THE SPATIAL VARIATION OF ECONOMIC AND ENVIRONMENTAL IMPACTS OF PETROLEUM PRODUCTS ON RIVERS: A CASE STUDY OF SELECTED RIVERS IN CENTRAL AND NORTHEASTERN OKLAHOMA

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CHAPTER I

INTRODUCTION

Since the early part of the 1900's petroleum products have become a major part of the everyday way of life for most Americans. From gasoline in our automobiles to jet fuel for our military, Americans depend heavily on the 30 million gallons of liquid petroleum products and millions of cubic feet of natural gas that flow through the 700,000 miles of underground pipelines (Hosmanek, 1984). Water is another commodity that Americans cannot live without. Not only for drinking purposes, water sources such as creeks, rivers and lakes create a large number of recreational opportunities across the United States as well as numerous nesting areas for wildlife and endangered species.

Oklahoma is no exception to the rule when it comes to petroleum products and the role that they play in the everyday lives of the people within the state. The oil industry in Oklahoma generates $5 billion a year and employs some 60,000 Oklahomans. With this type of dependency on the oil industry, Oklahoma has been exposed to numerous pipeline companies that have come into the state wanting to make a living by transporting various petroleum products from one area of the world to another. Oklahoma is also home to over 200 artificial lakes created by the damming of rivers such as the Grand and the Arkansas (Morgan, 1984). Each year these water sources become contaminated and polluted by a number of sources including products from petroleum pipelines. If the companies who own the pipelines were aware of what was downstream, the protection and cleanup of these sensitive areas could prove to be easier and less costly. This would benefit not only the company responsible for the spill but also the environment. However, due to the lack of any specific federal regulations and, until recently, technology that allowed a timely inventory of the river systems, the knowledge of what lies downstream from these pipelines has remained a mystery to the pipeline companies. Despite the efforts of the contractors, who are employed by the pipeline companies to reduce the damage and protect vital areas in the event of a spill, without this necessary information of what lies downstream, the results of even the most minimal spill can be devastating and costly.

Problem Statement

Water pollution by various forms of petroleum products seems to be a very sensitive and debatable topic in today's world. As oil tanker accidents increase in number and in severity, more research into this area will arise. The problem, however, is that while needed attention has been focused on marine spills, too little attention has been focused on lake and river spills. This is because most of the major petroleum spills have taken place either on or near the ocean. This does not mean that a product spill could not occur on a river or have devastating effects on the surrounding communities and habitat, this only means that thus far the spills on rivers have been less environmentally and economically damaging than the oceanic spills. Therefore, the goal of this research is to study the effects that a product spill would have on river habitat and adjoining areas, and to know what areas are most adversely affected in order to protect these areas and thus minimize the damage that could occur.

Research Questions and Hypotheses

The main focus of this study is to determine the spatial variation of the environmental and economic impacts of a product spill from a petroleum product pipeline on selected river segments of Central and Northeastern Oklahoma (Figure 1). For this study, the term "river segment" is defined by the crossing of a petroleum product pipeline over a river to the nearest dam downstream or maximum flow distance before dispersal. The term "product" is defined as any substance (crude oil, diesel, gasoline) that would be contained within, and transported through, a pipeline. The use of three river segments, the Arkansas River from 3 miles west of the pipeline near Sand Springs, OK to Webbers Falls Locke and Dam (Figure 2), the Cimarron River from 3 miles west of the pipeline crossing near I-35 to the Keystone Dam (Figure 3), and the Grand Lake Region extending from 2 miles north of the pipeline crossing southwest of Wyandotte, OK to Pensacola Dam (Figure 4) will be the focus of this study because of the various sensitive areas located along these river segments beyond the crossing

