov-Smirnov test of normality, and Spearman's Rho correlation tests) were applied to the collected water data.

Description of the Area Represented by the Sampling: Lake McMurtry

Lake McMurtry is 3440 total acres in size at floodpool (1155 surface acres) and is located seven miles to the northwest of Stillwater, Oklahoma (refer to Figure 1). The lake is also owned and operated by the City of Stillwater. The total watershed for this recreational lake is 16,200 acres. There are 28 miles of shoreline surrounding Lake McMurtry (Oklahoma Tourism and Recreation Department, 1995).

Lake McMurtry is only one-half mile north of Lake Carl Blackwell, which shares almost the same watershed characteristics (refer to Figure 2). However, Lake McMurtry is the shallower of the two lakes consisting of a 38-foot water column depth at the center (U. S. D. I., 1990).

Construction of Lake McMurtry began in the middle 1960s and was completed in the early 1970s. It was allowed to fill for the first time in 1974. The entire project was funded with United States of Agriculture (USDA) money (U.S.D.I., 1990).

Lake McMurtry receives most of its water level from runoff in the immediate vicinity. This aids in limiting bank erosion. The Lake McMurtry watershed is located in a climate zone that can experience significant temperature fluctuations throughout the year. Air temperatures can range from below 0° F from December through February to above 100° F from June through September. This area averages 31 inches of precipitation per year. Much of this comes during spring and summer via heavy convective storms of short duration (Harding and Taylor, 1972).

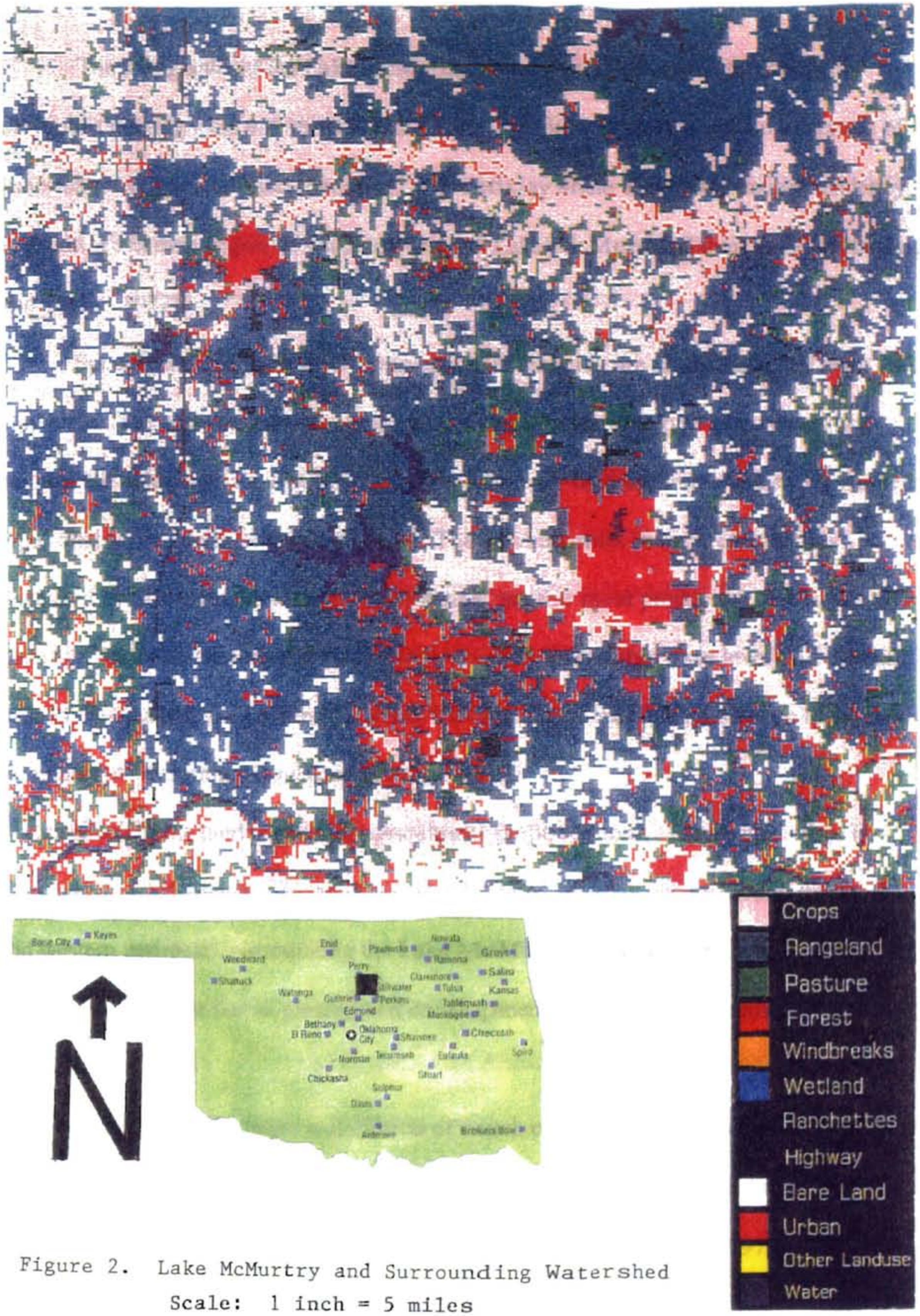


Figure 2. Lake McMurtry and Surrounding Watershed
Scale: 1 inch = 5 miles

The topography of the Lake McMurtry watershed is of moderate slope with elevations ranging from 950 to 1050 feet. Soils at Lake McMurtry contain a mixture of limestone, red clay shale and sandstone. The red clay shale maintain a natural tendency to produce a certain degree of water turbidity at Lake McMurtry (Bahnick, 1979; Harding and Taylor, 1972).

Specifically, the watershed's principal soil textures are sandy loam, silt loam and clay loam. The soil's character ranges from a rough, nonarable type of poor fertility, suitable for upland prairie as postoak-blackjack forests to deep, fertile and easily worked type suitable for alfalfa, maize and wheat. The alluvial soils in the area, which is deposited by Stillwater Creek and its tributaries, are the most productive. However, when Lake McMurtry reaches normal pool level (i. e., 952.3 feet above sea level), all the best soils in the area become covered by water, leaving the poorer quality soils on the uplands to support the remaining vegetation (Burks, 1972).

Much of the land is used for agricultural purposes such as cultivated crops (i. e., milo, wheat). Also, some grazing occurs there. Most grazing occurs around the southern and western perimeter, surrounding the Lake McMurtry area. Lesser amounts occur on the eastern perimeter due to greater land development (OSU Water Treatment Plant, 1996).

In 1972, the lake basin was cleared of much of its timber. This timber is presently located in piles of brush in the lake basin. These brush piles provide additional habitat and shelter for fish when normal pool elevation is maintained (Burks, 1972).

Recreational activities at Lake McMurtry include boating, camping, fishing, hiking, nature studies, picnicking and swimming. Hunting and fishing occur along the streams, impoundments and edge regions (Burks, 1972).

Finally, Lake McMurtry has a significant ecological diversity in terms of flora and fauna. Harding and Taylor (1972) stressed that this area is unique because it contains grasslands, forests and wetlands, all within its drainage basin.

Research Methodology

Field and laboratory analyses of limnological samples were conducted on the water quality, at three separate locations, in the southern half of Lake McMurtry. All testing parameters were sampled twice weekly from May 15 through September 15, 1996 (i. e., before, during and after peak motorboat use season). For the specific focus of this study, dissolved oxygen concentrations, water temperature, and water turbidity levels, were recorded five feet below the air/water interface.

The following is a descriptive summary of the research methods involved in this study. Information included in the summary covers: (1) the selection of monitoring sites; (2) research instruments; (3) water sampling days and times; (4) monitoring of motorboat use density; (5) Mesonet data represented; (6) groundwater data; and (7) analysis of data.

A total of three sampling locations were chosen at Lake McMurtry (refer Figure 3). All three sites are composed of bottom sediments consisting of a sandy-clay loam mixture. In addition, all sites contain water column depths ranging from 11 to 13 feet, depending on lake levels at any given time (OSU Water Treatment Plant, 1996, USDI, 1990). Sites one and two are located just inside the bay that surrounds the west side facilities at Lake McMurtry. Both sites are partially sheltered from prevailing so winds by an elevated strip of land ranging from 10 to 20 feet, within one quarter to the south (e. g., opposite side of the measuring locations across the bay). In a these sites are protected from surface winds ranging from 230° - 350° (i. e., sout through north-northwest).

Specifically, site one is located in the water column immediately north a adjacent to the fishing dock at the west-side facilities, and was the measuring lo containing the least amount of motorboat traffic in the immediate vicinity. Alth one is within 100 yards of the west-side boat ramp (i. e, site two), it is located w "no-wake zone" and receives only minor wake intensity. Site two is located in t column immediately adjacent to the west-side boat pier and contained the most motorboat traffic at Lake McMurtry (OSU Water Treatment Plant, 1996; USDI,

Site three is located in the water column immediately adjacent to the eas boat pier. Overall, this boat ramp area is less frequently used compared to the w ramp, thus allowing for less motorboat-induced wave action in this vicinity. Ho site three is exposed to much greater wave fetch, compared to sites one and two, from a more sustained south-southwest prevailing wind (180°-230°). In additio occasional high westerly winds (240°-300°) resulting from cold front passages, thunderstorms, etc. account for the greatest wind fetch (OSU Water Treatment 1996, USDI, 1990).

Pre-existing data collection instruments were chosen to monitor limnolo parameters at the three locations on Lake McMurtry. These instruments include *situ* and laboratory instruments. An *in situ* instrument was used to monitor diss oxygen concentrations and water temperature levels. This HACH Model DO175 Dissolved Oxygen Meter provides automatic water temperature and pressure compensation, as well as salinity correction. Specifications for dissolved oxygen readings concentrations include a range of 0-20.0 mg/L, a resolution of 0.1 mg/L, a relative accuracy of ±1%, a salinity correction of 0-40 ppt. and a barometric pressure compensation of 540-850 MnHg. Specifications for water temperature readings include a range of -5 to 45°C (-23 to 113° F) and a water temperature accuracy of ±1°C. Both parameters were displayed on an LCD display (HACH Products for Analysis: Ordering Catalog, 1996).

During sampling, the dissolved oxygen meter was lowered to a level of five feet below the water surface using a metal cable. The precise depth was measured from tick marks consisting of one-inch intervals. Immediately following depth adjustment, the dissolved oxygen meter was turned on for operation. Dissolved oxygen readings stabilized within 60 seconds, while water temperature readings stabilized within 30 seconds. After recording the two readings, the dissolved oxygen meter probe was raised out of the water and immediately placed into distilled water for future use. This insured correct calibration at all three measuring locations.

Next, water samples were collected, using a Wheaton grab sampler, at the five-foot level below the water surface, for the purpose of obtaining water turbidity samples. This instrument specifically allows for sub-surface sampling without surface water contamination. The Wheaton grab sampler consists of a metal, cylinder-shaped shell housing a glass bottle (HACH Products for Analysis: Ordering Catalog, 1996).

In this procedure, the sterilized, capped bottle was inserted into the grab sampler. The lined teflon cap was attached to a drop line made of metal chain material. The grab sampler was then lowered very slowly from the water surface down to the sampling depth of five feet. The depth was measured from tick marks consisting of one-inch intervals. Immediately following depth adjustment, the researcher firmly pulled the drop line, thus allowing the glass bottle to fill with sub-surface lake water. The bottle cap then sealed the bottle shut immediately upon ascent of the drop line. Once the uncontaminated water samples reached the surface, they were immediately transferred into white polyethylene bottles for laboratory analysis of water turbidity.

Next, the white polyethylene bottles were immediately packed into a totally dark, plastic container in order to prevent sunlight contamination (e. g., formation of bacteria that could possibly reduce water clarity even after short periods of time), while being transported to Stillwater Water Treatment Plant. These procedures were repeated at all three measuring sites at Lake McMurtry. The glass bottle housed in the Wheaton grab sampler was washed with distilled water before each use to prevent contamination from previous samples.

Immediately upon arrival at the Stillwater Water Treatment Plant, water turbidity measurements were conducted using a HACH Model 2100 N laboratory turbidimeter (EPA-approved). This laboratory instrument is a reliable device that provides accurate results over a wide range of water turbidity levels using either manual (0-1, 0-10, 0-100, 0-4000 NTUs) or automatic range (0-4000 NTUs) selection. The turbidimeter measures particles suspended in the water samples at a 90° angle. All samples were digested into three-ounce glass bottles and placed into the 2100N laboratory turbidimeter for instantaneous readouts. A total of six water samples per week (i. e., three samples twice a week) were transported from Lake McMurtry to the Stillwater Water Treatment Plant (HACH Products for Analysis: Ordering Catalog, 1995).

Individual sampling days for all water parameters included Wednesdays and Sundays. These two days were chosen by the researcher because of: (1) differing intensity of motorboat use and (2) possible differing settling potential in the lake waters. Samples measured on Wednesdays might be less influenced by motorboats. This is a time period when motorboat use is usually at a minimum, due to it being a workday, thus possibly allowing the lake waters to settle. At the other extreme. water parameter samples measured on Sundays may be more influenced by motorboat use (e. g., more similar readings in dissolved oxygen concentrations, water temperature and water turbidity levels due to possible higher use density and greater wave effects).

All water parameters at Lake McMurtry were sampled at two specific times (i. e., noon and evening) during each sampling week in order to reduce extraneous variables such as peak visitor use hours, fluctuations between night and day, or morning, afternoon and evening in terms of photosynthesis, respiration rates, etc. The three measuring sites were rotated on a weekly basis, in terms of these specific times (e. g., noon versus evening), in order to account for differences in limnological readings between noon and evening.