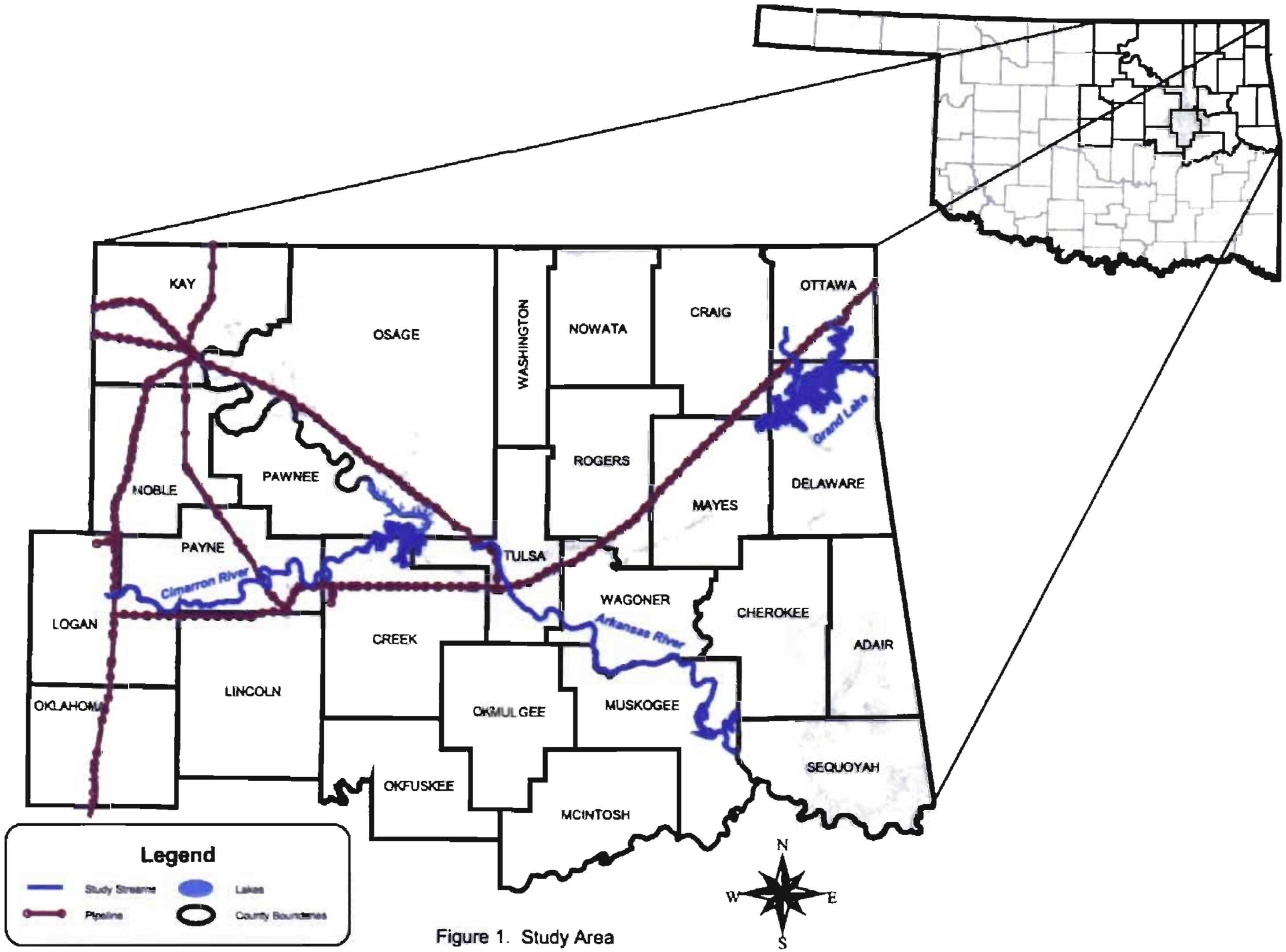

Figure 1. Study Area

Environmentally Sensitive Areas - Arkansas River

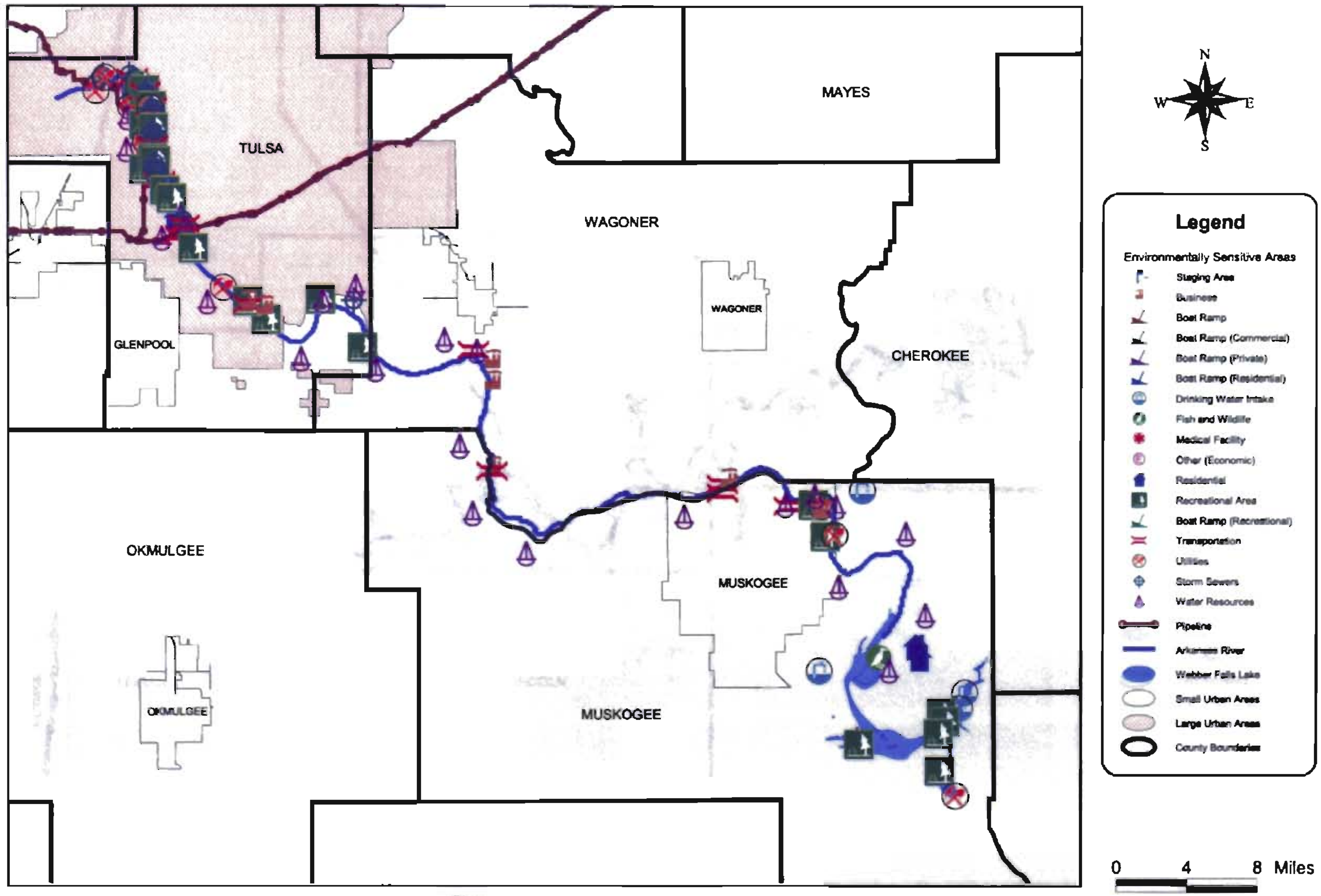

Figure 2. Arkansas River

Environmentally Sensitive Areas - Cimarron River

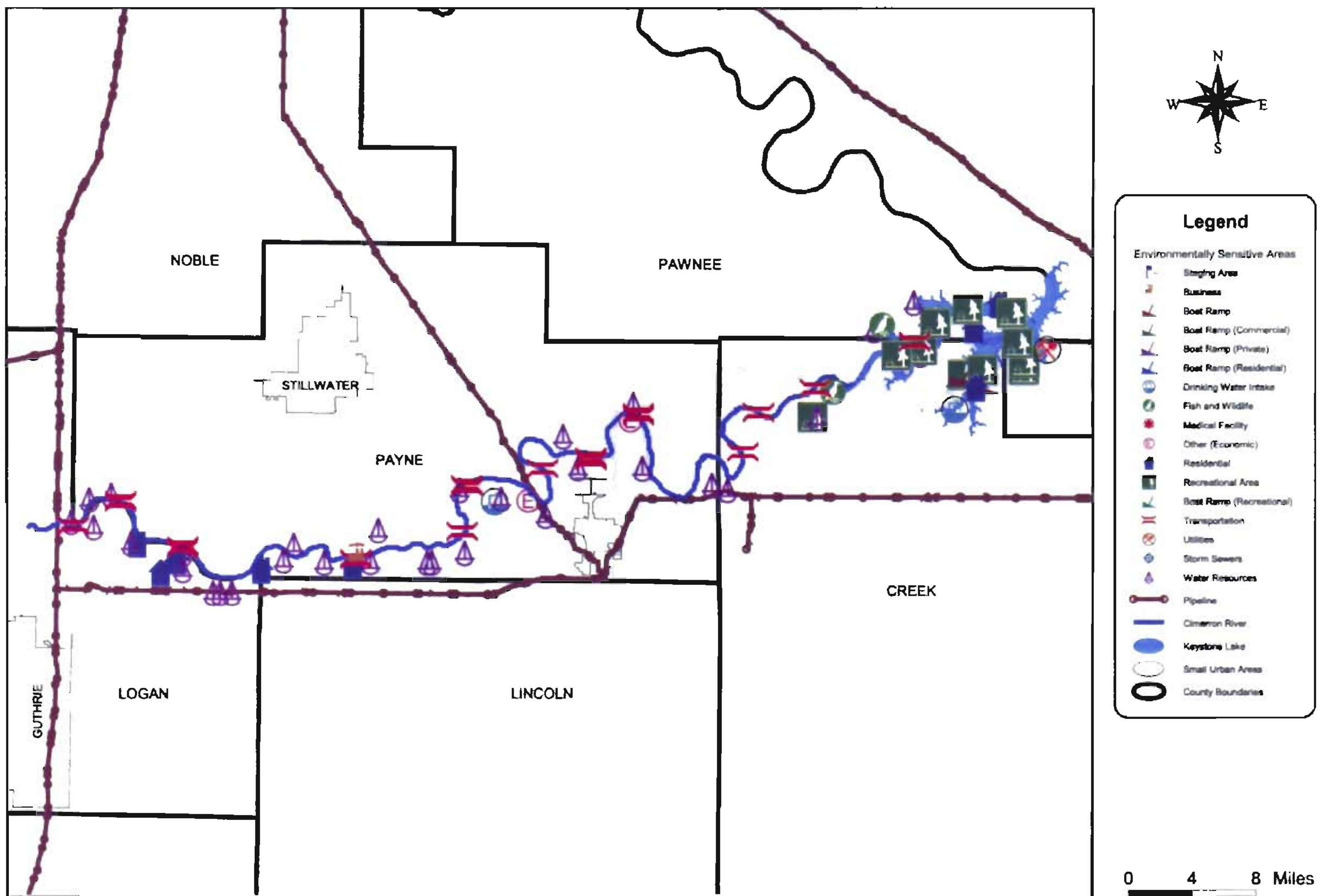

Figure 3. Cimarron River

Environmentally Sensitive Areas - Grand Lake

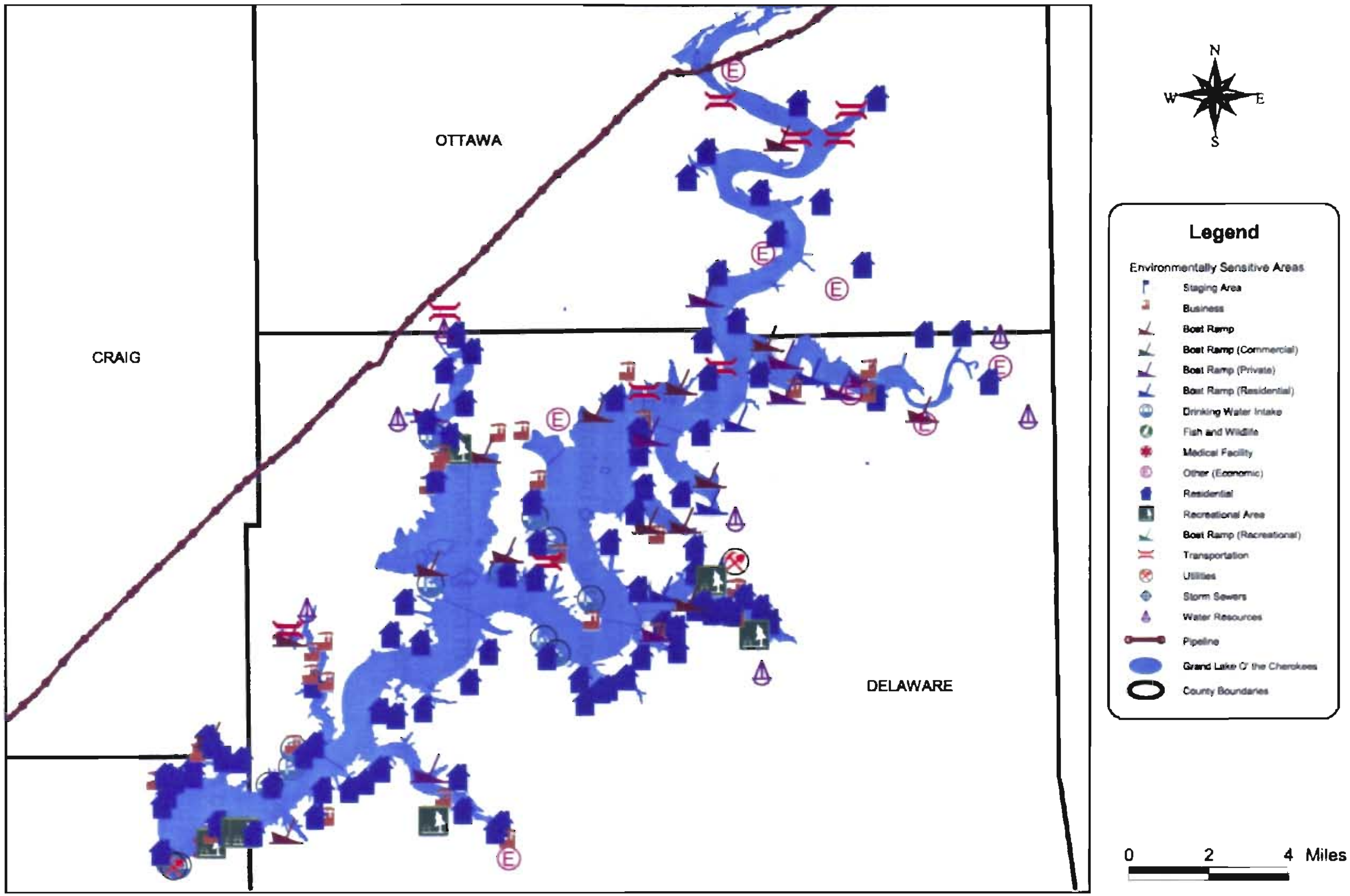

Figure 4. Grand Lake

of a pipeline. For this study, the analysis will be based on the following environmentally sensitive areas:

storm sewers	medical facilities	fish and wildlife
transportation	recreational areas	areas of economic interest
boat ramps	residential areas	water resources
utilities	drinking water intakes	businesses

Table 1. List of Environmentally Sensitive Areas

This study will define the location of each of these environmentally sensitive areas along the selected rivers and estimate the cost of cleaning up these areas in the event of a product spill. The objective of this study is to investigate two research questions:

Question 1) Which river segments in Northeastern and Central Oklahoma would be most environmentally affected by a worst-case product spill?

Hypothesis 1) The area of Grand Lake would be the most environmentally affected due to the recreational areas and wildlife that reside along that area.

Question 2) Of the defined river segments, which river segment would be most economically critical to protect, based on the environmentally sensitive areas located along that river segment?

Hypothesis 2) The river segment that would be most economically critical to protect would be the area of Grand Lake due to the habitat that can be found along that river segment.

The answer to the first research question was developed by considering the areas that were to be surveyed. Upon looking at Grand Lake there appeared to be a greater habitat potential due to the fact that the entire study area along Grand Lake was a large lake that has the potential to support a large number of wildlife species. Along this same line, a large lake has a greater possibility of recreational areas that are natural settings. The Arkansas River study area, being considered a more urban type setting would tend to have less environmentally sensitive areas and far fewer areas that could support a large number of wildlife species. It would also have fewer natural areas that serve as recreational areas. The recreational areas located in an urban area would more than likely be a park type area built specifically as a recreational area not a natural area that was developed for tourism. Although this river segment does end in a lake the area is considerably smaller and less developed than the Grand Lake area. The Cimarron River is the exact opposite of the Arkansas River in that the area is extremely rural with few sensitive areas located along the river segment. Although the majority of the sensitive points along the Cimarron would be considered threatened environmentally, the area is so rural that there are very few sensitive areas. Because of the limited number of areas that exist, Grand Lake would be a bigger threat due to the large number of areas that exist. With this in mind, it is because of these characteristics of all three river segments that Grand Lake was hypothesized to be the most environmentally impacted.

The second research question can be answered with the same sort of reasoning as described in relation to the first research question. With the large number of sensitive areas as well as the nature of the sensitive areas, it would be more costly to try to protect the Grand Lake area than the other two areas. The entire perimeter of the lake would be somewhat harder to access due to the lack of roads that would exist, thus adding to the cost. It would also be much more costly to try and protect areas with wildlife due to the concern of wildlife contamination caused by the petroleum spill. Grand Lake would also have a large economic loss in terms of lost business along the lake due to the contaminated water, thus adding to the economical price tag that would occur if a spill were to occur in this area. The other two segments would have an economic impact as well, but it would be Grand Lake that would be most affected economically.

Project Significance

Petroleum pipelines have been used for years to transport products from one area to another. Despite being one of the most economical modes of transportation, a pipeline offers many other advantages such as safety and immunity to harsh weather conditions (Hosmanek, 1984). However, even with these excellent advantages, accidents do occur and petroleum products are lost. As has been researched and documented by a number of sources, petroleum spills can be deadly to marine environments and therefore the same would most likely hold true for inland river environments as well. However, this educated guess has not been adequately documented.

This project is designed to add more information to our knowledge of petroleum spills and how the environment is affected by its presence. However, this project will focus on inland river environments, which are currently lacking in examination. In addition, this project will allow for further comparison of other inland rivers and how they too would be affected, both environmentally and economically, in the case of a petroleum product spill. Recently, pipeline companies have begun to focus on producing a better pipeline. However, research must also be done to design a plan in case the pipeline should break. Therefore, this project will provide research that will allow companies to have advanced knowledge as to what may be affected in the case of a spill.

Early Oklahoma Petroleum History

Oklahoma's history was dramatically changed in 1897 when the first commercial oil well was drilled by the Cudahy Oil Company in Bartlesville (Morgan, 1984). As word spread about the prospect of oil, many people began to gain interest in the search for oil. By 1910 there were over 300 producing wells within the state with no end in sight. Oil exploration continued to boom, and by 1913, Oklahoma became known as "the nation's major oil producer" (Morgan 1984: 155). Oil fields such as the Cushing and Healtdon were producing as many as 310,000 and 95,000 barrels of crude oil a day, respectively. As the industry continued to grow so did the numerous modes of transporting the oil out of the fields and into the refineries. Numerous pipelines crossed the state in every direction, thus giving the major oil fields such as the Cushing oil field (and the town that became known as Cushing) the title of "The Pipeline Crossing of the World." Due to this overwhelming amount of oil, the market become flooded and prices began to drop. However, this soon changed due to acceleration of the dream of every American to have an automobile and the outbreak of World War I in Europe. With the need for petroleum products soaring, Oklahoma once again rose to the occasion and nearly tripled the number of gas and oil producing wells in the state. Oklahoma's fate in the oil industry took a turn for the worse in 1931 when the Texas fields began production. Although Oklahoma would continue to depend heavily on its petroleum products throughout the mid-twentieth century, the excitement and glitter of the oil boom would never be felt in the state again.

Pipeline History

At the time of the Oklahoma discovery, pipeline transportation systems had already been in use for several years throughout the United States, with the first petroleum pipeline being constructed in 1863. Pipelines soon became the preferred mode of transportation due to their ability to transport large quantities of liquid products such as oil, diesel, and natural gas safely and conveniently over large areas. Before such networks were installed, products had to be shipped either by barge or railroad to their destination. Both of these modes of transport had their safety concerns and were known for taking a long time to arrive at their designated location. As pipeline construction expanded and continued, along with Oklahoma's increasing dependency on the oil industry for economic progress, the state was soon criss-crossed by a pattern of pipelines built to pick up or drop off various forms of petroleum products.

Oklahoma Waterways

After World War II, "water transformed Oklahoma as oil had earlier" (Morgan 1984: 170). Many rivers such as the Arkansas and the Grand were dammed in order to create more than 200 man-made lakes which provided not only hydroelectric power to the people of the surrounding communities but also recreational and economic opportunities, flood control, irrigation, and municipal water supplies. Keystone Lake, Lake Eufaula, and Grand Lake are just a few of the lakes that were formed by damming rivers that flow through Oklahoma and are all known throughout the state for their resorts and recreational facilities. Along with the natural waters of these lakes and rivers, there is an economic value that tends to attract businesses, residential areas, and numerous other activities that develop adjacent to these water resources. Not only do the people of these areas use these natural assets, but so do the various animal species that rely on the rivers and lakes as a source of food and water. If these natural resources were to become severely polluted, the effects would be devastating not only to the economic interests that lie along the riverbeds but also to the natural environment, whose maximum productivity depends on the cleanliness of the water.

As the pipeline network began to grow, it was only a matter of time until these transportation systems and the water resources of Oklahoma began to impact one another. At first, the crossing of pipelines and water resources seemed to pose no immediate threat and the chances of one of these pipelines leaking and spilling a product into the water seemed minute in theory, yet in actuality it is imminent. The first step in preventing massive damage is to be prepared and know exactly what lies down river and where the environmentally sensitive areas occur.