The amount of motorboat traffic, during the entire four-month study period, was monitored by the researcher according to the following method. Each of the three measuring sites containing active motorboat traffic, were represented according to the total number of motorboats in visual range of the researcher at the time of water measurements, ranging from less than ten feet to opposite shorelines. All active motorboats, regardless of proximity to each other, were counted for 20 minutes per site on each separate measuring day. This was the amount of time it took to collect water samples at each of the three measuring locations.

All motorboats, regardless of engine horsepower size, speed of travel on Lake McMurtry, and boat design were counted equally and represented only the total number of motorboats. This was allowed by the researcher due to the fact that Lake McMurtry is primarily a small fishing lake containing a maximum motorboat cruising speed of 25 mph. However, all motorboats counted exhibited active running engines, ranging from a stationary idle to maximum cruising speed. No motorboat with the engine shut off was included in the count. In addition, no motorboats or boat trailers parked out of the water were included in the count.

Mesonet data was employed for meteorological data. The Mesonet data system was developed in the early 1990's by a joint research team from the Department of Agronomy and Geography at OSU, as well as the Oklahoma Climatological Survey in Norman, Oklahoma. The Mesonet system consists of a network of meteorological measuring stations throughout the state.

For this study, the Marena Mesonet site just south of Lake Carl Blackwell was chosen (Oklahoma Climatological Survey, 1996). Specific Mesonet meteorological parameters analyzed included: (1) daily air temperatures including low and highs; (2) hourly wind speed and direction; (3) precipitation; and (4) a long-term average or mean of the above covering the fixed research period (i. e., May 15 through September 15, 1996).

All Mesonet data were used while evaluating water quality parameters from the three locations. They were compared to motorboat use intensity for each measuring day.

The researcher did not incorporate any groundwater data for the study region. Although groundwater can contribute to both the quantity and chemical quality of surface reservoirs through baseflow (e. g., into streams) and seepage, the contributions into the Lake McMurtry watershed and impoundment are negligible. According to Howick et al. (1982), this region is not located within a major groundwater basin.

Statistical variables used in this study were stored on a spreadsheet, then transferred to MS Excel for a one-way analysis of variance using Windows 98 in the OSU computer lab. The Statistical Package For the Social Sciences (SPSS), also in the OSU computer lab, was employed to calculate Tukey's Honestly Significant Difference, Games-Howell, the Kolmogorov-Smirnov test of normality, and Spearman's Rho tests.

CHAPTER IV

PRESENTATION OF FINDINGS AND ANALYSIS OF DATA

Introduction

The focus of this chapter is to describe collected data, and to present the analysis of that data. This research study was designed and carried out with the purpose of establishing a comparative pattern of water quality relationships on the time frame before, during and after peak boating season (i. e., May 15 through September 15, 1996) at Lake McMurtry in north central Oklahoma. For the specific focus of this study, water samples were collected at five to six feet below the water surface, and were analyzed both *in situ* and *ex situ* for dissolved oxygen concentrations, water temperature and water turbidity levels.

In this chapter, analysis and interpretation of findings are presented both descriptively and quantitatively in the form of tables and figures representing time-series graphs, which were segregated by individual water parameters to better facilitate the findings. An overview of Mesonet data is presented, which depicts weather trends at Lake McMurtry for the summer of 1996. This is followed by statistical analysis of the water parameters (i. e., dependent variables) represented in this study.

Overview of Mesonet Meteorological Data

A brief month-to-month meteorological summary is presented next. To accompany this summary, Figure 3 through Figure 5 (i. e., bar graphs) presented on the following three pages, depict meteorological trends at Lake McMurtry for the summer of 1996. In Appendix B, Table IX exhibits daily and monthly averages for air temperatures, precipitation, and wind speed and direction. The daily and monthly averages were calculated from readings taken every 15 minutes.

As previously mentioned, the Marena Mesonet site used in this study is located two miles south of Lake Carl Blackwell. This is approximately four nautical miles south-southwest of Lake McMurtry. It was assumed that this four-mile difference would experience very similar meteorological conditions, making it a viable part of the study. However, there were some minor meteorological differences between the water measuring locations and the Marena Mesonet site in terms of average air temperatures, elevation, precipitation amounts and occurrences, and windbreaks. For example, the Marena Mesonet site is located several feet above ground level, compared to surface elevation on the waters of Lake McMurtry. This, in combination with wind breaks such as elevated strips of land at measuring sites one and two at Lake McMurtry, probably allowed for greater average and maximum wind speeds at the Marena Mesonet site.

Precipitation amounts and occurrences may have varied also. For example, due to the fact that this study took place during summer months, most precipitation was

Figure 3. Average Daily Air Temperatures (Marena Mesonet Site - 1996)

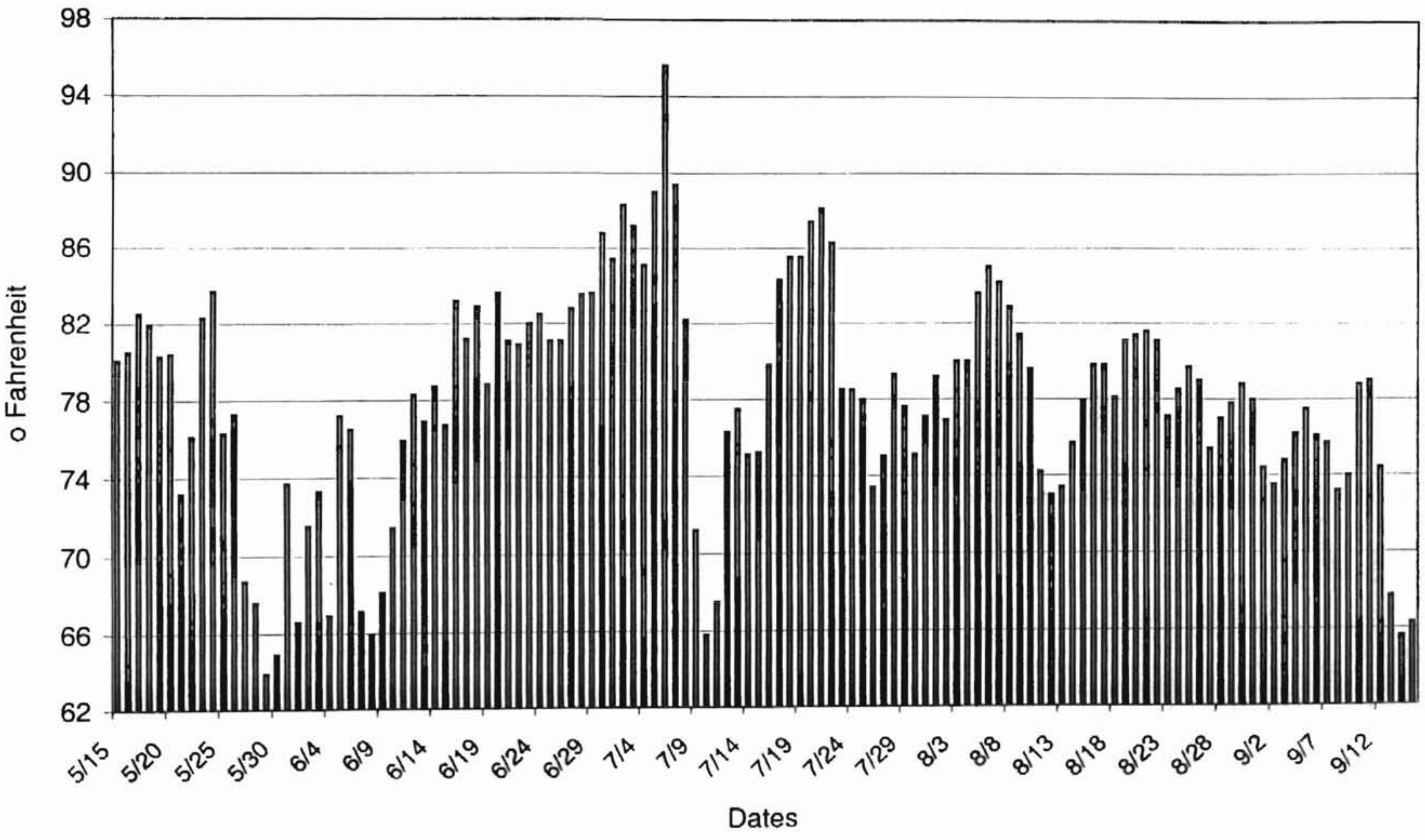


Figure 4. Average Daily Wind Speed (Marena Mesonet Site - 1996)

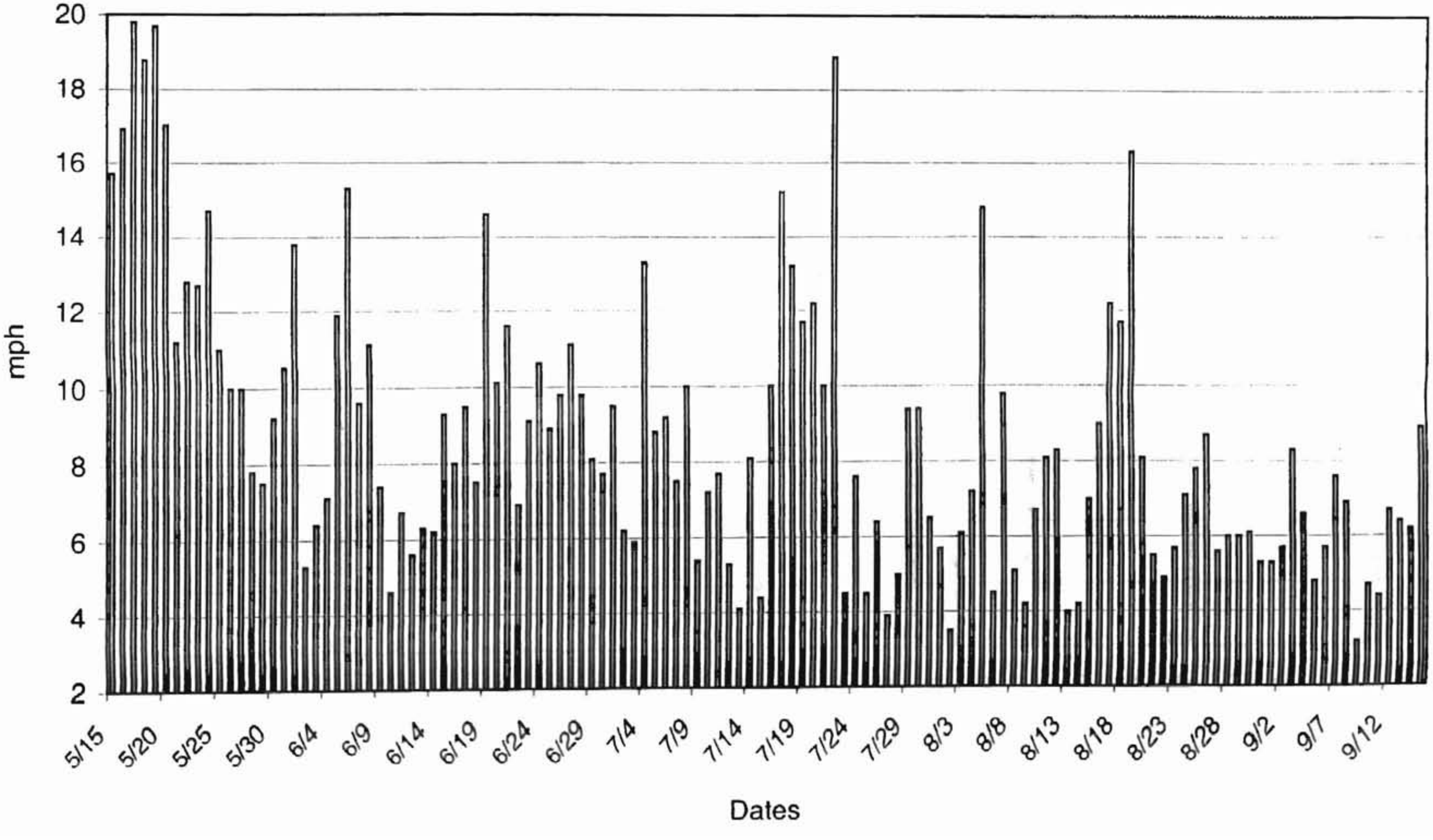
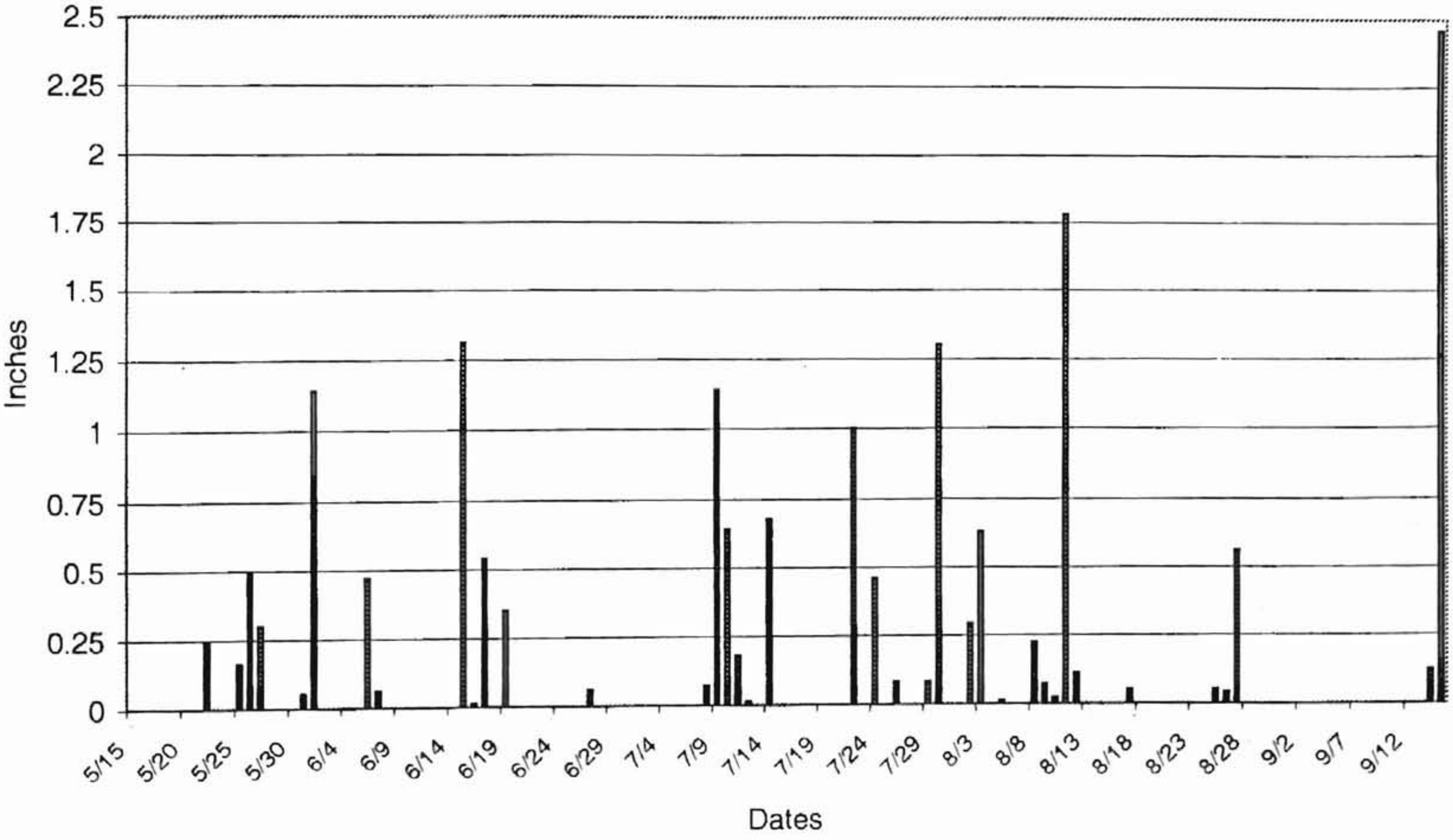


Figure 5. Precipitation Record (Marena Mesonet Site - 1996)



convective in nature. The more localized, hit and miss nature of convective storms made it possible for substantial differences to occur between the two locations, even though they were separated by only four miles. Also, average air temperatures could have been slightly lower at the Marena Mesonet site, since the more stable water temperatures at Lake McMurtry could have created a microclimate of greater consistency associated with air temperatures at the air/water interface. All of these minor differences were not calculated as part of the study results.

May 1996 marked the beginning of the field research period in the current study. According to the Mesonet data for May 1996, temperatures ranged from 48.0°F on May 1 to 92.7°F on May 23. Average daily temperatures ranged from 61.8°F on May 12 to 83.7°F on May 24. There were four days of 90°+ readings for the month.

May 1996 was also a very windy month, especially the second half of the month. The average wind speed for the period ranged from 6.6 mph on May 12 to 19.8 mph on May 17. Maximum gusts of 20+ mph occurred during 26 of the 31 days of May. Gusts of 30+ mph occurred for 15 days, while gusts of 40+ mph were recorded for four days, with a peak gust of 47.6 mph occurring on May 27. There were a total of eight days with measurable precipitation, ranging from 0.03 inches on May 14 to 0.49 inches on May 26. Total rainfall for May 1996 at the Marena Mesonet site was 1.56 inches.

June 1996 ushered in the most measurable precipitation since July 1995. Air temperatures ranged from 51.8°F on June 4 to 100.4°F on June 30. Average daily temperatures ranged from 65.9°F on June 8 to 86.8°F on June 30. There were 15 days of 90°+ readings for the month, and one day of 100°+ readings.

Although June averaged far below May in terms of surface wind speed, it was still a fairly breezy month. In addition, wind speeds were fairly uniform for the entire month. The average wind speed for the period ranged from 4.6 mph on June 10 to 15.3 mph on June 6. Maximum gusts of 20+ mph occurred during 21 of the 30 days of June. Gusts of 30+ mph occurred for three days, while gusts of 40+ mph were recorded for one day, with a peak gust of 45.6 mph occurring on June 6 during a thunderstorm.

There were a total of eight days of measurable precipitation, ranging from 0.01 inches on June 16 to 1.31 inches on June 15. Total rainfall for June 1996 at the Marena Mesonet site was 3.94 inches, which was the wettest month since July 1995.

Air temperatures ranged from 62.4°F on July 15 to 111.0°F on July 6. Average daily temperatures ranged from 65.8°F on July 11 to 95.6°F on July 6. There were 16 days of 90°+ readings for the month, and six days of 100°+ readings.

The average wind speed for the period ranged from 3.9 mph on July 27 to 18.9 mph on July 22. Maximum gusts of 20+ mph occurred during 17 of the 31 days of July, mainly in the middle of the month. Gusts of 30+ mph occurred for three days, with a peak gust of 51.9 mph occurring on July 22 during a thunderstorm.

There were a total of 11 days of measurable precipitation, ranging from 0.01 inches on July 12 to 1.30 inches on July 30. Total rainfall for July 1996 at the Marena Mesonet site was 5.64 inches, which was the wettest month since July 1995.

Air temperatures ranged from 61.2°F on August 13 to 94.3°F on August 7. Average daily temperatures ranged from 73°F on August 12 to 85°F on August 6. There were 12 days of 90°+ readings for the month.

The average wind speed for the period ranged from 3.5 mph on August 2 to 16.3 mph on August 19. Maximum gusts of 20+ mph occurred during 13 of the 31 days of August. Gusts of 30+ mph occurred only one day during August 1996. Overall, August was the second most tranquil month of the summer in terms of wind speed; only September remained calmer.

There were a total of 11 days of measurable precipitation, ranging from 0.01 inches on August 5 to 1.78 inches n August 11. The 1.78-inch total on August 11 was the second most significant 24 hour rain total during the entire summer at the Lake McMurtry area, next to the 2.46 inches recorded on September 15. Total rainfall for August 1996 at the Marena Mesonet site was 3.27 inches, which was the third wettest summer month behind July (i. e., 5.64 inches) and June (i. e., 3.94 inches), respectively.

Air temperatures for the first two weeks of September ranged from 58.6°F on September 9 to 94.6°F on September 11. Average daily temperatures for the same period ranged from 66.3°F on September 15 to 79°F on September 11. There were two days of 90°+ readings for the first half of the month, while afternoon highs remained in the 60's from September 13-15.

The average wind speed for the period ranged from 3.2 mph on September 9 to 8.9 mph on September 15. Maximum gusts of 20+ mph occurred during five of the first 15 days in September. All peak gusts remained under 30 mph, resulting in a fairly tranquil pattern through September 15. Overall, September was the most tranquil month of the summer in terms of wind speed.

There were a total of two days of measurable precipitation during the first 15 days of September 1996. These amounts were 0.12 inches on September 14 and 2.46 inches on September 15, which was directly related to the remains of Tropical Storm Fausto. The 2.46-inch total was the most substantial 24-hour rain total during the entire summer at the Lake McMurtry area. Total rainfall for the first half of September 1996 at the Marena Mesonet site was 2.59 inches, which was the fourth wettest period of the study.

Anomalies

Limnological sampling, involving the dependent variables of dissolved oxygen concentrations, water temperature and water turbidity levels, was conducted during meteorological extremes at Lake McMurtry, which may have affected the water samples to some degree. As previously mentioned in Chapter IV, the sampling period, from May 15 – July 7, 1996, was unusually hot and dry, in terms of average weather conditions expected for this region. This was followed by a cool and wet period from July 10 – Sept. 15, 1996.

The three water parameters measured are very sensitive to major shifts in weather patterns, as was indicated by Cross (1992), Entz (1980) and Howick et al (1982). For a complete description of specific meteorological data, refer to the section on overview of Mesonet meteorological data in Chapter IV. These factors must be considered when comparing readings for the entire four-month research period.

Statistical Analysis of Water Parameters: Lake McMurtry, 1996

Statistical analysis of water parameters (e. g., dependent variables including dissolved oxygen concentrations, water temperature and water turbidity levels) were conducted to determine any significant differences at the $\alpha = .05$ confidence level. This confidence level is used in most water research on an internatinoal basis according to Moss (1977) and Entz (1980). The sequence of statistical testing included the following stages. First, a one-way analysis of variance (ANOVA) was conducted on all dependent variables, both between each measuring site and within the three measuring locations.

The null hypothesis was tested, which stated that there are no significant differences between the means of the water parameters (i. e., dependent variables) or from within each group. If no significant differences were found, the null was not rejected and no further testing occurred. Second, if significant differences were noted during ANOVA testing, post hoc comparisons using Tukey's Honestly Significant Differences and Games-Howell tests were then employed for the purpose of making pair-wise comparisons. This isolated significant differences between each dependent variable.

Third, a Kolmogorov-Smirnov test was conducted for detecting significant differences occurring to normality patterns within water sampling locations. This test further isolates data from each measuring location and allows meaningful interpretation when spurious values (e. g., outliers) are present. Fourth, Spearman Rank Correlation Coefficient tests, also known as Spearman's Rho tests, were conducted. These tests indicate the direction (i. e., monotonically increasing or decreasing function) of the relationship between each dependent variable (e. g., dissolved oxygen, water temperature, and water turbidity) and all independent variables, including average daily wind speeds, air temperatures, precipitation events and motorboat counts. The absolute magnitude of the coefficient indicates the strength of association between the variables.

Dissolved Oxygen

Field observations of dissolved oxygen concentrations were recorded at three separate measuring locations at Lake McMurtry. Table VIII in Appendix A shows these measurements. Figure 6 represents a time-series line graph for dissolved oxygen concentrations, and covers the entire study period from May 15 through September 15, 1996.

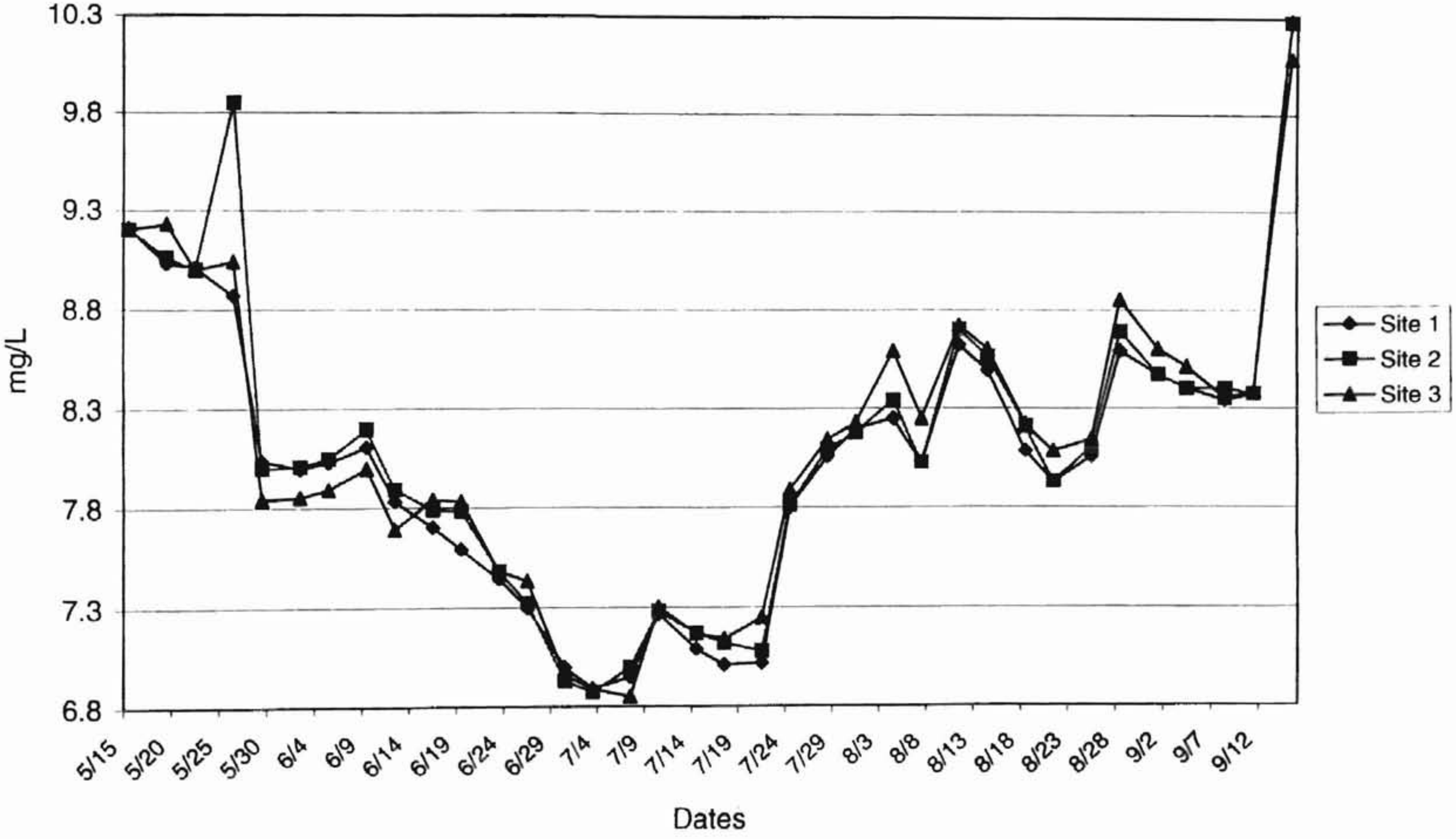
Dissolved oxygen concentrations ranged as follows: Site one ranged from 6.89 mg/L on 3 July 1996 to 10.29 mg/L on 15 September 1996. Site two ranged from 6.87 mg/L on 3 July 1996 to 10.28 mg/L on 15 September 1996. Site three ranged from 6.85 mg/L on 7 July 1996 to 10.09 mg/L on 15 September 1996.