CHAPTER II

LITERATURE REVIEW

Little information has been written that directly relates to the topic of oil spills that occur on rivers. However, there has been some related research about various aspects of this thesis topic. Several books deal with oil spills and their effects on the surrounding environment but most of these deal more specifically with coastal waters and habitats, not the inland waters that are of concern in this paper. There has also been little published about the costs of cleaning up inland oil spills or the effects that such would have on the inland habitat. Based on these limitations, the literature found on this matter tends to have a much broader scope than the topic presented in this thesis.

Pipeline Construction

Pipelines have become an important part of the petroleum industry as described in *Pipeline Construction* (Hosmanek, 1984). This network of pipelines covers some 700,000 miles across the United State and transports 30 million barrels of liquid a day for a reasonably cheaper price than other modes of transportation. The author of this manual gives an extended history of the pipeline industry and explains the products that are transported through the pipes. Hosmanek dedicates the majority of the manual to the history of pipeline construction as well as the modern types of pipeline and the techniques that are used in their placement across the United States. Sections of this manual also describe the costs associated with the laying of pipelines as well as explanations as to why this mode of transportation has become so crucial to the petroleum industry.

Impacts of Petroleum Spills

Oil Spill Control for Inland Waters and Harbors (Marschall, 1977) is a manual whose "primary objective is to provide an understanding of policy, rules, regulations, and procedures for the prevention and mitigation of oil spills, and, if they occur, the containment, removal, and disposal of the spilled oil" (Marschall, iii). This manual describes various aspects of an oil spill, such as the behavior of an oil spill, the impacts it will have on the surrounding environment, people and habitat, and what to do in certain situations that may occur because of the result of an oil spill. Various important characteristics of oil are included such as the toxicological conditions and the rates of combustion based on conditions in which the oil is released. This book also contains a number of useful appendices that would be helpful in the case of an emergency and no other means of information was available.

Although the majority of the information in these two books deals primarily with ocean spills, there is some useful data that can be related to inland spills. *Mechanical Systems for the Recovery of Oil Spills on Water* (Institute of Petroleum, 1975) is one such book that deals primarily with ocean related spills;

however, there are a few related sections as to how one might go about obtaining and placing booms on the rivers in order to protect areas that would be damaged by an oil spill. Also dealing primarily with oceanic spills is *Conference on Oil Spills, New Orleans* (Ludwigson, 1977), but this book does offer some useful information related to the prevention, behavior, and clean-up of various oil spills that have occurred. Despite their broader focus, these books could be quite beneficial and useful for their information if it was related to inland scenarios.

Before and After an Oil Spill: The Arthur Kill (Burger, 1994) gives the reader an excellent evaluation of what events take place during an oil spill and what occurs for several days afterwards in the cleanup processes. Burger discusses the government's and conservation organizations' role in the cleanup, legal considerations, and the rehabilitation of the wildlife that are contaminated by the spill. The author also discusses the economic effects that the spill had on the recreational area surrounding the Arthur Kill. Although Burger offered no dollar figure for indirect use of the waterway such as hiking, walking, and sports, she discusses the fact that these uses would be degraded by the spill and must be calculated into the damage caused by the accident. Some of the most useful information in this book is the detailed description of the biological effects of the oil on the vegetation, organisms, and specific animal species such as manatees, sea turtles and snow egrets that were located in the area. The editor discusses the lessons that can be learned from this spill and what can be done in the future to prevent such damage from occurring again.

The Exxon Valdez oil spill in Alaska was one of the more recent oil spills that have made a dramatic impact on the surrounding environment and the people who lived in that area. There are two pieces of literature that deal with this topic that has relevance to the Exxon Valdez oil spill. *The Economics of a Disaster: The Exxon Valdez Oil Spill* (Owen, et al., 1995) describes that not only did this oil spill have an environmental impact but also an economic impact on the world. The economic effects are discussed as well as the formulas and rationales that were used in order to determine the effects. The impacts on Alaska and the fishing industries are highlighted. An article featured in *Land Economics* journal also focuses on this topic. "Technological Disasters and Natural Resource Damage Assessment: An Evaluation of the Exxon Valdez Oil Spill" (Cohen, 1995) explains how the South-central coast of Alaska has had to pay not only economically for the Exxon Valdez spill but also socially, because of a loss to their fishing industry. A market model has been used to evaluate the social cost of the spill and the results are discussed.

Numerous articles have also been written about the Exxon Valdez such as the five-part series "Alaska's response the Exxon Valdez oil spill" (Kelso, 1991) which appeared in Environmental Science Technology. The first article in this series discusses the three phases of spill recovery that took place during the Exxon Valdez spill and the numerous problems that occurred in each phase that added to the disaster of this spill. The first phase "containment and recovery of oil from the water" is one of the most important because the more oil that is contained and removed in the early stages of the spill the better the chances that minimal damage to the environment will occur. This first stage was plagued with problems such as inadequate equipment and the spill response plan was not taken into consideration. Phase two consisted of emergency removal of oil from the shoreline. This included several trial techniques such as manual removal, high-pressure hot water spray and low-pressure cold water flushing. Each one of these techniques had its downfalls and it was unknown at the time what effects these methods would have on the fragile environment. The last phase, long-term treatment of oiled shorelines, consisted of several more experimental removal techniques. The concern during this last phase was the long-term effects that the oil would have on the natural resources as well as the contamination that may occur to the food supply of this area. In conclusion, the authors of this article discuss the fact that inadequate equipment and response time caused this spill to be much more devastating than necessary. Although at the time the article was published the effects on the natural resources had not been fully assessed, it had been concluded by the authors that prevention is the first step in keeping this type of disaster from occurring in the future.

Water Pollution by Petroleum Products

There are several books that contain information on water pollution, natural resource damage, and oil spills. *Water Pollution by Oil* (Hepple, 1971), includes the proceedings of a seminar held at Avienmore, Inverness-Shire, Scotland. This book explains in great detail the effects of oil pollution on various aquatic environments. Suggestions that may prevent accidents and pollution from various oil industries in the future are presented in the various papers. Another book in this category is *River Quality: Dynamics and Restoration* (Lanenen, 1997), which looks at water pollution problems throughout the world and discusses how each problem is being dealt with. The Vistuala River of Poland and the Willamette River of Oregon are the main focus of this book; however, other specific rivers with unique problems are addressed. The Vistuala River became increasingly polluted after World War II from the increasing industrialization and sewage from the growing population. Due to these increased pollutants by 1990, only 4% of the water in Poland was suitable for drinking (Laenen, 1997). By implementing new water management practices the water quality for Poland is slowing improving. The Willamette River was deemed the most polluted river in the Northwest due to the numerous paper mills, canneries, slaughterhouses and communities that were located along this waterway. Legislation was passed in 1967 that required waste-treatment facilities for the communities and businesses along this river. Due to this legislation, water quality began to increase substantially by 1970. Even though these books deal with topics beyond the research being conducted in this study, they still consist of information that could be used in relation to the topic at hand.

Environmental Valuation

There are several methods that can be used to classify geographic data as described in *Geography and Resource Analysis* (Mitchell, 1989). Mitchell describes a number of these methods, including the one that served as a basis for this study. Linton who wrote the article "The Assessment of Scenery as a Natural Resource" (Linton, 1968) conducted a survey that consisted of an "appraisal system based on two variables" in order to categorize the landscapes of Scotland. This method was derived because of the criticism and concerns that he had toward other methods that had been developed previously. Linton sought a method that was not overly complicated or time-consuming, and which would not require the expertise of skilled personnel.

Linton's study began by taking the two variables, landforms and land use, and deriving " six types of 'landform landscapes' appropriate to Scotland." These categories were based on the relief of the land and included such categories as lowlands, mountains and hill country. Once these categories were established, numerical values were assigned to each of the categories with the scoring being completely arbitrary. He based his numbering system on which categories were viewed as " at least interesting and may be highly exiting" as well as "intrinsically tame." He added extra points to areas that contained water because it was decided that water added to the scenic beauty of an area.

The second step of Linton's study was to determine the classification scheme for the second variable, land use. He produced this classification in much of the same manner as the landform variable, using such categories as continuous forest, urbanized and industrialized landscapes and wild landscapes. He assigned arbitrary values to each of these variables as in the other classification variable.

Using this method, Linton was able to produce maps based on the land use and landform categories by taking the individual scores and adding the two variables. Upon combining these maps, Linton was able to achieve his goal and produce the "first analytical representation of the scenic resources of Scotland." Linton also believed that the described method was a better representation for determining the scenic areas of Scotland than the other methods available at the time. He felt other individuals could repeat his study and that similar results could be achieved.

Although Linton felt that his method was the best solution to categorizing the landscapes, Mitchell discusses the criticisms that Linton faced for using such a method. The majority of the criticism came from the fact that the numerical rating system was completely arbitrary, though based on Linton's vast knowledge of the study area. Another area of concern was the breakdown of the individual landscapes while not incorporating the interaction of each part. However, Mitchell goes on to describe the positive effects of this study. The author states that Linton achieved his goal of trying to develop an inexpensive and reliable method of conducting a scenic inventory of Scotland. The method was later tested on two separate occasions by Gilg and a group of first-year Geography students. Gilg determined that the method did in fact produce accurate results without a lot of statistical or laboratory analysis.

Goldfarb introduces clashing perspective in his book *Taking Sides: Clashing Views on Controversial Environmental Issues* (1999). On one such topic Goldfarb presents the two different sides to the argument: Should a price be put on the goods and services provided by the world's ecosystem? Goldfarb begins this debate by giving a brief introduction as to why this topic is so important and why there has been such controversy revolving around this subject. Goldfarb states that the world has come to the reality that something must be done in order to halt the degradation of the ecosystems that the human race has come to rely on, however, the best method to achieve this goal has been the point of controversy. As the author states " it would be a violation of their fiduciary responsibilities for the board of directors of a corporation to take expensive steps to prevent its activities from contributing to the degradation of land, air, or water when there are no costs associated with failing to do so." The methods used thus far to try and add value to the environment such as the gross national product (GNP) have only added to the heated battle. The GNP, which measures a nation's economic productivity, actually increases in an environmental disaster by incorporating the income that was generated by the clean up efforts and failing to penalize the nation for degradation of nonrenewable resources.

The two opposing arguments that are presented in Goldfarb's book, the "yes" side by David Pearce (Pearce, 1998) and the "no" by Mark Sagoff (Sagoff, 1997) revolve around an article written by Robert Costanza in which he states that the "median estimated value for the entire biosphere is $33 trillion per year..." (Costanza, et al., 1997). Pearce's argument, titled " Auditing the Earth: The Value of the World's Ecosystem Services and Natural Capital.", begins with his ideas as to why a price should be placed on the ecosystem. He believes that as along as the services provided by the environment are perceived as free, the world will not see the benefits of trading natural services for commercial ones. An example given by Pearce is a hotel that replaces pristine coastline. People see the economic benefits of the new business but fail to see the lost value of the replaced coastline. Pearce states that two things must be happen before this situation can be corrected. First, a method must be derived to show that all ecosystems have economic value. Second, the "non-market values" of the ecosystems must be discovered and turned into true benefits for the people who become involved in conservation.

Sagoff, on the other hand, argues that a price cannot be placed on the world's ecosystems because the cost would be too great (Sagoff, 1997). Sagoff discusses the fact that the price of reproducing the world's resources would be so great that other methods would be sought. Sagoff gives the example of looking at the stars, which to most people is viewed as a free commodity. If that resource was taken away and reproduced by human means such as a planetarium, there would be a price at which most people would choose another activity before paying the price to enter the replicated resource such as the above mentioned planetarium. Sagoff argues that although the resource was reproduced, the economic value was never truly assessed. Goldfarb ends this discussion by stating that, although both authors have conflicting views on this issue, both agree that the natural resources of the world should not be taken for granted and a way of preserving them should be developed (Goldfarb, 1999).

There have been several books and articles written concerning placing a value on environmentally sensitive areas. Although most of these books and articles discuss methods that will not be conducted in this study, the authors make valid points in the controversy as to if and how value should be placed on the world's natural resources. *Methodological Issues in Valuing the Benefits of Environmentally Sensitive Areas* (Garrod and Willis, 1999) is one such example. The authors discuss the methods that were used in order to add value to environmentally sensitive areas. Contingent Valuation Method (CVM) and how it was applied to certain case studies is the main topic of this article, although the authors explain their concerns for this method of valuation. Garrod and Willis also use the article to offer some suggestions as to how the CVM could be improved, which may prove to be more useful in the valuation of environmentally sensitive areas.