Dissolved oxygen concentrations displayed the most similar readings (e. g., smallest range of difference in concentrations) between the three measuring stations. Dissolved oxygen concentrations were near totally uniform at 9 mg/L on 15 and 22 May 1996, 6.8 mg/L on 3 July 1996, 7.2 mg/L on 7 July 1996 and 8.3 mg/L on 11 September 1996.

Overall, due to hot and dry weather, dissolved oxygen concentrations steadily decreased (i. e., from > 9 mg/L to < 7 mg/L) over the period from 15 May through 4 July 1996. The period specifically between June 25 and July 24, 1996 reflected the warmest air temperatures of the year, and was inversely proportional to water temperature levels for the same period (refer to Figures 6 and 7).

The period from 7 July – 15 September experienced a sharp rise in dissolved oxygen concentrations (i. e., from < 7 mg/L to > 10 mg/L) due to greater rainfall and

Figure 6. Dissolved Oxygen (Lake McMurtry - 1996)



lower air temperatures over this period. The highest level at 10.29 mg/L was a result of the remains of Tropical Storm Fausto, which dumped 2.46 inches of rain over the area on 15 September 1996. This is in sharp contrast to the decreased water temperature levels for the same period.

An analysis of variance test was conducted. The probability of F determined that no significant differences occurred in dissolved oxygen concentrations between or within measuring locations, during the study period, at Lake McMurtry. Therefore the H_0 is not rejected. Results of this test are presented in Table I. Due to no significant differences, no further tests were conducted for dissolved oxygen concentrations.

TABLE I

ANALYSIS OF VARIANCE BETWEEN AND WITHIN MEASURING LOCATIONS FOR DISSOLVED OXYGEN

Source	SS	DF	MS	F	p
Between	.103	2	5.175	.092	.91
Within	59.051	105	.562		
Total	59.155	107			

Not significant, p > .05.

Variable	N	Mean	SD	SE
1	36	8.0383	.7369	.1228
2	36	8.1017	.7775	.1296
3	36	8.1061	.7347	.1224
Total	108	8.0820	.7435	7.155

Water Temperature

Field observations of water temperature levels were recorded at three separate measuring locations within Lake McMurtry. Table VIII in Appendix A shows the data. Figure 7 represents a time-series line graph for water temperature levels, and covers the entire study period from May 15 through September 15, 1996.

Water temperatures levels ranged as follows: Site one ranged from 71.6°F on 15 May 1996 to 86.°F on 3 and 7 July 1996. Site two ranged from 71.6°F on 15 May 1996 to 87.8°F on 3 July 1996, while site three ranged from 71.6°F on 15 May and 15 September 1996 to 89.6°F on 3 July 1996.

During the first half of the study period, water temperature levels were, overall, slightly lower (e. g., by 1 to 3°F) at site three versus sites one and two. This was indicative of site three being well mixed, through upwelling, by strong, persistent and prevailing southerly winds throughout the period. Average daily air temperatures, which were fairly uniform through the end of June, most likely contributed to the uniform water temperature levels during the periods of 15 May – 12 June 1996, as well as 23 June – 3 July 1996.

The second half of the field research period saw a more uniform and slightly lower water temperature level due to frequent rain and thunderstorm activity. All three sites displayed totally uniform water temperature levels on 10 July 1996, 11 and 14 August 1996, and 8 and 15 September 1996. These similarities were during periods of heavy rainfall and cloud cover. Water temperature levels at all three measuring locations contained the most frequent periods of total uniformity, compared to dissolved oxygen

CHAPTER IV

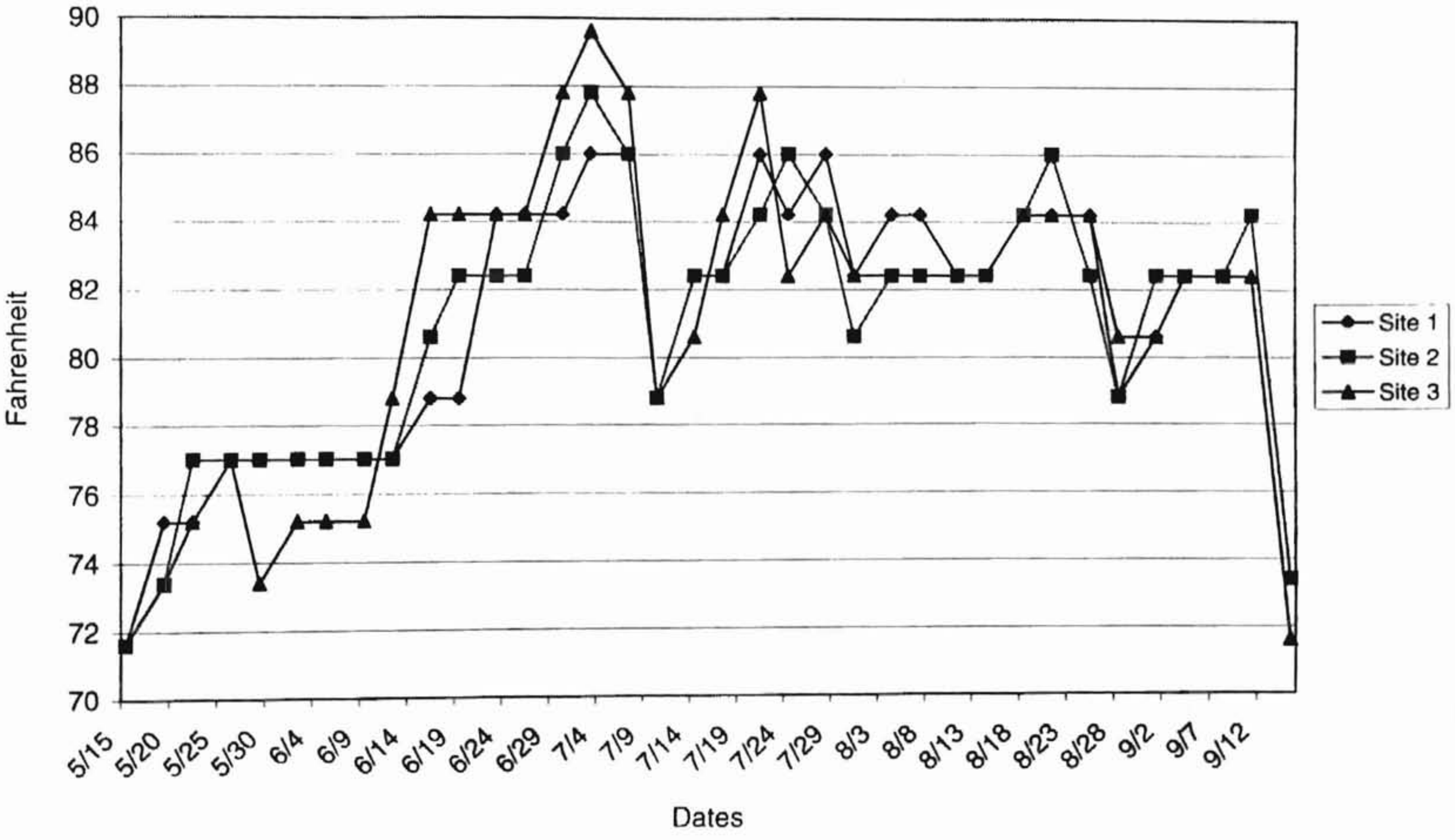
PRESENTATION OF FINDINGS AND ANALYSIS OF DATA

Introduction

The focus of this chapter is to describe collected data, and to present the analysis of that data. This research study was designed and carried out with the purpose of establishing a comparative pattern of water quality relationships on the time frame before, during and after peak boating season (i. e., May 15 through September 15, 1996) at Lake McMurtry in north central Oklahoma. For the specific focus of this study, water samples were collected at five to six feet below the water surface, and were analyzed both *in situ* and *ex situ* for dissolved oxygen concentrations, water temperature and water turbidity levels.

In this chapter, analysis and interpretation of findings are presented both descriptively and quantitatively in the form of tables and figures representing time-series graphs, which were segregated by individual water parameters to better facilitate the findings. An overview of Mesonet data is presented, which depicts weather trends at Lake McMurtry for the summer of 1996. This is followed by statistical analysis of the water parameters (i. e., dependent variables) represented in this study.

Figure 7. Water Temperature (Lake McMurtry - 1996)



concentrations and turbidity levels for the study period. Site three contained the lowest overall water temperature levels and highest dissolved oxygen concentrations, which are indicators of a typical windward facing shoreline, according to both research results in Chapter II and other literature.

An analysis of variance test was conducted. The probability of F determined that no significant differences occurred in water temperature levels between or within measuring locations, during the study period, at Lake McMurtry. Data results of this test are presented in Table II. Due to no significant differences, no further tests were conducted for water temperature levels.

TABLE II

ANALYSIS OF VARIANCE BETWEEN AND WITHIN MEASURING LOCATIONS FOR WATER TEMPERATURE

Source	SS	DF	MS	F	p
Between	.240	2	.120	.007	.99
Within	1858.680	105	17.702		
Total	1858.920	107			

Not significant, p > .05.

Variable	N	Mean	SD	SE
1	36	81.0000	3.9462	.6577
2	36	81.0000	3.9227	.6538
3	36	81.1000	4.7059	.7843
Total	108	81.0333	4.1681	.4011

Water Turbidity

Laboratory analysis of water turbidity levels, which consisted of *ex situ* water samples, were recorded from three separate measuring locations at Lake McMurtry. Table VIII in Appendix A shows descriptive results of these measurements. Figure 8 represents a time-series line graph for water turbidity levels, and covers the entire study period from May 15 through September 15, 1996.

Water turbidity levels ranged as follows: Site one ranged from 5.11 NTU's on 8 September 1996 to 23.3 NTU's on 15 May 1996. Site two ranged from 4.81 NTU's to 23.3 NTU's on 15 May 1996. Water turbidity levels at site three ranged from 6.12 NTU's on 8 September 1996 to 22.6 NTU's on 19 May 1996. Water turbidity levels at site three, during most of the study period, were consistently higher than sites one and two.

An analysis of variance test was conducted. The probability of F determined that significant differences did occur in water turbidity levels. Results of this test are presented in Table III.

According to ANOVA, the H_0 that states there is no significant difference in water turbidity levels between the three locations or within each location, during the study period, is rejected.

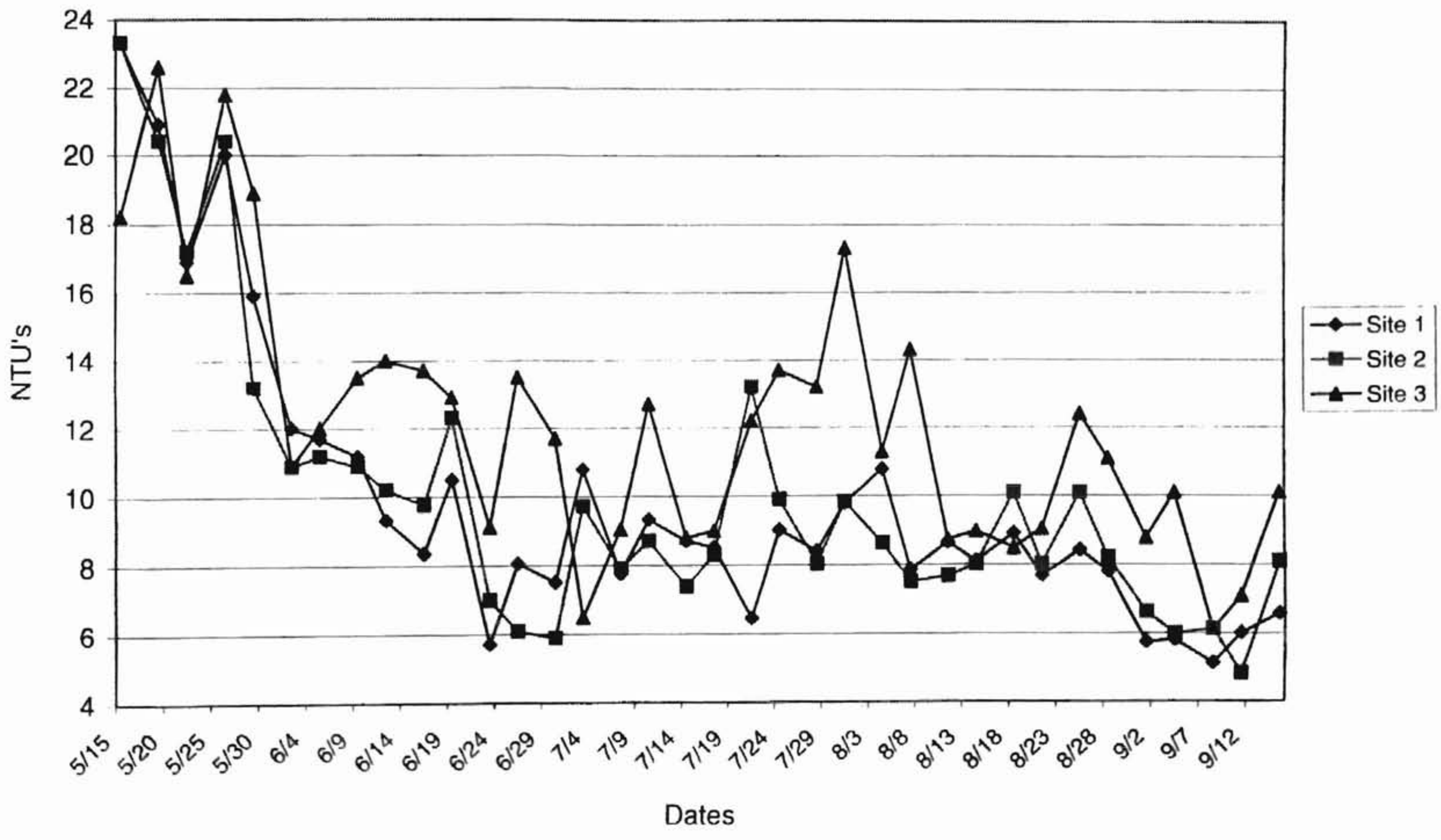


Figure 8. Water Turbidity (Lake McMurtry - 1996)

TABLE III

ANALYSIS OF VARIANCE BETWEEN AND WITHIN MEASURING LOCATIONS FOR WATER TURBIDITY

Source	SS	DF	MS	F	p
Between	114.855	2	57.428	3.276	.04*
Within	1840.441	105	17.528		
Total	1955.296	107			

*Significant, p < .05.