Another source dedicated to the description of adding value to the world's resources is *The Application of Economic Techniques in Environmental Impact Assessment* (James, 1994). This book dedicates an entire chapter to an in-depth review of several of the more common methods used in environmental economics, as well as other chapters on the concept and analysis of environmental impact assessments. This book is unique in that it devotes several chapters to specific case studies. One such case study is the water pollution problem in Jakarta Bay. The author does an excellent job of explaining the problems that occurred in this area as well as what steps were taking in order to try and limit some of the effects of the growing industrial area. James goes into great detail when describing the cultural and industrial aspects of this region while explaining the pollution problems and the management practices that were proposed.

Investing in Natural Capital: The Ecological Economics in Environmental Impact Assessment (Jansson, et al., 1994) gives an excellent review of the "socioeconomic values" that can be derived from the environment. The chapter titled "Environmental Functions and the Economic Value of Natural Ecosystems", by Rudolf S. de Groot, offers a brief description of such topics as conservation value, option value and consumptive use value. de Groot also illustrates the concept of economic value by devoting three sections of his chapter to the description of the economic value of three of the world's natural resources such as the coastal wetlands.

John A Dixon and Paul B Sherman use a chapter in their book, *Economics of Protected Areas: A New Look at Benefits and Costs* (1990), to review some terms and definitions such as rivalry and nonrivalry that are frequently used in conjunction with the topic of environmental economics. The authors also take the opportunity in this chapter to discuss the ways that values are added to natural resources, including techniques based on market prices and cost based approaches. The chapter concludes by explaining to the reader the ways that the value techniques can be applied to certain circumstances and that the best method is always case sensitive.

Oil spills that occur on inland waters have not been a well-documented topic. However, the information on water pollution and oil spills on coastal waters include information that can be related to this area of research. Any type of pollution is going to cause significant damage to the habitat and people of the surrounding area and must be dealt with in a very careful manner. In order for such incidents to be prevented in the future, much more research needs to be conducted in order to educate oil companies and the people associated with these industries as to the effects caused by the negligence of their people. It will only be as these people are educated that there will be a need for less documentation on how to clean up and prevent the mass destruction caused by an oil spill.

CHAPTER III

METHODOLOGY AND COST ANALYSIS

The main goal of the research conducted in this study is to compare the economic and environmental impacts of a petroleum product spill on three rivers in Oklahoma. The focus of this chapter is to describe the methodology of the research that was conducted on these rivers. This chapter discusses how the data was collected as well and the rationale for choosing and collection the data. A discussion of the economic impacts of a petroleum spill will be included in order to describe the damage that can be brought about by a petroleum spill. The ranking systems that were developed in order to compare the rivers will also be described.

The three river segments that were surveyed for the purpose of this research were the Arkansas River, Cimarron River and the Grand Lake Region. The Arkansas River is surveyed from the point where a pipeline crosses the Arkansas River, continuing roughly 100 miles downstream, through a major urban setting as well as some rural areas, until the river passes through the Webber Falls Locke and Dam (Figure 5). The Cimarron River is surveyed for a length of 110 miles, mostly through rural settings, starting at a pipeline crossing and continuing until the Cimarron River empties into Keystone Lake (Figure 6). The Grand Lake survey began at a point where a pipeline transverses the lake

Environmentally Sensitive Areas - Arkansas River between River Mile 6 and 7

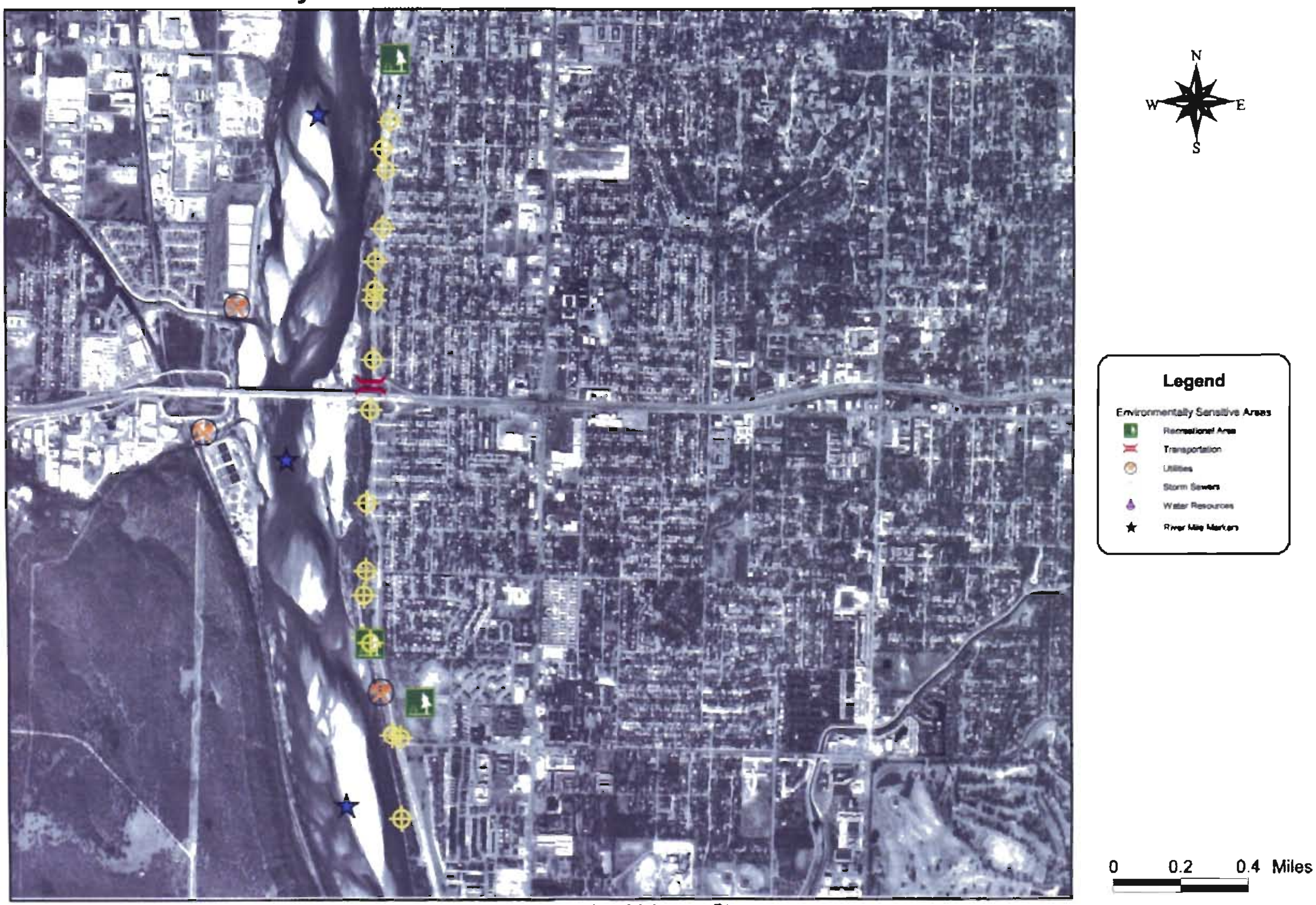

Figure 5. Orthophotography of Arkansas River

Environmentally Sensitive Areas - Cimarron River on River Mile 24

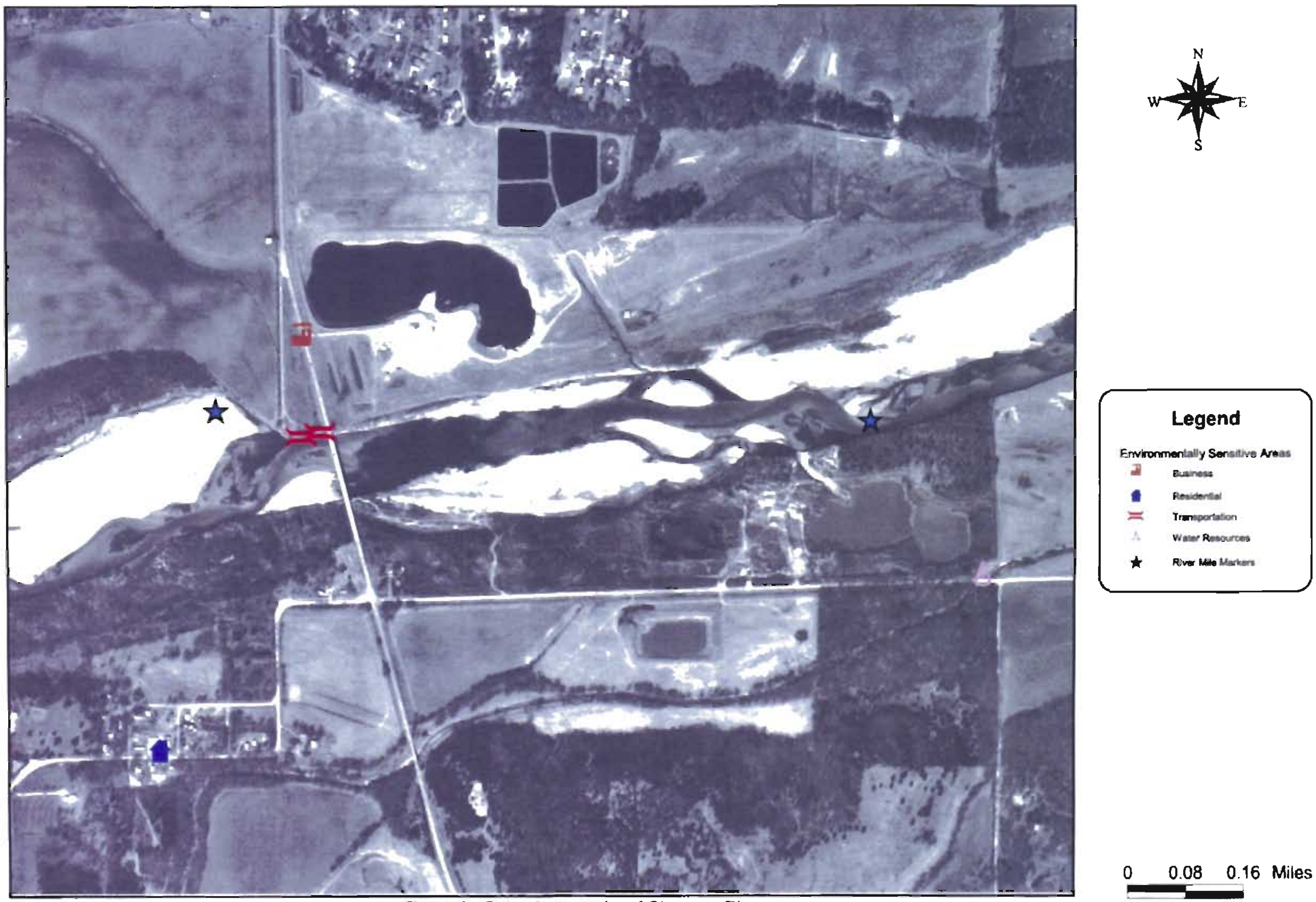

Figure 6. Orthophotography of Cimarron River

and continued approximately 45 miles downstream to the Pensacola Dam (Figure 7). Although environmental and economic health of the entire river segment is important, the first 5 river miles of each river (downstream from the pipeline crossing) is excluded from the analysis because, if a spill were to occur, the first 5 miles would be devastated. Based on this assumption, the river miles are calculated in 10 mile segments starting from river mile 5. The reasoning for the 10 mile segments is to make comparisons among segments and the knowledge that a spill could realistically be controlled within a 10 mile region.

Data Gathering and Field Work

The data for this study was conducted by fieldwork over a period of two summers. Two field workers were hired to walk the three river segments and look for certain places that a pipeline company would deem environmentally sensitive. The field workers were given a list of twelve types of areas that were of importance to the pipeline company and were instructed to only record these types of areas (e.g. see Table 1), although other areas along the river segments might also be impacted in the event of a spill. Once these areas were located, a global positioning system (GPS) point was taken. Along with gathering GPS points of the locations, other information gathered included driving directions, the type of sensitive area, and pictures of each location. Once the field workers returned to the office, the GPS points were downloaded from the GPS units and

Environmentally Sensitive Areas - Grand Lake River Mile 42

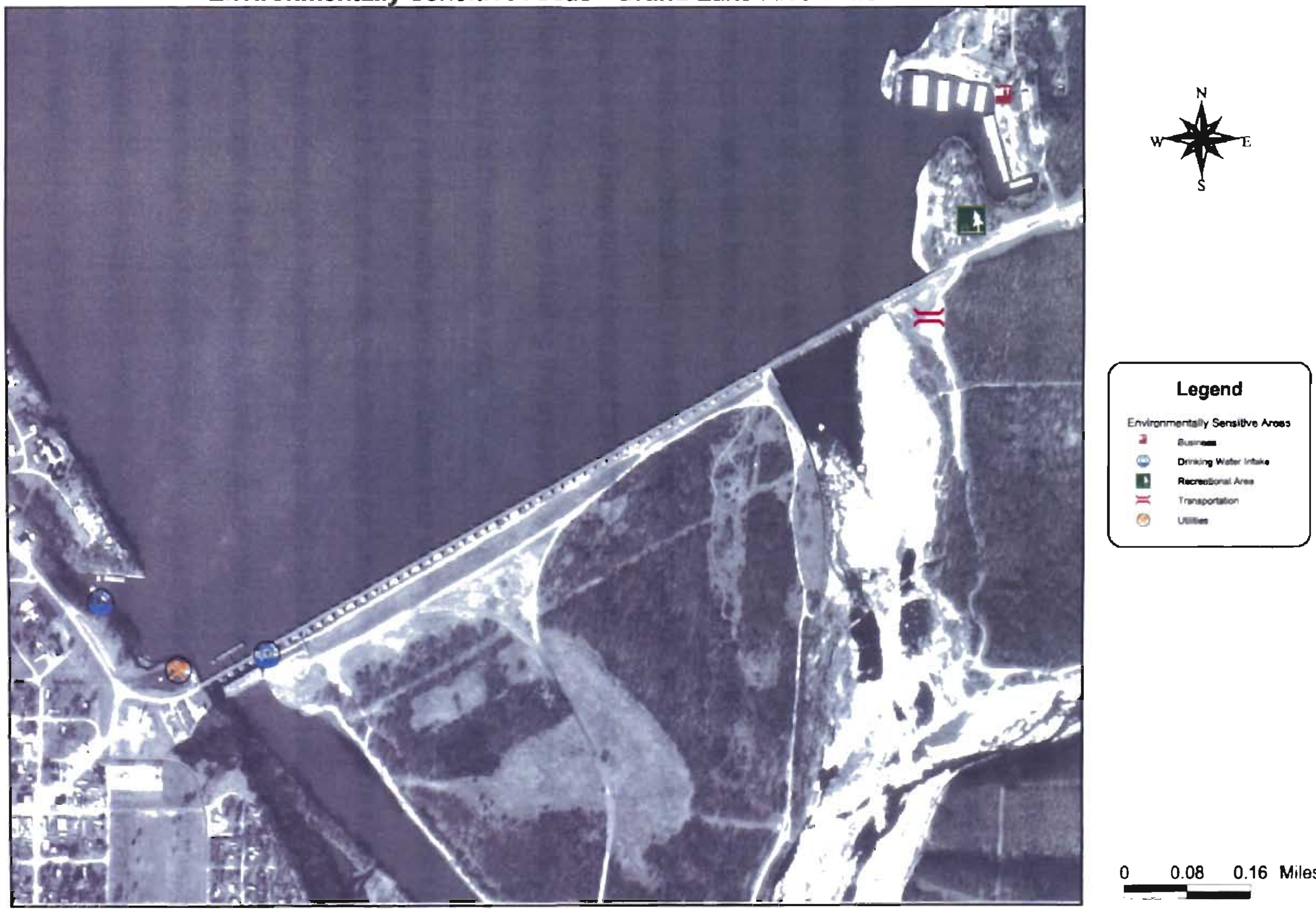

Figure 7. Orthophotography of Grand Lake

processed. With an overall error of 2 – 5 meters, the GPS points were then added to the GIS system that was built to house all of the information gathered. The GIS system was to be used in the case of a spill to allow the pipeline company to have easy and fast access to a map of the areas that were located downstream from the pipelines. In the case of a spill, the GIS system would allow the spill response team to make quick decisions as to the areas in need of protection, as well as the areas that were likely to be impacted. Driving directions to each of the sensitive areas were given in the GIS system so that crews could easily find the sensitive areas in the case of an emergency. Pictures were also included so that a response team would have an idea as to what the area was like before the spill, thus giving them another tool with which to make response decisions. The GIS system is housed at the regional office of the pipeline company on a series of CD's that are easily portable from one location to another, thus making the system very usable if a spill were to occur anywhere within the research area.

The environmentally sensitive areas that were surveyed consisted of 12 categories that a pipeline company deemed as a high risk in the event of a petroleum product spill. The sensitive areas included medical facilities, businesses, residential areas, storm sewers, utilities, transportation areas, drinking water intakes, fish and wildlife areas, recreational areas, boat docks, water resources and areas of economic interest. Several of the sensitive areas, such as medical facilities, businesses, and recreational areas, are self explanatory as to why they are considered important, while others may not be as evident. Storm sewers are added to the list because, if a petroleum product were to flow into a storm sewer, it could be diverted to other stream segments and cause areas that would normally be unaffected by a product spill to become contaminated. Utilities, such as water treatment plants and pipelines, and transportation areas, such as bridges and roads, are areas that may not be directly affected by the spill but could cause significant impacts if these areas were to be shut down due to the spill flowing through or coming into contact with an area. Drinking water intakes are areas located around rivers and lakes that take water from these sources and transfer it to towns. These areas are highly susceptible to the spills because petroleum contamination could affect the drinking water of large numbers of people and possibly leave them without drinking water if the spill were to contaminate the entire area. Fish and wildlife areas can be described as nesting areas or wildlife refuges that contain species that would be more impacted by a petroleum spill, either in terms of a limited habitat along the river bed or by being located in a refuge with no means of escaping the contaminated areas. The environmentally sensitive areas that are labeled as water resources consist entirely of creeks that flow into the surveyed rivers and thus could be contaminated by a spill as it moved past the confluence of the two water bodies. Although an area of economic interest may include businesses, this type of sensitive area is more likely to be a church camp, hay field or an orchard. These areas were placed on the list because of the economic disaster that could be caused to these areas if a spill were to come into contact within the perimeter of the economic activity. Boat docks are also impacted by a spill and were placed on the list because they could be viewed as sources of entrance to the water bodies, not only for people trying to use the water for recreational purposes but also as an entrance point for cleanup in the case of a spill.

Economic Impact

In terms of the economic impacts that would result from a petroleum product spill, the damage depends on a number of circumstances, the first being the amount of product being released from a pipeline. Depending on the scale of the spill, the cost of the estimated damage increased or decreased accordingly. A second fact that must be considered is the type of product spilled into the water. Within the study area, three types of product--crude oil, diesel or gas--could be the possible cause of the environmental damage in the case of a pipeline break. The product released would also play a role in the cost to clean up an area. Although diesel and gas would involve a similar cost of clean up, crude oil would be somewhat more expensive, because gas and diesel would evaporate while the crude oil would have a tendency to coat things as it proceeded down the river. The third factor that would affect the economic status of a spill is the manner in which the pipeline company chose to deal with the spill. The cost to protect sensitive areas versus the cost to clean up the sensitive areas plays a role in the amount of money that will be spent by the company responsible for the spill. The protection costs include the cost of equipment, such as booms that must be placed around each sensitive area in order to protect it from the petroleum product as it flows downstream, while the clean up costs would be the costs associated with going along the river segment and cleaning up the petroleum product after the spill has been contained.

With the help of a contractor, Mr. David Pollard, a cost estimate was established for each river. These estimates were based on equipment such as man power, booms, trucks, boats as well as any other equipment that would be needed in order to clean up and protect the sensitive areas from a petroleum product spill. Using only the sensitive areas employed in this study, the contractor calculated the estimated cost for three types of spills: a small spill containing 5,000 gallons of product released, a medium spill with 10,000 gallons, and an extreme spill discharging 20,000 gallons of product. These calculations are based on the scenario that the petroleum spill traveled from the pipeline to the dam located at the end of each of the rivers surveyed. With each of these spills Mr. Pollard stated that the estimated cost for diesel and gas spills, which are the totals listed in this study, would be the same while the crude oil spill would be another 10% higher than the totals that he had calculated for diesel and gas. For the Arkansas River the cost for the clean up of the 5,000 gallon spill would be $48,000, $125,000 for 10,000 gallons and $165,000 for 20,000 gallons. In order to protect all of the sensitive areas found near the Arkansas River, the cost just to protect the designated sensitive areas would be $18,000. In comparison, for the Cimarron River the calculated costs would be $62,200 for the 5,000 gallon spill, $185,000 for the 10,000 gallon spill and $296,000 for the 20,000 gallon spill, while the cost to protect all sensitive areas would be $22,000.

The calculated cost for the Grand Lake area is fairly close to the Cimarron River estimate with the 5,000 gallon spill being calculated at $78,000, 10,000 gallons being $190,000 and 20,000 gallons estimated at $285,000. The cost to protect the sensitive areas located around Grand Lake would be $44,000.

Based on the economic cost that have been calculated if a spill were to occur along each river at the exact same time, we could determine which area a pipeline company would want to target in order to spend the least amount of money on a spill. For a 5,000 gallon spill, the area that would be most economically affected would be the Grand Lake area followed by the Cimarron River and the Arkansas River. In terms of a 10,000 gallon spill the results stay the same. A 20,000 gallon spill, however, offers an interesting change in that the Cimarron River becomes the most impacted followed by the Grand Lake area and then the Arkansas River. This change could be explained by the fact that once the petroleum product enters into a lake it has nowhere to go and pools. Once the petroleum product contaminates everything in the area, adding more product will not increase the damage to the environmentally sensitive areas. The Cimarron River would sustain more damage with the larger amount of product because of the large number of points located at the end of the river. With the larger amount of product, more environmentally sensitive areas would sustain heavy damage.

In terms of protecting the areas, the cost of the Arkansas River would be the least. This cost analysis is logical because of the type of sensitive areas found along the Arkansas River in comparison to the other two river segments as well as the ease of getting to the river to protect the sensitive areas. The majority of the sensitive areas along the Arkansas River are grouped in roughly the first 25 miles along the river, thus making it much more cost-effective to protect those areas. Also, since the majority of the points are storm sewers, the cost to protect these areas would be somewhat less than it would be to protect fish and wildlife. The cost to protect areas in the Cimarron River would be somewhat more expensive because of the distance that occurs between the sensitive areas and the type of points that occur within the river boundaries. The largest numbers of points in this area are water resources and transportation areas, which are widely scattered and would have to be protected separately. This is in contrast to the areas along the Arkansas River that could be protected together. The Grand Lake region would be the most expensive to protect, again due to the fact that the majority of the points would be scattered. From the economic information provided in this section, one can conclude that the Grand Lake region would be the most economically impacted in the event of a petroleum spill. This conclusion is based on the cost to protect the sensitive points as well as the cost to clean up the areas in all but the 20,000 gallon petroleum spill. The Cimarron River and the Arkansas River follow Grand Lake, making them a lower priority in the case of a multi-area spill.

Ranking System

In order to compare the river segments of this study, an impact ranking system was developed. This system is similar to the ranking system developed by Linton (Linton, 1968) as described in the book *Geography and Resource Analysis* (Mitchell, 1989). The ranking system will be used to add value to the environmental side of the study, allowing the environmental issues to be compared to the economic issues. The ranking system will also be used in order to compare the various rivers, as was done with the economic information that had been provided.

The ranking system was developed with the idea that an environmentally sensitive area that was naturally created, and could not be reproduced by human means, would be more impacted by a petroleum spill than a sensitive area that was human produced to begin with. For example, a sensitive area such as fish and wildlife could not be reproduced by human means because the death of a species could not be undone. However, a boat dock could easily be replaced, thus making it much less environmentally impacted. When developing this system, six different fields were developed, which fell under three different categories. The categories were based on resources that had either been created by natural means, natural means with a human influence, or strictly artificially produced. The fields were then developed by breaking the categories into two levels of resources. After the categories and fields were developed, a rank of one through six was given to each field, with six being the most environmentally impacted and one being the least.

Rank	Criteria
	Natural Resources
6	Totally natural cannot be recreated by any type of human means
5	Natural yet a small hint of human interaction can be detected
	Natural Resources with Human Interactions
4	Naturally created phenomena yet human interference can be readily noted
3	Naturally created yet human interaction is strongly noted and human interaction occurs for numerous reasons
	Human Made Resources
2	Human produced but will take longer than one year to recreate or will disrupt a large number of human lives
1	Human produced which is easily fixed and will disrupt few lives for a long period of time

Table 2. Summary of Ranking Categories

Once the field and categories were defined, the environmentally sensitive areas had to be given a rank in order for an analysis of each river to begin.