Sites	N	Mean	SD	SE
1	36	9.9294	4.3306	.7218
2	36	10.0425	4.2518	.7086
3	36	12.1714	3.9688	.6615
Total	108	10.7144	4.2748	.4113

To determine where the significant differences occurred post hoc tests (i. e., Tukey's HSD, Games-Howell) were conducted. Table IV outlines the results for Tukey's HSD and Games-Howell water turbidity testing. Both Tukey's HSD and Games-Howell tests were chosen in order to eliminate possible conflict between variance, since Tukey's HSD assumes equal variance and Games-Howell does not.

Table IV shows that no significant differences exist in water turbidity levels, according to Tukey's HSD testing, between all three measuring sites combined or between sites one and two, and three, and one and three on individual comparisons. Table IV also shows similar results on the Games-Howell descriptions.

TABLE IV

TUKEY HSD POST HOC TEST FOR WATER TURBIDITY

Post Hoc Test	Site	Site	MD	SE	p
Tukey HSD	1	2	-.1131	.987	.993
		3	-2.2419	.987	.064
	2	1	.1131	.987	.993
		3	-2.1289	.987	.083
	3	1	2.2419	.987	.064
		2	2.1289	.987	.083
Games-Howell	1	2	-.1131	.987	.993
		3	-2.2419	.987	.064
	2	1	.1131	.987	.993
		3	-2.1289	.987	.079
	3	1	2.2419	.987	.064
		2	2.1289	.987	.079

*Significant, p > 0.05

Tukey HSD	1	36	9.9294
	2	36	10.0425
	3	36	12.1714
	p		.064

*Significant, p > 0.05

Due to the fact that non-normal distributions can influence an ANOVA significance level (e. g., becoming meaningless due to the appearance of spurious values), the researcher proceeded to conduct a Kolmogorov-Smirnov test of normality. This test further isolates data from each measuring location, and is a very reliable indicator of normality. Table V below also confirms that sites one and two have non-normal distributions on measures of water turbidity levels, while site three is normally distributed on the same measures.

TABLE V

KOLMOGOROV-SMIRNOV TEST OF NORMALITY FOR WATER TURBIDITY

Variable	Statistic	df	p
Site 1	.223	35	<.001*
Site 2	.207	35	<.001*
Site 3	.129	35	.136

*Significant at $\alpha = .05$

The null hypothesis, based on the original results of the analysis of variance test, was rejected. However, based on skewness and non-normal distribution in two of the three factors, it was determined that the ANOVA contained spurious values, that gave a false indication of significant differences at the .05 confidence level. In actuality there were no significant differences. Therefore, based on this fact, the H_0 that states there is no significant differences in water turbidity levels between the three locations or within each location, during the study period, is not rejected.

Spearman Rank Correlation Analysis

A Spearman Rank Correlation Coefficient Analysis was conducted for all dependent variables (i. e., dissolved oxygen concentrations, water temperature and water turbidity levels). In addition, the Spearman's Rho was conducted for all independent variables (i. e., average air temperature, average wind speeds, motorboat counts and rainfall) for the entire four-month study period.

The specific method of Spearman's Rho calculations used in this research included averaging the combined coefficients for all independent variables, at 24-hour intervals, for a total duration of 72 hours preceding each measuring day. The only exception was with motorboat counts, where the coefficients were averaged for a period of 72 – 96 hours preceding each motorboat count day, since motorboats were only counted on Wednesdays and Sundays.

Table VI shows Spearman's Rho correlations for all independent variables. The sign of the coefficient indicates the direction of the relationship between each set of two variables, and the absolute magnitude of the coefficient indicates the strengths of association between each set of two variables. The Spearman's Rho probability was .445 at the $\alpha = .05$ confidence level. This is in conjunction with 36 sampling periods. Only absolute values greater than .445 will be discussed as significant.

Spearman's Rho correlational values range from zero (i. e, weakest) to plus or minus one (i. e., strongest). Positive correlational values are directly proportional to the independent variables. This indicates that the independent variables (i. e., left column of Table VI) may be related to or associated with dependent variable levels. These variables

TABLE VI

SPEARMAN RANK CORRELATION COEFFICIENTS (ASSOCIATIONS)

Independent Variables		Dependent Variables		
		Water Turbidity	Dissolved Oxygen	Water Temperature
Average Air Temperatures	r_s =	-.22	-.47*	.63*
	p =	.090	.034	.009
	N =	36	36	36
Motorboat Use Density	r_s =	.09	.18	-.04
	p =	.116	.086	.136
	N =	36	36	36
Average Wind Speeds	r_s =	.61*	.33	-.55*
	p =	.012	.065	.026
	N =	36	36	36
Precipitation	r_s =	.29	.52*	-.64*
	p =	.071	.025	.006
	N =	36	36	36

* significant at $\alpha = .05$

included dissolved oxygen concentrations, water temperature and water turbidity levels within the waters of Lake McMurtry. For example, as measures of one independent variable increased, so did measures on the dependent variable.

Negative correlation values are inversely proportional to the independent variables. This indicates that measures of the independent variables decline as measures of the dependent variables rose or vice versa.

Dissolved Oxygen

Rainfall was associated with the strongest correlation to dissolved oxygen concentrations, during the study period at Lake McMurtry. The .52 average Spearman's Rho coefficient indicates a moderate, positive correlated relationship. These conclusions indicate that increases in precipitation events were related to or associated with increases in dissolved oxygen concentrations or amounts over the study period. Thus, rainfall was related to the addition of atmospheric oxygen to the water columns at Lake McMurtry.

The second strongest correlation with dissolved oxygen concentrations, over the study period at Lake McMurtry, was associated with average air temperatures, as indicated by a -.47 Spearman's Rho coefficient. This accounts for a moderate, negative-correlated relationship between variables. These conclusions indicate that increases in air temperatures were related to or associated with decreases in dissolved oxygen concentrations, on a moderate basis, over the study period. Thus, cooler water was related to higher dissolved oxygen concentrations at Lake McMurtry.

Water Temperature

Rainfall was the strongest associated independent variable with water temperature levels, during the study period, at Lake McMurtry. The -.64 average Spearman's Rho coefficient indicates a moderate, negative-correlated relationship between variables. These conclusions indicate that decreases in precipitation events and amounts were related to or associated with increases in water temperature levels. Thus, rainfall was related to the cooling of waters at Lake McMurtry.

The second strongest correlation with water temperature levels, during the study period at Lake McMurtry, was associated with average air temperatures. This is indicated by a .63 Spearman's Rho coefficient, which is a moderate to strong, positive relationship between varibles. These conclusions indicate that increases in air temperatures were related to or associated with increases in water temperature levels. Thus, higher air temperatures were related to warmer water temperatures at Lake McMurtry.

Average wind speeds accounted for the third strongest correlation or association with water temperature levels during the study period at Lake McMurtry, as indicative of a -.55 Spearman's Rho coefficient. This accounts for a moderate, negative-correlated relationship between variables. These conclusions indicate that decreases in wind speeds were related to or associated with increases in water temperature levels. Thus, higher surface winds were related to cooler water temperatures. The winds provided a mixing effect between cooler air temperatures and water temperature levels at Lake McMurtry.

Water Turbidity

Average wind speeds showed the strongest correlation with water turbidity levels, over the study period, at Lake McMurtry. This is indicated by a .61 Spearman's Rho coefficient, which is indicative of a moderate, positive association between variables. These conclusions indicate that increases in wind speeds were related to or associated with increases in water turbidity levels. Thus, there was a relationship between higher water turbidity levels and wind-induced turbulence through wave action, which acted to erode shorelines and stir up bottom sediments at Lake McMurtry.

Finally, motorboat use density did not display significant relationships or associations with either dissolved oxygen concentrations, water temperature or water turbidity levels, according to the Spearman's Rho correlation analysis. These coefficients were only .09, .18, and -.04, respectively. Previous analysis involving ANOVA, associated follow-up tests, as well as the Kolmogorov-Smirnov test also revealed that no significant differences existed in water turbidity levels between or within the three measuring locations. Therefore, even though motorboat counts varied significantly between the three sites, over the four-month study period (refer to Figure 9), motorboat use density was not related to or associated with fluctuating water turbidity levels at Lake McMurtry during the summer of 1996.

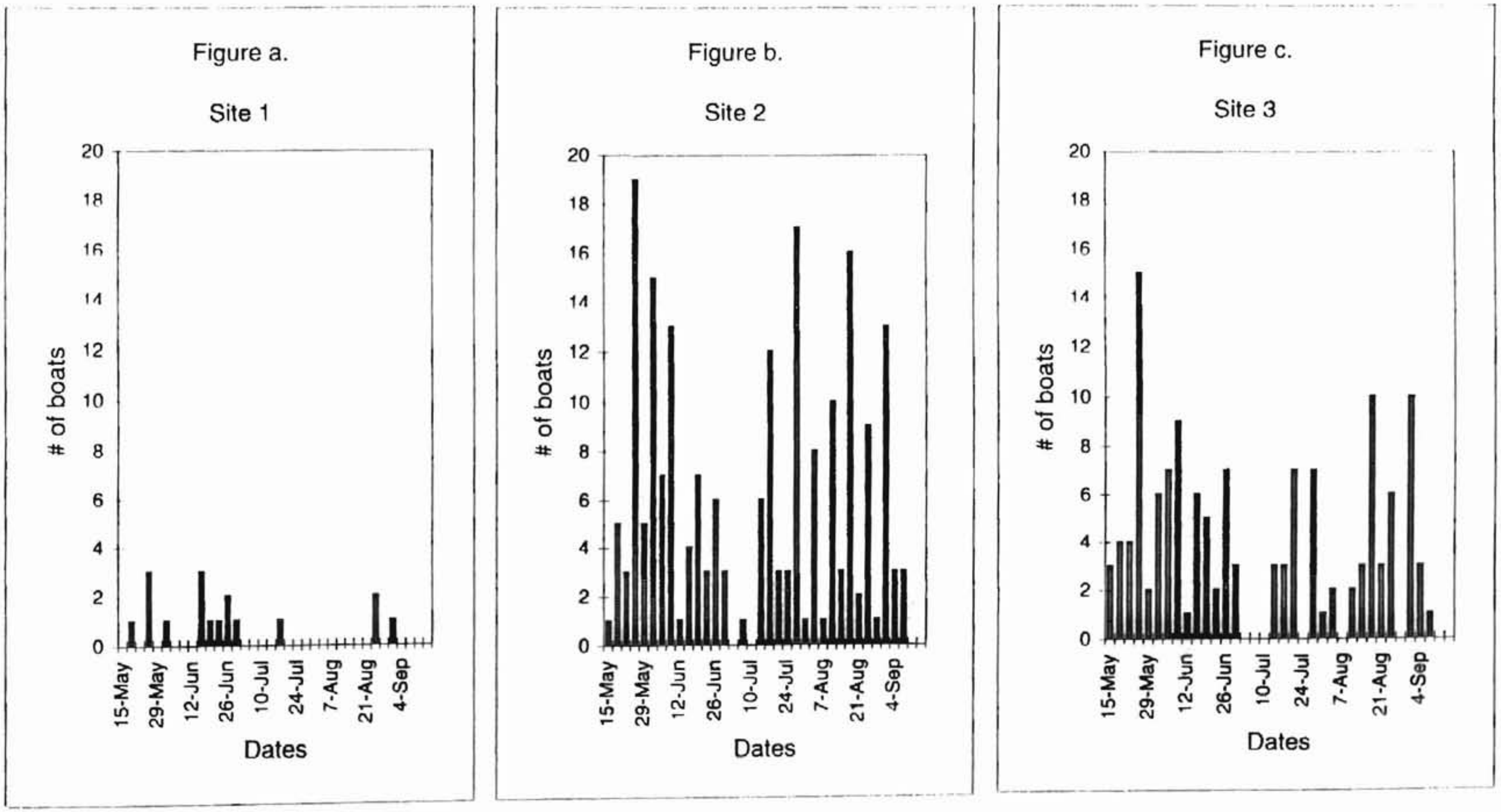


Figure 9. Number of Motorboats Per Sampling Location (Lake McMurtry - 1996)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Summary

The number of visitors to freshwater lakes as well as those actively participating in water-oriented recreation (e. g., motorboat use) continues to increase. Preservation of environmental quality, including water clarity, has become a growing issue, especially to boaters, fishermen, jet skiers, swimmers, water skiers, etc. As aquatic recreation at lakes continues to rise, the saturation point is approaching whereby usage may need to be balanced with long-term preservation. Additional knowledge and further research aimed at ecological impact upon these fragile ecosystems is needed. Recreationists as well as local, state and federal agencies need to unite in an effort to preserve recreational water quality.

This study was designed to establish a comparative pattern of water quality relationships based on the time frame before, during and after peak motorboat season (i. e., summer) at Lake McMurtry, which is an aquatic recreation area located in north central Oklahoma. Specifically, a comparison was made between various levels of motorboat use and meteorological conditions. These comparisons were aimed at identifying which, if any, of the physical or chemical parameters, including dissolved oxygen concentrations, water temperature and water turbidity levels, were altered both between three separate measuring locations and within each location over the linear four-month study period.