Sensitive Area	Rank
Fish and Wildlife	6
Water Resources	5
Drinking Water Intakes	4
Recreational Areas	3
Medical Facilities	2
Residential	2
Transportation	2
Utilities	2
Boat Docks	1
Business	1
Other (Economic)	1
Storm Sewers	1

Table 3. List of Ranks for Environmentally Sensitive Areas

Many things contributed to the reasoning behind the rankings. For the highest rank of six, the area could not be recreated by human process and thus the reasoning why only the fish and wildlife areas were given this rank. Although a habitat for the wildlife could be recreated after several years, if the animals were to come into contact with the contaminated areas, there would be little that could be done by human process to save the wildlife from the pollution of the petroleum product. Water resources were given a rank of five. Although a natural resource, several of the water resources surveyed showed signs of human interaction, such as dredging and channelizations, thus giving them a slightly lower rank. The rank of four was given to the drinking water intakes because they are a natural creation that could be highly contaminated by a product spill, but also have several human influences that could be easily repaired in the event of a spill. The water that would be impacted by a spill would be damaged for an indefinite amount of time and has the possibility of affecting a large number of fish and wildlife that rely on that source as a sole means of water in their area. However, for a town or community that relied on this source of drinking water, the people in that area could obtain water from another source. Although somewhat less convenient for the community, the loss to the environment in terms of clean water would be more of a devastating loss than the loss of drinking water. The recreational areas with a rank of three are usually very natural areas that have been modified in various ways, even if it is nothing more than a picnic area or a campsite with playgrounds and visitor centers. These areas could be drastically impacted by a product spill since the natural habitat could be compromised and forever changed, but also because the access to the recreational area would be restricted until the petroleum product was removed. This is a good example of environmental versus economic damage that could be caused by a product spill. In environmental terms, the natural area could possibly be contaminated beyond human repair and thus lost for several generations. However, the park and picnic areas could be restored within a matter of months. All of the sensitive points ranked as two are areas that have little to no natural resources associated with them but would cause a large disruption in the everyday lives of the people in the area, or would take longer than a year to recreate. These areas, such as the utilities or the transportation areas, although an inconvenience to the public, could easily be rebuilt or relocated, thus not creating a huge environmental impact. The lowest rank of one was given to the boat docks because they would not have an environmental impact if they were to become contaminated and it would not take much to replace them if they were destroyed.

By creating an inventory of the rivers and ranking potentially impacted sites, as described above, an analysis of each river can be accomplished. In the next chapter a break down of the points that are found along each river will be offered, along with a brief description of the unique characteristics of each of the ten mile segments. In later chapters, a statistical analysis will be described that assigns each river segment a number, based on the ranking system, that can be compared in order to decide which river segment would be most environmentally impacted in the case of a multi-pipeline spill across the state of Oklahoma.

CHAPTER IV

ENVIRONMENTAL IMPACTS

The purpose of this research is to discover the impact that a petroleum spill would have on a select group of environmentally sensitive locations along three river segments in Oklahoma. This chapter will discuss what the rivers and sensitive areas would consist of before a spill and how they would be impacted after the spill had occurred. There will also be a discussion as to which of these selected river segments would be most environmentally impacted and which would be most economically impacted.

The Arkansas River

The Arkansas River consists of 172 sensitive areas along its shores as surveyed by the summer field workers (Table 4). The storm sewers, which comprise the largest number of points found, are located primarily in the large urban area while the water resources, the second most frequently found, are located throughout the entire length of the river. The recreational areas seem to be concentrated along the section of the river that passes through the urban area and toward the end of the surveyed area near the Webber Falls Locke and Dam.

River Section (10 mile section)	Arkansas River - Environmental Senstive Areas													
	Drinking Water Intakes	Fish and Wildlife	Recreational Areas	Boat Docks	Water Resources	Medical Facilities	Business	Residential	Storm Sewers	Utilities	Transportation	Areas of Economic Interest		Total Number of Points
0	0	2	4	0	1	1	0	2	29	4	3	0		46
10	0	1	9	0	8	0	0	1	42	3	4	1		69
20	0	0	3	0	3	0	2	1	0	1	1	0		11
30	0	0	0	0	2	0	0	1	1	0	0	0		4
40	0	0	0	0	3	0	3	0	0	0	2	0		8
50	0	0	0	0	2	0	0	0	0	0	0	0		2
60	0	0	0	0	1	0	1	0	0	0	2	0		4
70	1	0	2	0	4	0	1	0	0	2	2	0		12
80	1	1	0	0	3	0	0	2	0	0	0	0		7
90	2	0	5	0	1	0	0	0	0	1	0	0		9
Total	**4**	**4**	**23**	**0**	**28**	**1**	**7**	**7**	**72**	**11**	**14**	**1**		**172**

Table 4. Environmentally Sensitive Areas of the Arkansas River

There seem to be few recreational areas located between these two areas probably due to the rural setting that is found in the middle of this survey river. The first 10 miles of the Arkansas River, which flows through the downtown Tulsa area known as the River Parks, are by far the most sensitive miles on the river in terms of total points. This stretch of river contains 69 of the 172 sensitive areas that occur on the Arkansas River. The water intakes in this area mostly consist of storm sewers located in the River Parks area. The nine recreational areas consist of parks, bingo facilities, wilderness areas and athletic complexes. The eight water resource areas and four transportation areas consist of mainly creeks and bridges that crossed the creeks or the Arkansas River itself. The fish and wildlife point found in this area is a least tern endangered species, which makes its nesting ground on the banks of the river. This stretch of 10 miles has a very diverse range of sensitive points and could receive catastrophic devastation in the case of a spill, not only in terms of number of points, but also by its proximity to the pipeline.

The second segment along the Arkansas River, centered on river mile 20, has significantly fewer points than the previous section but still a large number in comparison to some of the other segments along this river. This segment continues to flow out of the Tulsa area, therefore being somewhat more urban than other segments. Six of the 11 points found in the area consist of water resources and recreational areas. The remaining five points consist of two businesses, a residential area, one transportation and one utility. Although there are fewer points in this segment than the previous 10 miles, several of these points are highly dependent on the river's condition and could be greatly impacted by a petroleum spill. Also, because the pipeline is only 25 miles from these locations, the probability that these areas would be impacted by the spill is still extremely high.

The river segment centered on river mile 30 of the Arkansas River shows the difference in the number of points that occur in an urban versus rural setting. This segment only contains four sensitive areas that are composed of two water resources, one residential area and one water intake. Because these points are 35 miles from the pipeline the chances of damage are somewhat slimmer than the previous segments. Under normal circumstances, a petroleum spill would try to be controlled before river mile 35; therefore these points, as well as the points down river from this segment, may suffer little damage by a spill.

The next segment, focused on river mile 40, has a total of eight points, which is higher than would be expected in the rural area that the river is flowing through. In relation to the previous segment, this area has twice the number of sensitive areas and only three less than the urban area near Tulsa. This increased number of points can be explained by the fact that three of these points are sand and gravel companies that use the sand from the river. Due to the distance from the pipeline there would be little threat of impact from a spill under normal circumstances. However, if a spill were to reach this area the effects would be very damaging to the businesses as well as the creeks and bridges.

Due to the rural setting at river mile 50 and river mile 60, there are a total of six points along this 20 mile stretch of river, two being in river mile 50 and four in river mile 60. The two points in river mile 50 are both creeks, which are categorized as water resources. The four points in the following segment are somewhat more diverse with two transportation areas, bridges that allow people to cross the creeks and the river, one water resource, Pecan Creek, and one business, another sand company that relies on the sand of the river bottoms.

The area of the river that is made up of river mile 70 has another interesting increase in the number of sensitive areas. This segment has a total of 12 points, which is a larger concentration than the second segment flowing through the Tulsa area. This increased number of points can be explained by two unrelated occurrences. The first explanation would be the larger number of water resources in the area. In this segment alone there are four creeks that flow into the Arkansas. The other explanation is that this segment of the river runs through a more urbanized area and is impacted by the recreational and urban demands of the town of Muskogee. Because of the urban influence there are two utilities, a water treatment plant and a power plant, two recreational areas, one business, the Port of Muskogee, and a drinking water intake. The other two points that occur along this stretch of river are bridges, transportation areas that are not uncommon along the entire length of the Arkansas. Because the large number of points that exist in this river segment the impact of an oil spill would be very tragic not only to the recreational areas but also the drinking water for the town of Muskogee.

The segment centered on river mile 80 again decreases in the number of points but not to the extreme of the more rural areas. This 10 mile segment has seven points found within its boundaries, three of which are water resources that have been found so frequently throughout the Arkansas River. The other four points are two residential areas, one of which is the town of Braggs and the other a military facility, a fish and wildlife management area, and a drinking water intake. With the fish and wildlife area being located where it is along the river, a petroleum spill that reached this stretch of the river could have extremely damaging effects to the habitat of the animals. However, as it has been stated about the earlier segments, under a normal situation the spill would never be allowed to travel 85 miles down stream, especially with the knowledge that a wildlife area existed at such a place along the river.

The last segment along the Arkansas River has a total of nine points. Being that this 10 mile segment ends at the Webber Falls Locke and Dam, impounding Greenleaf Lake, it is normal that five of the nine points are recreational areas. These recreational areas consist of several campgrounds, and a state park. The other four points are also to be expected such as the two drinking water intakes, one utility and a water resource. The drinking water intakes pump water out of the lake for drinking water while the utility is the dam that creates the lake. If a petroleum spill were to reach this area of the Arkansas River the spill would be contained by the dam, thus not proceeding any farther down river. However, if a spill were to proceed this far the consequences of the damage done to the river would not only be costly in terms of economic loss but also in terms of environmental loss. The Arkansas River is a very diverse system dealing with not only urban and rural settings but also economic and environmental issues. A petroleum spill located any where on this river would be very damaging. However the Arkansas is unique in that 73.3 % of all the sensitive areas located on this river occur in the first twenty five miles from the pipeline, 66.9% within the first 15 miles. The first 25 miles of the river are the ones most in danger of impact from a spill, and with the large number of points located in this area, a petroleum spill along the Arkansas River would definitely prove to be devastating.

The Cimarron River

The Cimarron River tends to have fewer sensitive areas than the other two river segments surveyed, with a total of 84 environmentally sensitive areas (Table 5). Due to the rural characteristics of this river, there are very few residential, business areas, utilities or recreational areas. The largest numbers of sensitive areas are water resources and transportation areas, which usually occur in pairs and can be found throughout the entire surveyed area. This would be expected because several of the water resources are creeks while the transportation areas are the bridges that would be needed in order to cross these sensitive points.

The segment that has the greatest number of points is the last segment of the Cimarron River, while the second largest number of points per segment occurs in the first segment. This is also due to the rural nature of the river and

River Section (10 mile section)	Cimarron River - Environmental Senstive Areas													
	Drinking Water Intakes	**Fish and Wildlife**	**Recreational Areas**	**Boat Docks**	**Water Resources**	**Medical Facilities**	**Business**	**Residential**	**Storm Sewers**	**Utilities**	**Transportation**	**Areas of Economic Interest**		**Total Number of Points**
0	0	0	0	0	4	0	0	0	0	0	3	0		7
10	0	0	0	0	6	0	0	3	0	0	2	0		11
20	0	0	0	0	4	0	1	2	0	0	2	0		9
30	0	0	0	0	5	0	0	0	0	0	2	0		7
40	1	0	0	0	2	0	0	0	0	0	3	1		7
50	0	0	0	0	2	0	0	0	0	0	2	0		4
60	0	0	0	0	2	0	0	0	0	0	2	1		5
70	0	0	0	0	2	0	0	0	0	0	3	0		5
80	0	1	1	0	1	0	0	0	0	0	2	0		5
90	0	1	3	0	3	0	0	0	0	0	2	0		9
100	1	0	10	0	0	0	0	3	0	1	0	0		15
Total	**2**	**2**	**14**	**0**	**31**	**0**	**1**	**8**	**0**	**1**	**23**	**2**		**84**

Table 5. Environmentally Sensitive Areas of the Cimarron River

the fact that the river ends in a lake, thus creating more recreational and residential opportunities toward the end of the river. The first segment is closer to the towns of Langston and Coyle, which would account for the larger number of points on the first section. The one unique factor that occurs along the Cimarron River is that the number of sensitive areas per ten mile segment are more uniform along the length of the river. In both the Arkansas River and Grand Lake, there is at least one segment with a significantly higher number of points. In the Cimarron, the points are more uniformly distributed. The section that would be most in danger of damage, river mile 10, has a relatively small number of sensitive areas. The largest number of sensitive areas that are found in this surveyed area are water resources (six). This is followed by three residential areas and two transportation areas. The three residential areas include two houses and the town of Coyle. The houses are very small, unlike the houses that would be found along the banks of Grand Lake. The town of Coyle is a very small rural community with a population of less than 300. Although the people in this town would be significantly impacted by a spill, the total population of this town is relatively small, thus reducing the damage and increasing the chances for evacuations as compared to the effects if a spill were to occur in a larger metropolitan areas such as Tulsa. With this segment being so close to the pipeline, significant damage to these areas is almost certain.

The segment focused on river mile 20 has roughly the same number and distribution of sensitive areas as river mile 10. There are nine points located in this 10 mile segment; four water resources, two transportation areas, two residential areas, and one business. The only sensitive area that deviates from the previous segment is the one business that can be found along the banks of the river, (a sand company). This segment also is close enough to the pipeline that damage is likely to occur to the points mentioned in this area. However, because the business is located between river mile 24 and 25 the spill could realistically be contained by this point, thus sparing it from total economic disaster.

The third segment that is surveyed along the Cimarron River, in terms of environmentally sensitive areas, would realistically be affected only minimally if a spill were to occur both in terms of its relative location to the pipe and the number and type of sensitive areas that are found in this area. The only other damage would be to the riverbanks, with its exposure to the petroleum products. In this segment only seven points were identified, five water resources and two transportation areas.