Current literature, included in this study, indicates that some forms of recreational activity, precipitation runoff into local freshwater lakes, and other forms of discharge into surrounding watersheds do have an impact on the water quality, regardless of the geographical setting of the recreation area. Other research, also included in this study, has been less conclusive.

The following table is a descriptive summary indicating the significance and non-significance of ANOVA results for all dependent variables tested in the study. The significance level was set at the $\alpha = .05$ confidence level.

TABLE VII

SIGNIFICANCE AND NON-SIGNIFICANCE OF ANOVA RESULTS FOR DEPENDENT VARIABLES TESTED

Group	H_0 Prediction	ANOVA Results
Dissolved Oxygen	N	N
Water Temperature	N	N
Water Turbidity	N	S*

N means not significant at alpha = .05
S means significant at alpha = .05
*Significant difference was due to spurious value resulting from non-normal distributions within sites one and two (refer to Chapter IV for further explanation).

Conclusions

Based on conclusive scientific results in the related literature section, located in Chapter II, as well as the limitations, deliminations and results of this study, the following conclusions are drawn.

1. Statistical analysis (i. e., ANOVA) of limnological observations, encompassing dissolved oxygen concentrations and water temperature levels, showed that no significant differences existed at the $\alpha = 0.5$ confidence level, between or within the three sampling locations over the four-month research period. Water turbidity levels also displayed no significant differences both between the three sampling locations and within site three, at the $\alpha = .05$ confidence level, during ANOVA testing.

According to ANOVA results, there were significant differences, at the $\alpha = .05$ confidence level, involving water turbidity levels within sites one and two, over the four-month study period at Lake McMurtry. However, following post hoc tests (i. e., Tukey's Honestly Significance Difference and Games-Howell), as well as the Kolmogorov-Smirnov test of normality, it was determined that significance differences in water turbidity levels within sites one and two were due to spurious values. The ANOVA only appeared significant due to non-normal distributions. In actuality there were no significant differences in water turbidity levels either between or within these locations.

2. Dissolved oxygen concentrations at Lake McMurtry, during the summer of 1996, exhibited no unusual fluctuations outside of normal seasonal variation and short-term meteorological phenomena. This was true both between the three measuring locations and within each location. The periods of greatest dissolved oxygen concentration and

water temperature level fluctuations were noted during storm and major precipitation events, as well as windy periods in general. Fall overturn accounted for the sharp rise and fall in dissolved oxygen concentrations and water temperature levels at the end of the study period, respectively.

Lake McMurtry, being a small and shallow lake, was sensitive to meteorological gradients as Imboden and Wuest (1995) claimed for this type of lake morphology. These conditions as Lighthill (1978) suggested occasionally created large surface waves, as was observed during the research phase at Lake McMurtry, thus increasing the mixing ratio between dissolved oxygen concentrations and atmospheric oxygen.

Lighthill (1978) also stated that dissolved oxygen concentrations were generally higher on the leeward or fetch end of a lake. Although Lighthill (1978) was referring to a much larger lake, site three at Lake McMurtry was also consistently higher in dissolved oxygen concentrations. Although site three was not statistically significant from the other two sites, this supports Lighthill's claim. Site three received the most wind stress, thus piling water up and mixing it at all levels simultaneously. Leonard (1950) also discovered this phenomena on the northern shoreline of Lake Carl Blackwell.

The final conclusion associated both dissolved oxygen concentrations and water temperature levels at Lake McMurtry with natural or meteorological induced fluctuations including air temperature, rainfall and wind speed. The lake does not appear to be entering into a eutrophication stage due to either low dissolved oxygen concentrations or high water temperature levels, according to conditions described in both the literature and research conducted by Liddle and Scorgie (1980) and Yousef (1974), respectively.

3. Water turbidity levels at Lake McMurtry, during the summer of 1996, also exhibited similar trends. These levels, like dissolved oxygen concentrations and water temperature levels there, were also controlled by natural phenomena such as air temperatures, rainfall rates creating inflow, and wind speed and direction. According to Yousef (1974), water turbidity only becomes significant to water quality, outside of aesthetics, when dissolved oxygen concentration rates fall below 1 or 2 mg/L. Lake McMurtry, as previously emphasized, was well above this level during the entire four-month study period.

The water turbidity patterns in Lake McMurtry were similar to Entz's (1980), Hysmith's (1975) and Johnson's (1991) findings whereby wave action, from higher wind speeds, was related to a reduction of water transparency, especially on the wave fetch or northeast shoreline area.

The current water turbidity findings also agree with Irwin and Stevenson (1951) and Leonard's (1950) Lake Carl Blackwell conclusions, that indicated heavier rainfall periods produce an increase in silt and montmorillonite clay levels via inflow into Lake Carl Blackwell. The result is higher water turbidity levels, within 72 hours, following significant rainfall events.

Motorboat activity on Lake McMurtry did not contribute to either higher water turbidity levels or damage to the aquatic environment in general. This was also the conclusion from Moss' (1977) study. Therefore, the long-term build-up of motorboat-induced water turbidity, at Lake McMurtry, through summer peak-use seasons is unlikely, if motorboat speeds remain no higher than 25 mph.

4. The fact that no significant differences were noted in limnological observations, either between or within sampling locations does not answer the question whether future recreational impacts on aquatic environments can be measured, or whether future recreational impacts can occur in the waters of Lake McMurtry. If speed limits and/or motorboat use density ever increase at Lake McMurtry, then current results on motorboat data may need to be updated and/or included in a possible trend study. In addition, meteorological observations taken in future years may yield significantly different results, as Cross (1992) stressed.

Recommendations

Based on conclusive scientific results found in the literature section of Chapter II, as well as the limitations, delimitations and the results of this study, the following recommendations are made:

1. A comparative study is needed between lakes of similar size and depth, compared to Lake McMurtry, but with other varying attributes (e. g., different bottom sediment types, surrounding land-use patterns, varying physical and chemical parameters such as inflow rates, salinity content, transparency, etc.). In addition, varying meteorological/climatological characteristics are recommended for comparison purposes, especially water clarity studies.

2. As Hilton and Phillips (1982) recommended, an experimental study is needed involving manipulation of motorboat use (e. g., density and frequency), engine design (e. g., outboard versus inboard), engine size or horsepower, boat hull size and design (e. g., speedboats designed for racing, larger houseboats, etc. In addition, this type of study

should involve control variables, such as restricting motorboat use in certain areas (e. g., bays or other inlets).

3. A study involving measurement of water quality parameters at multiple depths, within each water column site, as well as depths relative to the bottom, is recommended for a more thorough analysis. This is very similar to the study conducted by Yousef (1974), and should include alkalinity, carbon dioxide, conductivity, nitrate, and phosphorus, in addition to the dependent variables used in the current analysis. These additional water parameters could provide further evidence of possible mixing (e. g., fluctuations or similarities in concentration levels) due to motorboat-induced turbulence within water columns.

The importance of this, according to Liddle and Scorgie (1980), is that if nitrate and phosphorus concentrations are disturbed and resuspended from their natural accumulations on lake-floor sediments, this could rapidly increase eutrophication rates. Liddle and Scorgie (1980) also claim that if nitrate and phosphorus accumulations remain undisturbed at the water/sediment interface, they are dormant in affecting dissolved oxygen concentrations and algae concentrations. Measuring depths of one-foot intervals could more accurately plot this type of disturbance, within water columns, resulting from motorboat use.

4. A similar study, to the current, is needed in a shallow lake that is perpendicular to prevailing surface winds (e. g., Lake Carl Blackwell that has an oriented axis from east to west with a prevailing south wind). Lake McMurtry is aligned nearly parallel to prevailing surface winds. In addition, differences in the alignment and density of tree cover, due to a different orientation axis, could allow for a viable comparison.

SELECTED BIBLIOGRAPHY

Bahnick, Donald A., Markee, Thomas P., and Roubal, Ronald K. 1979 (January). Chemical effects of red clays on western Lake Superior. USEPA. Chicago, Illinois. 1-5, 27-29, 58 pp.

Berner, Elizabeth Kay and Berner, Robert A. 1987. The global water cycle: geochemistry and environment. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 104-12. 120-28, 183-89, 227-36, 241-83 pp.

Burks, Bud. 1972 (May 2). A wildlife management plan for Lake McMurtry. Prepared by the Students in Zoology 5414: Wildlife Management Techniques. Oklahoma State University. Stillwater, Oklahoma. 9-13 pp.

Climatological Data - Oklahoma. 1996 (May). Prepared by the National Oceanic and Atmospheric Administration (NOAA). Dept of Commerce. Vol. 105 (5). Pub by the National Climatic Data Center. Asheville, NC.

Climatological Data - Oklahoma. 1996 (June). Prepared by the National Oceanic and Atmospheric Administration (NOAA). Dept of Commerce. Vol. 105 (6). Pub by the National Climatic Data Center. Asheville, NC.

Climatological Data - Oklahoma. 1996 (July). Prepared by the National Oceanic and Atmospheric Administration (NOAA). Dept of Commerce. Vol. 105 (7). Pub by the National Climatic Data Center. Asheville, NC.

Climatological Data - Oklahoma. 1996 (August). Prepared by the National Oceanic and Atmospheric Administration (NOAA). Dept of Commerce. Vol. 105 (8). Pub by the National Climatic Data Center. Asheville, NC.

Climatological Data - Oklahoma. 1996 (September). Prepared by the National Oceanic and Atmospheric Administration (NOAA). Dept of Commerce. Vol. 105 (9). Pub by the National Climatic Data Center. Asheville, NC.

Cole, Gerald A. 1994. Textbook of limnology. 4th Ed. Waveland Press, Inc. Prospect Heights, Illinois. 3, 10, 42, 69, 75 pp.

Cross, W. L. 1992. Recreational visitor attitude and selected limnological measurements of recreational impact at Lake Carl Blackwell. Thesis. OSU, Stillwater, Okla. 2-5, 11-15 pp.

Entz, B. 1980. Physical and chemical microstratifications in the shallow Lake Balaton and their biotic and abiotic aspects. Developments in Hydrobiology: Shallow Lakes. Vol. 3. ed. M. Dokulil, H. Metz and D. Jewson. Dr. W .Junk bv Publishers, The Hague. 63-72 pp.

Goldman, C. R., and Horne, A. L. 1983. Limnology. McGraw-Hill Book Company. New York. 12-19, 24-33, 39-55, 58-82, 87-94, 200-212, 241-243 pp.

HACH Products for Analysis: Ordering Catalog. 1996. HACH Company. Loveland, Colorado. 14-15, 60, 61 pp.

HACH Water Analysis Handbook. 1992. 2nd ed. HACH Company. Loveland, Colorado. 66, 68, 270, 318-20, 412-18, 771, 783, 786, 788, 795 pp.

Hall, J. A., and Morrison, J. W. 1978. Environmental studies: a field and laboratory approach. Arco Pub. Co., Inc. New York. 13-36 pp.

Hammitt, W. E., and Cole, D. N. 1987. Wildland recreation: ecology and management. John Wiley and Sons. New York. 21, 103-109, 117-121, 158, 236 pp.

Harding, E. R., and Taylor, R. T. 1972 (May). Lake McMurtry watershed and its affect on the McMurtry wildlife management area. Research Report for Wildlife Ecology, OSU 5-9 pp.

Hilton, J., and Phillips, G. L. 1982. The effect of boat activity on turbidity in a shallow broadland river. Journal of Applied Ecology. British Ecological Society, 19 (1), 143-150 pp.

Howick, Gregory L., Wilhm, Jerry L., Toetz, Dale W., and Burks, Sterling L. 1982. Diagnostic study of Lake Carl Blackwell. Dept. of Zoology: Oklahoma State University. Stillwater, OK. 1-2, 6, 13-17, 19-40, 53-54, 59, 61-83, 124-132 pp.

Hutchinson, J. D. 1957. All about boats. Popular Mechanics Press. Chicago, Illinois. 14, 59 pp.

Hysmith, B. T. 1975. Influence of sediment cycling on primary productivity in Lake Carl Blackwell, Oklahoma. Thesis. OSU, Stillwater, Okla. 1, 7-11, 53 pp.

Imboden, D. M., and Wuest, A. 1995. Mixing mechanisms in lakes: physics and chemistry of lakes. 2nd ed. ed. A. Lerman, D. Imboden, and J. Gat. Springer-Verlag. New York. 83-138 pp.

Johnson, Dwayne Allan. 1991. The effects of pH change on the physicochemical water quality of two east Texas ponds. Dissertation for Ph.D. Dept. of Biology, Limnology, and Ecology. Stephen F Austin State University. 154 pp.

Kurklin, Joanne K. 1990. Water quality in Gaines Creek and Gaines Creek Arm, Eufaula Lake, Oklahoma. USDI/USGS Water-Resources Investigations Report 86-0412. Oklahoma City, Oklahoma. 7-8, 17, 25 pp.

Leonard, E. M. 1950. Limnological features and successional changes of Lake Carl Blackwell, Oklahoma. Dissertation. OSU, Stillwater, Okla. 1, 3-5, 10, 16, 27, 71 pp.

Liddle, M. J., and Scorgie, H. R. A. 1980. The effects of recreation on freshwater plants and animals: A Review. Biological Conservation, 17, Applied Science Pub. London. 184-192 pp.

Lighthill, J. 1978. Waves in fluids. Cambridge University Press. Cambridge, Mass. 10-22 pp.

Mackenthun, K. M., Ingram, W. M., and Porges R. 1964. Limnological aspects of recreational lakes. U. S. Dept. of Health, Education, and Welfare. Public Health Service. Division of Water Supply and Pollution Control. 5, 5-18, 25-26, 119-120, 126, 133 pp.

Martin, E. A. 1977. A Dictionary of Life Sciences. Pica Press: New York. 38, 122, 261, 264 pp.

Mauck, P. E. and Summerfelt, R. C. 1970. Length-weight relationships, age composition, growth, and condition factors of carp in Lake Carl Blackwell. Proc. Okla. Acad. Sci. 50, 61-68 pp.

Mele, A. 1993. Polluting for pleasure. W. W. Norton and Company. New York/London. 17-86 pp.

Mesonet Data. 1996. Climatological Data Recorded at the Marina Mesonet site (2 miles south of Lake Carl Blackwell) from May 1 - September 15, 1996.

Moss, B. 1977. Conservation problems in the Norfolk broads and rivers of East Anglia, England - phytoplankton, boats and the causes of turbidity. Biological Conservation, 12, Applied Science Pub. London. 95-112 pp.

Nelson, E. 1994 (November). Special report: polluting for pleasure. Soil, 25 (11), 26-35 pp.

Norton, J. L. 1968. The Distribution, character, and abundance of sediments in a 300 acre impoundment in Payne County, Oklahoma. M. S. Thesis, Oklahoma State University. 76 pp.

Oklahoma Climatological Survey. 1996. Norman, Oklahoma.

Oklahoma Tourism and Recreation Department. 1995. Oklahoma camping and lake guide. Oklahoma City, Oklahoma. 24 pp.

OSU Water Treatment Plant. 1996. Information Presented from an Interview on February 6, 1996.

Parshall, G. 1994 (November 14). The newest pollution target: motorboats. U. S. News and World Report, 117 (19), 25 pp.

Powell, P. 1985 (April). Use attainability assessment of Stillwater Creek near Stillwater, Oklahoma. Water Quality Division. Oklahoma Water Resources Board. Oklahoma City, Oklahoma. 56-69, 76, 93-98, 132 pp.

Schreiber, J. F. 1959. Sedimentation survey of Lake Carl Blackwell - Payne and Noble Counties - Oklahoma Dept. of Geology. OSU, Stillwater, Okla. 4-6 pp.

Simpson, J. T. 1991 (December). Volunteer Lake Monitoring: A Methods Manual. U. S. EPA. Washington, DC. 6, 10-22, 26-41, 70-86, 89-117 pp.

Statistical Package for the Social Sciences (SPSS). 1998 version.

Stillwater Parks and Recreation Dept. 1996. Visitor Guide Map to Lake McMurtry.

USDI Geological Survey. 1990. Topographic Map. Lake Carl Blackwell Quadrangle, Oklahoma. N3607.5-W9707. 5/7.5 Minute Series.

Yousef, Y. A. 1974 (October). Assessing effects on water quality by boating activity. (National Environmental Research Center). U. S. EPA. Cincinnati, Ohio. 3-4, 12-13, 17-18, 31-32, 36, 50, 51, 56 pp.

APPENDICES

APPENDIX A

TABLE OF DATA RESULTS FOR FIELD RESEARCH: LAKE MCMURTRY

TABLE VIII

DATA RESULTS FOR FIELD RESEARCH: LAKE MCMURTRY, MAY 15 - SEPTEMBER 15, 1996

Date	Water Meas. Location	Time	Dissolved Oxygen Mg/L - Ppm	Water Temp. °F	Turbidity NTU's	Boat Count
May 15	Site 1	18:00	9.21	71.6	23.3	0
	Site 2	18:40	9.20	71.6	23.3	1
	Site 3	19:30	9.20	71.6	18.2	3
May 19	Site 1	13:00	9.03	75.2	20.9	1
	Site 2	13:40	9.06	73.4	20.4	5
	Site 3	14:30	9.23	73.4	22.6	4
May 22	Site 1	13:00	9.01	75.2	16.9	0
	Site 2	13:40	9.00	77.0	17.2	3
	Site 3	14:30	9.00	75.2	16.5	4
May 26	Site 1	18:00	8.87	77.0	20.0	3
	Site 2	18:40	9.85	77.0	20.4	19
	Site 3	19:30	9.04	77.0	21.8	15
May 29	Site 1	18:00	8.04	77.0	15.9	0
	Site 2	18:40	8.00	77.0	13.2	5
	Site 3	19:30	7.84	73.4	18.9	2
June 2	Site 1	13:00	8.00	77.0	12.0	1
	Site 2	13:40	8.01	77.0	10.9	15
	Site 3	14:30	7.85	75.2	10.9	6
June 5	Site 1	13:00	8.03	77.0	11.7	0
	Site 2	13:40	8.05	77.0	11.2	7
	Site 3	14:30	7.89	75.2	12.0	7
June 9	Site 1	18:00	8.11	77.0	11.2	0
	Site 2	18:40	8.20	77.0	10.9	13
	Site 3	19:30	8.00	75.2	13.5	9
June 12	Site 1	18:00	7.83	77.0	9.31	0
	Site 2	18:40	7.89	77.0	10.2	1
	Site 3	19:30	7.69	78.8	14.0	1
June 16	Site 1	13:00	7.70	78.8	8.34	3
	Site 2	13:40	7.79	80.6	9.75	4
	Site 3	14:30	7.84	84.2	13.7	6

Date	Water Meas. Location	Time	Dissolved Oxygen Mg/L Ppm	Water Temp. °F	Turbidity NTU's	Boat Count
June 19	Site 1	13:00	7.59	78.8	10.5	1
	Site 2	13:40	7.78	82.4	12.3	7
	Site 3	14:30	7.83	84.2	12.9	5
June 23	Site 1	18:00	7.44	84.2	5.70	1
	Site 2	18:40	7.48	82.4	7.01	3
	Site 3	19:30	7.48	84.2	9.10	2
June 26	Site 1	18:00	7.30	84.2	8.05	2
	Site 2	18:40	7.32	82.4	6.09	6
	Site 3	19:30	7.43	84.2	13.5	7
June 30	Site 1	13:00	7.00	84.2	7.51	1
	Site 2	13:40	6.93	86.0	5.88	3
	Site 3	14:30	6.96	87.8	11.7	3
July 3	Site 1	13:00	6.89	86.0	10.8	0
	Site 2	13:40	6.87	87.8	9.71	0
	Site 3	14:30	6.89	89.6	6.49	0
July 7	Site 1	18:00	6.95	86.0	7.75	0
	Site 2	18:40	7.00	86.0	7.90	1
	Site 3	19:30	6.85	87.8	9.03	0
July 10	Site 1	18:00	7.27	78.8	9.32	0
	Site 2	18:40	7.28	78.8	8.70	0
	Site 3	19:30	7.30	78.8	12.7	0
July 14	Site 1	13:00	7.09	82.4	8.68	0
	Site 2	13:40	7.17	82.4	7.38	6
	Site 3	14:30	7.17	80.6	8.78	3
July 17	Site 1	13:00	7.01	82.4	8.51	1
	Site 2	13:40	7.12	82.4	8.30	12
	Site 3	14:30	7.14	84.2	8.99	3
July 21	Site 1	18:00	7.02	86.0	6.46	0
	Site 2	18:40	7.08	84.2	13.2	3
	Site 3	19:30	7.25	87.8	12.2	7

Date	Water Meas. Location	Time	Dissolved Oxygen Mg/L - Ppm	Water Temp. °F	Turbidity NTU's	Boat Count
July 24	Site 1	18:00	7.80	84.2	9.01	0
	Site 2	18:45	7.81	86.0	9.90	3
	Site 3	19:30	7.89	82.4	13.7	0
July 28	Site 1	13:00	8.06	86.0	8.39	0
	Site 2	13:40	8.10	84.2	8.02	17
	Site 3	14:30	8.15	84.2	13.2	7
July 31	Site 1	13:00	8.20	82.4	9.79	0
	Site 2	13:40	8.18	80.6	9.83	1
	Site 3	14:30	8.23	82.4	17.3	1
Aug. 4	Site 1	18:00	8.25	84.2	10.8	0
	Site 2	18:40	8.34	82.4	8.61	8
	Site 3	19:30	8.59	82.4	11.3	2
Aug. 7	Site 1	18:00	8.03	84.2	7.85	0
	Site 2	18:40	8.03	82.4	7.50	1
	Site 3	19:30	8.25	82.4	14.3	0
Aug. 11	Site 1	13:00	8.62	82.4	8.64	0
	Site 2	13:$0	8.70	82.4	7.68	10
	Site 3	14:30	8.72	82.4	8.72	2
Aug. 14	Site 1	13:00	8.49	82.4	8.10	0
	Site 2	13:40	8.56	82.4	8.01	3
	Site 3	14:30	8.60	82.4	8.96	3
Aug. 18	Site 1	18:00	8.09	84.2	8.90	0
	Site 2	18:40	8.21	84.2	10.1	16
	Site 3	19:30	8.22	84.2	8.48	10
Aug. 21	Site 1	18:00	7.93	84.2	7.69	0
	Site 2	18:40	7.93	86.0	8.01	2
	Site 3	19:30	8.09	84.2	9.03	3
Aug. 25	Site 1	13:00	8.06	84.2	8.41	2
	Site 2	13:40	8.11	82.4	10.1	9
	Site 3	14:30	8.15	84.2	12.4	6

Date	Water Meas. Location	Time	Dissolved Oxygen Mg/L - Ppm	Water Temp. °F	Turbidity NTU's	Boat Count
Aug. 28	Site 1	13:00	8.59	78.8	7.80	0
	Site 2	13:40	8.69	78.8	8.19	1
	Site 3	14:30	8.85	80.6	11.1	0
Sept. 1	Site 1	18:00	8.47	80.6	5.74	1
	Site 2	18:40	8.47	82.4	6.64	13
	Site 3	19:30	8.60	80.6	8.77	10
Sept. 4	Site 1	18:00	8.40	82.4	5.81	0
	Site 2	18:40	8.40	82.4	5.99	3
	Site 3	19:30	8.51	82.4	10.1	3
Sept. 8	Site 1	13:00	8.34	82.4	5.11	0
	Site 2	13:40	8.40	82.4	6.13	3
	Site 3	14:30	8.35	82.4	6.12	1
Sept. 11	Site 1	13:00	8.37	84.2	6.00	0
	Site 2	13:40	8.37	84.2	4.81	0
	Site 3	14:30	8.38	82.4	7.10	0
Sept. 15	Site 1	18:00	10.29	73.4	6.59	0
	Site 2	18:40	10.28	73.4	8.09	0
	Site 3	19:30	10.09	71.6	10.1	0

APPENDIX B

TABLE OF METEOROLOGICAL DATA FOR LAKE MCMURTRY

TABLE IX

METEOROLOGICAL DATA FOR LAKE MCMURTRY, MAY 15 - SEPTEMBER 15, 1996

Day of Month	Air Temp. °F		Average Air Temp.	Average Wind Speed	Max Wind Speed	Prevailing Wind Direction	Precipitation
May	Min	Max	°F	Mph	Mph	0-360°	in.
15	73.2	86.9	80.1	15.7	31.8	182(SSE)	0.00
16	71.1	89.8	80.5	16.9	36.5	170(SSE)	0.00
17	73.9	91.0	82.5	19.8	39.4	183(SSW)	0.00
18	74.7	89.1	81.9	18.8	38.9	180(S)	0.00
19	75.2	85.3	80.3	19.7	40.9	188(SSW)	0.00
20	73.9	86.9	80.4	17.0	40.7	232(SW)	0.00
21	62.4	84.2	73.2	11.2	26.6	041(NE)	0.00
22	65.3	86.9	76.1	12.8	31.1	113(ESE)	0.24
23	71.8	92.7	82.3	12.7	33.1	160(SSE)	0.00
24	76.6	90.7	83.7	14.7	29.3	171(SSE)	0.00
25	64.4	88.2	76.3	11.0	28.6	139(SE)	0.16
26	74.3	80.2	77.3	10.0	43.2	151(SE)	0.49
27	53.6	83.8	68.7	10.0	47.6	265(W)	0.30
28	53.2	82.0	67.6	7.8	25.1	351(NNW)	0.00
29	51.3	76.5	63.9	7.5	22.8	048(NE)	0.00
30	55.0	74.8	64.9	9.2	16.8	070(NE)	0.00
31	67.5	79.9	73.7	10.5	25.5	122(SE)	0.05
June							
1	61.3	71.8	66.6	13.8	34.9	341(NW)	1.14
2	57.4	85.8	71.5	5.3	14.8	260(WSW)	0.00
3	60.6	86.0	73.3	6.4	20.6	316(NW)	0.00
4	51.8	82.0	66.9	7.1	19.9	331(NW)	0.00
5	65.3	89.1	77.2	11.9	26.8	149(SE)	0.00
6	67.1	85.8	76.5	15.3	45.6	345(NNW)	0.47
7	60.4	73.8	67.1	9.6	28.6	338(NW)	0.06
8	56.3	75.4	65.9	11.1	24.2	360(N)	0.00
9	52.9	83.3	68.1	7.4	19.5	338(NW)	0.00
10	56.3	86.4	71.4	4.6	14.1	140(SE)	0.00
11	64.0	87.8	75.9	6.7	16.1	159(SSE)	0.00
12	68.0	88.5	78.3	5.6	16.3	161(SSE)	0.00
13	63.3	90.5	76.9	6.3	19.2	172(SSE)	0.00
14	68.4	88.9	78.7	6.2	16.3	142(SE)	0.00
15	68.5	84.9	76.7	9.3	27.7	121(SE)	1.31
16	73.0	93.4	83.2	8.0	23.7	175(SSE)	0.01
17	70.9	91.4	81.2	9.5	29.1	290(NW)	0.54
18	70.3	95.4	82.9	7.5	22.8	191(SSW)	0.00
19	64.9	92.7	78.8	14.6	33.8	138(SE)	0.35
20	73.6	93.6	83.6	10.1	23.7	127(SE)	0.00
21	70.3	91.8	81.1	11.6	24.4	163(SSE)	0.00
22	70.7	91.0	80.9	6.9	20.4	141(SE)	0.00
23	72.1	91.8	82.0	9.1	24.6	171(SSE)	0.00