The area of the Cimarron River located along river mile 40 also has nine sensitive areas located within its 10 mile stretch; however there is a larger range of sensitive areas represented. Although the majority of the areas are water resources and transportation areas (two and three respectively), this segment also includes a drinking water intake and an area of economic interest. The other water resource is a water treatment facility for one of the rural towns located along the banks of the river. The drinking water intake is a lake that supplies water to these rural communities, while the area of economic interest is an oil field that is also located along the shores. This segment would be somewhat more crucial to protect than the previous segments because of the types of sensitive areas found. With the drinking water intake and the water treatment facility, a larger group of people would be impacted if a petroleum spill were to shut down these points. Due to the distance from the pipeline, farther than the 35 miles that a pipeline company would allow a spill to travel under normal conditions, these areas would be fairly safe but the impacts could be significant if a spill reached these areas.

The surveyed segments on river miles 50, 60, and 70 contain only 14 points along the entire 30 mile stretch, four in river mile 50, five in river mile 60, and five in river mile 70. The four points in the first segment consist of two water resources and two bridges that follow the same pattern as mentioned in all of the other segments. The same holds true for the two water resources and two transportation areas found in river mile 60. The last remaining point located in river mile 60 is made up of an area of economic interest, which happened to be an oil storage facility. This facility is located at least 100 feet from the banks of the Cimarron; therefore it would not be directly impacted if a spill were to continue down stream to this point. The five sensitive areas in river mile 70 are three transportation areas and two water resources that do not deviate from the other segments.

The number and types of sensitive areas begin to change somewhat as the river progresses into river mile 80. This segment enters into the Keystone Lake area, thus leaving the rural type features and offering more recreational opportunities. The rural nature of the previous segments limited the number of points as well as the variations of these areas. All of the creeks were small, thus not lending themselves to many recreational opportunities. As the river grows closer to the lake however these opportunities tend to increase. This is shown in river mile 80. Although there is one water resource and two transportation areas, there is also a recreational area and a fish and wildlife area here. The chances of a petroleum spill reaching this far from the pipeline would be somewhat slim because a pipeline company would try to contain a spill by this point. However, the risk exists that the spill would reach River Mile 80 and therefore this segment would be in extreme danger of having these areas contaminated. Unlike the towns found previously on this river, the wildlife that depends on the water would not be able to seek other sources with such ease as the people in the area. This should alert the pipeline companies to that fact that if a spill were to occur along this river, it must be stopped before it reaches this point of the river.

The segment centered on river mile 90 is completely contained by the lake, thus offering more recreational opportunities and more opportunities for wildlife habitat. As with the previous segment, this one also includes the wildlife management area and three recreational areas. These areas consist of two campgrounds and a marina type area. The three water resources deviate from the norm in that one is categorized as Keystone Lake, one a wetland area and the other is an arm of Keystone Lake. This segment would also be heavily affected if the product spill were to reach this area. Not only would the wildlife management area be affected but the spill would also damage the wetland area and the campgrounds that are so dependent on the condition of the lake, although for totally different reasons. If a spill were to reach this point, the product would begin to pool rather than flow, the effects of which will be explained in more detail in the survey description of Grand Lake. The best defense that a company would have to save these sites against a spill would be to ensure that it never reached Keystone Lake.

The last segment of the Cimarron River, centered on river mile 100, has the largest number of points. The majority of these areas are recreational areas (10 out of 15 points). Of the remaining five areas, there are three residential areas, one utility and one drinking water intake. The recreational areas range from campgrounds to marinas. The final sensitive area found is the Keystone Dam, which is labeled as a utility. This dam would be the absolute stopping point of the petroleum product if the spill could not be stopped by any other means.

Although this river has fewer points than the other two river segments, there still would be considerable damage done if a spill were to occur. However, due to the rural nature of the river and the fact that no more than 0.17% of all the points are located in any one segment, this river would be the least affected in terms of overall points impacted. However, the economic and environmental damage done could still be extensive considering that 31 of the 84 sensitive areas are water resources that would face long term damage if affected by a spill.

The Grand Lake

The sensitive areas that are included in the Grand Lake area are much more clustered and grouped than is the case in the other segments (Table 6). This is due to the fact that the areas are found around the perimeter of the lake, which only consists of some 45 river miles, unlike the other two segments that have more than 90 miles of river area. Residential areas are the most abundant feature found along this area, with businesses and boat ramps being the next most frequent. These areas would be found more frequently along the lakefront as opposed to riverfronts because of the tendency of people to spend more time on boats and living along the banks of a lake.

The first 10 mile river segment of Grand Lake has the fewest number of sensitive points. The reason for the small number of points could be explained by the fact that at this point the area is still considered more of a river segment and has not branched out into the lake. This would limit some of the activities that would typically be found in a lake area. Within the area, the sensitive points consist of a large number of residential areas (15), several boat docks (eight), areas of economic interest (five), businesses (three), water resources (two), and transportation area (1). Although this segment has the fewest number of points, it would be the most impacted by a spill due to its close proximity to the pipeline. The lake is somewhat unique, though, in that if a spill were to occur the petroleum product would only be allowed to travel a short distance before a dam would stop it. Although this would stop the spilled product from traveling long distances, this would cause a pooling effect, thus pushing the products farther

River Section (10 mile section)	Grand River - Environmental Senstive Areas													
	Drinking Water Intakes	Fish and Wildlife	Recreational Areas	Boat Docks	Water Resources	Medical Facilities	Business	Residential	Storm Sewers	Utilities	Transportation	Areas of Economic Interest		Total Number of Points
0	0	0	0	1	0	0	0	2	0	0	4	1		8
10	0	0	0	8	2	0	3	15	0	0	1	5		34
20	3	0	0	8	1	0	7	13	0	0	2	1		35
30	6	0	3	8	3	0	9	34	0	1	1	0		65
40	5	0	4	5	1	0	13	29	0	1	2	1		61
Total	**14**	**0**	**7**	**30**	**7**	**0**	**32**	**93**	**0**	**2**	**10**	**8**		**203**

Table 6. Environmentally Sensitive Areas of Grand Lake

into the water resources and causing more damage to the areas that are found along the banks of the lake. Unlike the other rivers that were studied, the spilled contents would not simply flow down the river and be gone once the pipeline had been shut off. With the lake pooling the product, the damage would be much more severe as it would be much harder to minimize the damage to the sensitive areas. Therefore, due to both the closeness of this segment to the pipeline and the lake effect, the sensitive areas described above would be in extreme danger if a spill were to occur.

The second segment of Grand Lake is much like the first in that it has 35 sensitive areas, which is considerably less than the other two segments along the lake. The total number of residential areas largely influences the number of points as 13 of the 35 points are classified as residential. Businesses are usually attracted to lake areas, so the seven businesses and eight boat ramps located in this 10 mile region are not unexpected. The three drinking water intakes in this region are also to be expected due to the fact that this is a body of water that is an excellent source of drinking water for the Grand Lake region. The two transportation areas found are not the typical bridges as in other areas. One of the transportation areas is a bridge but it is a much taller bridge developed specifically to allow sailboats to pass underneath it while still allowing cars to pass from one side of the lake to another. The second transportation area is an airport that is used by the resorts to accommodate the weekend travelers who frequently fly into the Grand Lake region for vacation. The last two points that can be found in this 10 mile segment are an area of economic interest and a water resource. This segment of the stream includes three drinking water intakes, so the effects could be felt over a more widespread area because the drinking water for several communities could be affected if the water is contaminated.

Within the Grand Lake region, the segment focused on river mile 30 has the largest number of points. The 65 sensitive areas in the segment make up 32% of the total 203 sensitive areas surveyed along Grand Lake. At the distance that this segment is from the pipeline, under normal conditions the spill would be controlled by this point. However, due to the nature of lakes and how they react with spilled substances, the sensitive areas at this point in the lake are still at high risk of being impacted by a pipeline break. The largest number of points found in this region, as with the other segments in this survey, are residential areas. In this 10 mile length there are 34 residential areas which comprise more than half of the total points. The difference with this segment is that even if omitting the 34 residential areas, 31 points still remain, almost the total number of points located in each of the previous two segments. The second largest number of sensitive areas found were businesses, which consisted of resorts, marinas, and restaurants. There were eight boat docks discovered in this sector, with those being broken into four recreational/public, two private and two residential. The six drinking water intakes that are found in this vicinity supply the drinking water for two different towns as well as one rural water district. This could be very dangerous if they were to become contaminated. The eight remaining points are comprised of three recreational areas, three water resources, one transportation area and one utility. The one utility is a water treatment plant for the town of Grove. This plant would also cause considerable problems if it had to be shut down due to contaminations in the water supply. This would not only affect the people along the shores and banks but also an entire community whose livelihood depends on the purity of the lake water. As I have stated throughout the description of river mile 30, if a petroleum products spill were to reach this section of the lake, the damage caused could take years from which to recover. Even though the residential areas and boat docks would be affected, the biggest problems would come from the drinking water intakes, utility and recreational areas found here. The one saving point of this segment is that it is farther from the pipeline, thereby offering some hope that if a spill were to occur the product would not be allowed to come into contact with all of these sensitive areas.

The final region, the segment centered on river mile 40 of Grand Lake, contains 61 points. This increase in number makes sense in that the lake has become bigger at this point and spread out more during the last 20 miles of the lake, in comparison to the first 20 miles, where the lake takes on more of a river-type appearance. As the lake increases in size there is more room for resort-type establishments, therefore bringing in more businesses, residential houses, and recreational opportunities. In this final segment, the largest number of points are residential areas (29) and businesses (13). The next most frequent areas were drinking water intakes and boat ramps, which had a total of five each. The five drinking water intakes supply water to one town and several subdivisions as well as for the Pensacola Dam, which uses the water to generate electricity. The largest number of recreational areas along Grand Lake can be found in this ten mile segment. The two transportation areas are bridges that allow access from one side of the lake to another, with one of these areas being the dam itself. The Pensacola Dam is unique in that it is classified in this survey as three different points, a transportation area, drinking water resource and the only utility found in this section. The dam serves a number of purposes and, as stated above, is used to generate electricity for the Grand River Dam Authority (GRDA) to be sold throughout the entire state of Oklahoma. If this dam were to become incapacitated due to a products spill, towns such as Stillwater and Claremore in Oklahoma would have to switch to alternative power sources until the dam could be placed into operation again. As I have pointed out in the description of this segment, any contamination that might reach this area by terms of a pipeline break could cause a chain reaction of effects that theoretically could be felt across the state. If the Grand Lake region were to ever experience a petroleum product spill, the hope would be that the spill could be contained within the first 20 miles from the pipeline, where there are far fewer sensitive areas. There would be fewer areas affected as a whole and far fewer highly dependent points that rely entirely on the purity of the lake. If a spill were to reach the Pensacola Dam, the pooling effect described earlier would be devastating and could cause damage that would be felt for many years to come.

By breaking the rivers into 10 mile segments, a comparison can be done to show which areas of the state would be more affected by a petroleum spill. In chapter five, this information will be combined with the ranking system described in chapter three to generate numerical output for comparing the sensitivity of the rivers to equal petroleum product spills. With the combination of the description given above, and the statistical methods of comparing the rivers, a more educated decision can be made about which areas would be in the greatest danger of petroleum contamination in the event of a spill.

CHAPTER V

STATISTICAL METHODS AND ANAYLSIS

Although each of the rivers surveyed would be damaged by a petroleum spill, some would face more damage than others. Pipeline companies have a way of categorizing environmentally sensitive areas based on their own needs but this categorization has little to do with overall river impact. This chapter will discuss the way a pipeline company would categorize the points surveyed and will go on to discuss how the ranking system developed for this study will be used to determine which river segments will be more impacted in terms of both economic and environmental damage.

Industry Standards

Whenever a petroleum product spill occurs, the main priorities of any pipeline company are to protect human life, protect the environment, and control the source. By protecting human life, the pipeline company is concerned with the safety of its personnel, evaluating the threat to public safety, and evacuating people who are in danger. With respect to the environment, the main concerns are to limit the spread of the spill, to protect the environmentally sensitive areas, and to protect the wildlife and water intakes. While controlling the source would entail shutting down the source of the spill, this would also include containment and restoration. It is within these goals that a pipeline company has decided that a spill should never proceed beyond river mile 34. They have also set the standard that all shoreline cleanup should be completed within 10 days of the spill. Using these goals, two categories have been determined using the 12 categories of environmentally sensitive areas that were defined at the beginning of this study. Category One would be the areas of highest concern and would be the areas that the pipeline company would try to protect first, while Category Two areas would be of less concern. During a product spill the areas that a pipeline company would first look for are water intakes and fish and wildlife areas. Once these areas are located, protecting these areas becomes top priority along with the other sensitive areas listed in category one.