Day of Month	Air Temp. °F		Average Air Temp.	Average Wind Speed	Max Wind Speed	Prevailing Wind Direction	Precipitation
June	Min	Max	°F	Mph	Mph	0-360°	in.
24	73.6	91.4	82.5	10.6	24.2	102(ESE)	0.00
25	72.0	90.1	81.1	8.9	22.8	128(SE)	0.00
26	72.5	89.6	81.1	9.8	25.3	132(SE)	0.00
27	74.5	91.0	82.8	11.1	24.4	158(SE)	0.06
28	73.6	93.4	83.5	9.8	21.3	164(SSE)	0.00
29	70.7	96.4	83.6	8.1	20.6	178(SSE)	0.00
30	73.2	100.4	86.8	7.7	19.5	175(SSE)	0.00
July							
1	70.6	100.2	85.4	9.5	24.6	173(SSE)	0.00
2	73.2	103.3	88.3	6.2	15.4	152(SE)	0.00
3	72.5	101.8	87.2	5.9	16.1	128(SE)	0.00
4	73.8	96.4	85.1	13.3	33.1	142(SE)	0.00
5	68.5	109.4	89.0	8.8	19.7	190(SSW)	0.00
6	80.2	111.0	95.6	9.2	28.4	236(SW)	0.00
7	81.3	97.5	89.4	7.5	20.4	092(E)	0.00
8	72.1	92.3	82.2	10.0	28.6	027(NNE)	0.07
9	63.9	78.4	71.2	5.4	23.9	055(NE)	1.14
10	64.0	67.6	65.8	7.2	15.4	073(ENE)	0.64
11	63.3	71.7	67.5	7.7	17.4	113(ESE)	0.18
12	67.8	84.7	76.3	5.3	13.9	081(ENE)	0.01
13	68.0	86.7	77.5	4.1	13.6	135(SE)	0.00
14	67.5	82.6	75.1	8.1	21.5	351(NNW)	0.68
15	62.4	88.0	75.2	4.4	14.1	195(SSW)	0.00
16	68.0	91.6	79.8	10.0	24.6	151(SE)	0.00
17	76.8	91.8	84.3	15.2	30.0	175(SSE)	0.00
18	77.7	93.2	85.5	13.2	29.1	180(S)	0.00
19	75.7	95.2	85.5	11.7	24.4	177(SSE)	0.00
20	76.1	98.6	87.4	12.2	25.9	178(SSE)	0.00
21	75.9	100.2	88.1	10.0	24.2	186(SSW)	0.00
22	77.2	95.4	86.3	18.9	51.9	080(ENE)	1.00
23	68.7	88.3	78.5	4.5	14.1	089(ENE)	0.00
24	69.6	87.3	78.5	7.6	21.3	284(WNW)	0.46
25	68.5	87.4	78.0	4.5	12.3	116(SE)	0.00
26	67.1	79.7	73.4	6.4	19.9	125(SE)	0.08
27	62.6	87.3	75.0	3.9	13.2	012(NNE)	0.00
28	67.6	91.0	79.3	5.0	14.5	220(SW)	0.00
29	73.4	81.7	77.6	9.4	25.1	161(SSE)	0.08
30	69.4	80.8	75.1	9.4	23.3	283(WNW)	1.30
31	69.1	85.1	77.1	6.5	17.4	106(ESE)	0.00
August							
1	69.1	89.3	79.2	5.7	17.7	142(SE)	0.00
2	66.7	87.1	76.9	3.5	13.4	139(SE)	0.29
3	69.4	90.6	80.0	6.1	18.7	157(SE)	0.63
4	70.2	89.7	80.0	7.2	18.1	170(SSE)	0.00
5	76.1	91.0	83.6	14.8	29.4	183(SSW)	0.01

Day of Month	Air Temp. °F		Average Air Temp.	Average Wind Speed	Max Wind Speed	Prevailing Wind Direction	Precipitation
August	Min	Max	°F	Mph	Mph	0-360°	in.
6	76.4	93.5	85.0	4.5	13.1	182(SSW)	0.00
7	74.1	94.3	84.2	9.8	24.1	187(SSW)	0.00
8	71.8	94.0	82.9	5.1	17.0	191(SSW)	0.22
9	69.0	93.8	81.4	4.2	12.7	172(SSE)	0.07
10	69.3	89.9	79.6	6.7	20.6	163(SE)	0.02
11	68.7	79.6	74.2	8.1	19.7	131(SE)	1.78
12	66.4	79.5	73.0	8.3	21.4	091(ESE)	0.11
13	61.2	85.1	73.4	4.0	13.0	131(SE)	0.00
14	63.4	87.9	75.7	4.2	12.7	161(SSE)	0.00
15	66.2	89.6	77.9	7.0	21.3	165(SSE)	0.00
16	70.1	89.5	79.8	9.0	22.6	170(SSE)	0.00
17	72.6	87.0	79.8	12.2	25.7	182(SSW)	0.05
18	71.4	84.8	78.1	11.7	26.9	030(NE)	0.00
19	73.0	89.1	81.1	16.3	33.1	113(SE)	0.00
20	70.2	92.6	81.4	8.1	19.7	180(S)	0.00
21	71.8	91.4	81.6	5.5	17.2	178(SSE)	0.00
22	70.8	91.3	81.1	4.9	14.1	168(SE)	0.00
23	61.3	92.9	77.1	5.7	21.8	177(SSE)	0.00
24	68.3	88.7	78.5	7.1	19.7	139(SE)	0.00
25	69.1	90.3	79.7	7.8	20.0	200(SSW)	0.05
26	72.5	85.5	79.0	8.7	23.1	286(WSW)	0.04
27	69.3	81.4	75.4	5.6	16.4	028(NE)	0.56
28	68.7	85.2	77.0	6.0	18.1	047(NE)	0.00
29	68.9	86.7	77.8	6.0	16.1	130(SE)	0.00
30	66.1	91.4	78.8	6.1	22.4	176(SSE)	0.00
31	67.9	88.1	78.0	5.3	13.6	142(SE)	0.00
Sept.							
1	65.3	83.5	74.4	5.3	15.9	129(SE)	0.00
2	63.5	83.5	73.5	5.7	15.2	150(SE)	0.00
3	64.9	84.7	74.8	8.3	27.1	134(SE)	0.00
4	65.1	87.3	76.2	6.6	20.4	145(SE)	0.00
5	66.0	88.9	77.5	4.8	13.4	211(SW)	0.00
6	64.4	87.8	76.1	5.7	13.4	187(SSW)	0.00
7	65.7	85.6	75.7	7.6	20.1	223(SW)	0.00
8	64.2	82.2	73.2	6.9	21.9	355(NNW)	0.00
9	58.6	89.4	74.0	3.2	13.2	281(WNW)	0.00
10	63.7	93.9	78.8	4.7	12.8	130(SE)	0.00
11	63.3	94.6	79.0	4.4	13.9	175(SSE)	0.00
12	64.6	84.2	74.4	6.7	17.7	051(NE)	0.00
13	59.7	75.7	67.7	6.4	21.7	080(ENE)	0.00
14	59.7	71.4	65.6	6.2	14.8	112(SE)	0.12
15	64.6	68.0	66.3	8.9	17.4	021(NE)	2.46

APPENDIX C

SPSS DESCRIPTIVE STATISTICS FOR WATER TURBIDITY

TABLE X

SPSS DESCRIPTIVES FOR WATER TURBIDITY

SITE	DESCRIPTIVES		NTU's	STANDARD ERROR
1.	Mean		9.9294	.721
	95% Confidence	Lower Bound	8.4642	
	Interval for Mean	Upper Bound	11.3947	
	5% Trimmed Mean		9.4991	
	Median		8.5750	
	Variance		18.754	
	Std. Deviation		4.3306	
	Minimum		5.11	
	Maximum		23.30	
	Range		18.19	
	Interquartile Range		3.0950	
	Skewness		1.767	.39
	Kurtosis		2.755	.76
2.	Mean		10.0425	.708
	95% Confidence	Lower Bound	8.6039	
	Interval for Mean	Upper Bound	11.4811	
	5% Trimmed Mean		9.6419	
	Median		8.6550	
	Variance		18.078	
	Std. Deviation		4.2518	
	Minimum		4.81	
	Maximum		23.30	
	Range		18.49	
	Interquartile Range		3.3550	
	Skewness		1.739	.39
	Kurtosis		2.850	.76
3.	Mean		12.1714	.661
	95% Confidence	Lower Bound	10.8285	
	Interval for Mean	Upper Bound	13.5143	
	5% Trimmed Mean		11.9388	
	Median		11.8500	
	Variance		15.752	
	Std. Deviation		3.9688	
	Minimum		6.12	
	Maximum		22.60	
	Range		16.48	
	Interquartile Range		4.7000	
	Skewness		.925	.39

APPENDIX D

CITY OF STILLWATER PARKS AND RECREATION DEPARTMENT: APPROVAL FOR THESIS RESEARCH AT LAKE MCMURTRY

OSU

School of Health, Physical Education and Leisure
103 Colvin Physical Education Center
Stillwater, Oklahoma 74078-2021
405-744-5493
Fax 405-744-6507

March 29, 1996

Bill Nelson
Director of Parks and Recreation
City of Stillwater
315 E. 9th
Stillwater, OK 74075

Dear Bill:

As we have discussed earlier. Bill Mosenthin is interested in conducting his field research for his thesis at Lake McMurtry. He would gather data this spring and summer on the southern half of Lake McMurtry. Specifically we request permission to do water quality testing on the four lower bays at Lake McMurtry.

The thesis field research will begin May 1 and terminate on September 29. Bill will be taking water samples and conducting counts of visitor use on Sundays and Wednesdays. He will follow all rules and regulations governing Lake McMurtry while conducting his research. Bill will be operating a personal boat to go from one research site to another. As we had discussed, is it possible for Bill to receive a complimentary permit for boat access to Lake McMurtry this summer?

We are most appreciative of permission to access Lake McMurtry for this research. The experience and knowledge gained will be extremely valuable. Thank you for your assistance.

Sincerely,

Lowell Caneday

Lowell Caneday, Ph.D.
Professor and Director

William S Mosenthin

William S. Mosenthin
Graduate Student

stillwater
WHERE OKLAHOMA BEGAN

May 7. 1996

To Whom it May Concern;

We have given permission for Bill Mosenthin to conduct field research for his thesis out at Lake McMurtry During the spring and summer, he will be doing water quality testing at several areas at Lake McMurtry.

Because this information will be helpful to us. Bill has been given permission to park his car and to access the lake with his boat. He will follow all the rules and regulations governing Lake McMurty while doing this research. This research will begin approximately May 1 and terminate approximately October 1.

Sincerely,

William Nelson,
Director Parks and Recreation

WN/jms

APPENDIX E

CITY OF STILLWATER WATER TREATMENT PLANT: APPROVAL FOR USING WATER CHEMISTRY LABORATORY FOR THESIS RESEARCH

OSU

School of Health, Physical Education and Leisure
103 Colvin Physical Education Center
Stillwater, Oklahoma 74078-2021
405-744-5493
Fax 405-744-6507

March 29, 1996

Scott Taylor
Water Treatment Plant
City of Stillwater
723 S. Lewis
Stillwater, OK 74075

Dear Scott:

This letter is in regard to the chemical analysis portion of Bill's thesis research which is scheduled for this spring and summer. We are most appreciative of your support for Bill in this project. In following up on your conversation with Bill, we wanted to document both the request for access to laboratory equipment and your permission in written form.

The thesis field research based on water quality sampling at Lake McMurtry will begin May 1 and terminate September 29. Bill will be collecting samples in four bays at Lake McMurtry on Sundays and Wednesdays throughout the spring and summer.

We would like to take this opportunity to express our appreciation for your support on this project. The laboratory equipment in your plant will provide the reliability and accuracy needed to permit a proper thesis. Thank you for your assistance.

Sincerely,

Lowell Caneday

Lowell Caneday, Ph.D.
Professor and Director

William S. Mosenthin

William S. Mosenthin
Graduate Student

2

VITA

William Steve Mosenthin

Candidate for the Degree of

Master of Science

Thesis: MOTORBOAT USE DENSITY AND NATURAL FORCES AS FACTORS IN WATER QUALITY

Major Field: Environmental Science

Biographical:

Personal data: Born in Tulsa, Oklahoma, on October 28, 1956, the son of William Lewis and Beverly Jean Glenn Mosenthin.

Education: Graduated from Broken Arrow High School, Broken Arrow, Oklahoma in May 1975; received Associate of Science degree in Chemistry from Rogers State College, Claremore, Oklahoma in May 1990; received Bachelor of Science degree in Sociology from Oklahoma State University, Stillwater, Oklahoma in December 1993. Completed the requirements for the Master of Science degree with a major in Environmental Science at Oklahoma State University in December, 1999.

Experience: Served in U. S. Air Force as a part of the Military Airlift Command Unit, during the late 1970s. Duties included transporting handling and security responsibilities of military supplies (hazardous substances and miscellaneous hardware) from the U. S. to various foreign supply-link terminals; employed by Dominos Pizza, Inc., in management, advertising, customer relations and promotions, 1986-1991; employed by Rogers State College as an undergraduate teaching aid; Rogers State College, Department of Natural Sciences, Claremore, Oklahoma, 1989 to 1990; conducted thesis research at the water chemistry lab, Stillwater, Oklahoma Water Treatment Plant, Summer of 1996; employed by Stillwater Public Schools as a substitute teacher and school bus driver, 1998 to present.

Professional Memberships: Society of Environmental Scientists, Rock and Mineral Society.