Ranking System Method

Although this scheme works well for the pipeline company from a purely economic or environmental perspective, more information needs to be taken into consideration. The ranking system described in Chapter 3 was developed for this reason. It would be valuable for a pipeline company to know, before a spill occurred, which areas along a river course would be more affected environmentally and economically, therefore being better prepared to take precautionary measures to protect these areas. To achieve this goal a number of statistical measures were applied. For each individual river, the first step was to apply the rank to each environmentally sensitive area and multiply this rank times the number of occurrences of each point (Ranking Total Index = {(Rank x

Number of Occurrences)). By using this method a number can be applied to each river that can be used to compare the rivers as a whole. In this case, the Arkansas River would be the most environmentally affected because it has the highest Ranking Total Index (Table 7). Although this is a valid way to compare these rivers, an average severity index was then taken. By dividing the ranking total index by the total number of points, an average severity index for each river was determined (Average Severity Index = (Ranking Total Index / Total Number of Points)). When applying this method the Cimarron River (Table 8) has by far the largest average severity index while Grand Lake (Table 9) had the lowest.

The idea behind the ranking scheme was to put a higher emphasis on the areas that would suffer more environmental damage in a product spill so a critical sum calculation was performed on these points. By taking the number of environmentally sensitive areas that had a rank of 5 or 6 and adding the total number of these points together (Critical Sum = (Sum of Number of Points Ranking 5 or 6)), a critical sum was calculated for each river as well. This allows the pipeline companies to have a quick way to look at the rivers in terms of the most environmentally sensitive areas. A chart with just the critical sums displayed would be beneficial in that someone could look at that specific measure and know which river would be more environmentally damaged. Again, the Cimarron River had the highest number thus suggesting a more environmentally sensitive river.

Arkansas River			
Category I			
Type	**Rank**	**Number of Points**	**Total**
Drinking Water Intakes	4	4	16
Fish and Wildlife	6	4	24
Recreational Areas	3	23	69
Boat Docks	1	0	0
Water Resources	5	28	140
Total		**59**	**249**
Category II			
Type		**Number of Points**	**Total**
Medical Facilities	2	1	2
Business	1	7	7
Residential	2	7	14
Storm Sewers	1	72	72
Utilites	2	11	22
Transportation	2	14	28
Area of Economic Interest	1	1	1
Total		**113**	**146**
Ranking Total Index		**172**	**395**
		Average Severity Index	**2.296512**
		Critical Sum	**164**

Table 7. Summary of Arkansas River

Cimarron River			
Category I			
Type	**Rank**	**Number of Points**	**Total**
Drinking Water Intakes	4	2	8
Fish and Wildlife	6	2	12
Recreational Areas	3	14	42
Boat Docks	1	0	0
Water Resources	5	31	155
Total		**49**	**217**
Category II			
Type	**Rank**	**Number of Points**	**Total**
Medical Facilities	2	0	0
Business	1	1	1
Residential	2	8	16
Storm Sewers	1	0	0
Utilites	2	1	2
Transportation	2	23	46
Area of Economic Interest	1	2	2
Total		**35**	**67**
Ranking Total Index		**84**	**284**
		Average Severity Index	**3.380952**
		Critical Sum	**167**

Table 8. Summary of Cimarron River

Grand Lake			
Category I			
Type	**Rank**	**Number of Points**	**Total**
Drinking Water Intakes	4	14	56
Fish and Wildlife	6	0	0
Recreational Areas	3	7	21
Boat Docks	1	30	30
Water Resources	5	7	35
Total		**58**	**142**
Category II			
Type	**Rank**	**Number of Points**	**Total**
Medical Facilities	2	0	0
Business	1	32	32
Residential	2	93	186
Storm Sewers	1	0	0
Utilites	2	2	4
Transportation	2	10	20
Area of Economic Interest	1	8	8
Total		**145**	**250**
Ranking Total Index		**203**	**392**
		Average Severity Index	**1.931034**
		Critical Sum	**35**

Table 9. Summary of Grand Lake

Individual River Segments

All of these methods were applied to the individual river segments so that not only could an individual river be tagged but also a specific section of that river. Therefore the pipeline company could immediately send the necessary personnel to those areas to ensure that as little damage as possible was done to these areas. After the ranking total index, averages severity index and critical sums were calculated for each river segment, each segment was ranked based on the overall number for each of the statistical methods. This gives the pipeline companies an easy way to look at a table and see which river segment is the most environmentally sensitive using either or all methods, with one being the highest or having the greatest rank and ten being the lowest (Table 10, 11, 12).

By using the methods described in this chapter a pipeline company or anyone else interested in the environmental sensitivity of the rivers surveyed can focus on the river or specific river segment that could be damaged by any kind of contamination. Although no one river stands out as the most environmentally sensitive in all three statistical tests, the pipeline company can use the results in a planning situation to determine which areas would be in most need of protection.

Results of Ranking System

Arkansas River

The Arkansas River was included in this study as a method of comparing rural versus urban circumstances. When a pipeline spill occurs, the majority of

Arkansas River			
Overall Rank of each River Segment			
River Segment	Ranking Total Index	Average Severity Index	Critical Sum
River Mile 10	1	4	1
River Mile 20	3	7	4
River Mile 30	7	3	6
River Mile 40	6	8	4
River Mile 50	8	1	6
River Mile 60	8	9	8
River Mile 70	2	6	3
River Mile 80	5	2	2
River Mile 90	4	5	8

Table10. Individual River Ranking for Arkansas River

Cimarron River			
Overall Rank of each River Segment			
River Segment	Ranking Total Index	Average Severity Index	Critical Sum
River Mile 10	2	4	1
River Mile 20	4	5	4
River Mile 30	4	1	2
River Mile 40	6	7	6
River Mile 50	10	7	6
River Mile 60	9	7	6
River Mile 70	8	6	6
River Mile 80	7	2	5
River Mile 90	3	3	3
River Mile 100	1	7	10

Table 11. Individual River Ranking for Cimarron River

Grand Lake			
Overall Rank of each River Segment			
River Segment	Ranking Total Index	Average Severity Index	Critical Sum
River Mile 10	4	4	2
River Mile 20	3	1	3
River Mile 30	1	2	1
River Mile 40	2	3	3

Table 12. Individual River Ranking for Grand Lake

the media is going to focus on the areas that impact a large number of people, thus placing more attention on a spill that occurs on the Arkansas as compared to a spill that would occur on the Cimarron River. With the Arkansas River flowing through downtown Tulsa it would seem that a pipeline company would want to prevent a spill from occurring in that area to prevent bad press. However, this does not take into account the economic or environmental implications of the area.

By applying the economic data and the ranking system to each river we find that, in reality, the Arkansas River would not be the most economically or environmentally impacted. In terms of the economic data, the Arkansas River would be the least impacted in any type of a spill when compared to the other two rivers surveyed. When comparing the cost to clean up a spill, the Arkansas River only has a cost range of $117,000 from a small-scale spill to a large-scale spill as described by the data derived from David Pollard. However, with the other two rivers the cost range is much more substantial, with the Cimarron being over $230,000 and the Grand Lake region having a total of $207,000. The costs to protect the areas along the Arkansas River are somewhat less, with an overall total of only $18,000.

The ranking system gives us a somewhat different picture of the Arkansas River. When comparing the three statistical methods, ranking total index, average severity index and critical sum, in spite of the fact that the Cimarron River was deemed most environmentally impacted with two of the three tests, the Arkansas was ranked second. However, this is not the case when comparing the individual river segments of the three rivers. River Mile 10 contains the largest ranking total index and critical sum of any of the river segments found in the three rivers. This could be explained by the large cluster of points found in the River Parks area of Tulsa. However, when comparing this segment to River Mile 30 of the Grand Lake region, although the two areas have roughly the same number of sensitive areas, the average severity index and critical sum for the Grand Lake section is considerably lower. This would suggest that if a spill were to occur along all three rivers, this river segment would be one that needed to be protected if the pipeline company was looking strictly at the numbers of the ranking system. This river also contains the highest average severity index found among the river segments. River Mile 50 has an average severity index of 5. This is more of a function of lack of points than of a large number of environmentally sensitive areas, however. It is because of occurrences like this that several statistical methods were applied. Although a high average severity index was found, there were only two sensitive areas located within the 10 mile segment. With both of these areas being water resources, the average severity index was extremely high. When using this ranking system, the pipeline company must look at the number of points as well as the type of sensitive areas found in order to make sound decisions about which areas would be more impacted.

Cimarron River

The Cimarron River, which was chosen to be surveyed due to its rural nature, proved to be somewhat more important than originally thought. If a spill were to occur along this river little media attention would be given to this area because of the limited number of people that would be impacted. Except for the people who lived along this river, or if the spill reached an area that was traveled by a large percentage of the population, the general public may not know about the spill. When applying the economic and environmental data that was gathered during this study, we see that the Cimarron River is a very important river and in need of protection.

When looking at the economic data that was obtained, the Cimarron River is second in terms of most economically impacted (except in a large spill, when it is considered the most economically impacted). This indicates that more attention should be given to this river in terms of planning. When the ranking system was applied to not only the river as a whole but also the individual segments, the true importance of this river began to be revealed. With two out of three of the statistical measures rating the highest among the three river segments, one would believe that this is the river most in need of protection from a petroleum spill. When looking at the individual segments, there is not one segment that really stands out, as in the other two rivers surveyed. Each of the individual segments that rank high in one statistical method score relatively low in another. For example, River Mile 100 has the highest ranking total index but a lower average severity index and the lowest critical sum. This shows that although there are a large number of sensitive areas found in this 10 mile segment, these areas are not necessarily considered environmentally sensitive. The segment with the highest critical sum, river mile 10, gives a better representation of the sensitive areas with the ranking total index ranking second and the average severity index ranking fourth. It is examples like this that should be taken into consideration when using these numbers. When looking for individual segments that are in need of protection, the pipeline company should look for areas that score high in all three methods instead of in just one. With this ranking system and the economic data that was obtained, this research showed that it is not necessarily the urban areas that are in need of protection but the rural areas that, while having fewer environmentally sensitive areas, are still in the most danger of combined environmental and economic destruction.

Grand Lake

The Grand Lake area was included in this study as to compare how a river that forms a large lake would be impacted by a petroleum spill. If a spill were to occur in this area, the media would be quick to point fingers at the pipeline company responsible. As with the Arkansas, this media coverage would be based on the large population that would be impacted by the contamination, such as the fisherman and recreational population who use the lake on a regular basis. When beginning this study, it was thought that the Grand Lake region would be the most economically and environmentally impacted due to the large number of environmentally sensitive areas that were found in this area. The hypothesis was only partially correct.

The economic data that was gathered concluded that Grand Lake would be more costly to clean up than the other two river segments in all but the largest spill. This is explained by the pooling effect of the petroleum products. The cost to protect the sensitive areas is double what it is for the other rivers, suggesting that it would be of benefit to the pipeline company to insure that a petroleum spill did not occur in this area. The surprise came when the ranking system was applied to the Grand Lake area. In none of the statistical methods did Grand Lake rank first and in only one did it even rank second. This would suggest that Grand Lake is the least environmentally impacted of the three rivers that were surveyed. In terms of the ranking total index, Grand Lake came in second behind the Arkansas River but this would be expected considering Grand Lake had the largest number of environmentally sensitive areas. The average severity index was well below the other two rivers and the critical sum was extremely low, much lower than anticipated. If the pipeline company were to look at the four individual segments of Grand Lake they would find another interesting occurrence. The ranking total index of each of the segments were higher than any other segment across the three rivers except for river mile 10 on the Arkansas River. Again, this is because Grand Lake has the largest number of sensitive areas but the lowest number of river miles. The average severity indexes of the river mile segments were the lowest found. The lowest average severity index found on the Arkansas River was 2.5 while the lowest of the

Cimarron River was three. This is compared to the highest average severity index of Grand Lake being 2.11. This can be seen in the critical sum test as well. Although the critical sums are comparable with the other rivers, ranging from 15 to 5, the critical sum is extremely low for the large number of sensitive areas that are found. River Mile 10 of the Arkansas River has a ranking total index of 69 and a critical sum of 46. Compared to River Mile 30 of Grand Lake, which has 65 sensitive areas but a critical sum of only 15. In both rivers, the Arkansas and the Cimarron, for a critical sum to be around 5 to 10 the number of sensitive areas found ranged from roughly 4 to 10. Any more points than that and the critical sum rose well above the number found for Grand Lake. The environmental assessment, combined with the economic data for this area, indicates that Grand Lake is much more economically impacted than environmentally impacted, with the majority of the environmentally sensitive areas also considered economically sensitive. With this being unveiled, the pipeline company can make informed decisions about the region of Grand Lake and realize that, although environmental damage would be considerable in the case of a multiple pipeline spill, Grand Lake would be the least environmentally damaged, but the most economically damaged. The pipeline company would then be forced to decide which is more important to them in the event of a multiple pipeline spill, the environment or the economic activities.

CHAPTER VI

CONCLUSIONS

The pipeline industry plays an important role in the everyday lives of almost everyone in the world. Without the technology and convenience of pipelines, the world might be a much different place. However, with this convenience comes a price. When this mode of transportation breaks, the environment and other areas that come into contact with the pipeline's contents often pays dearly both in terms of the environment and economics.

The purpose of this study was to try and find critical areas that would need to be protected in the event of a pipeline spill across three river segments within the state of Oklahoma. As defined by a major pipeline company, 12 types of points were listed as environmentally sensitive and in need of protection. With the help of two field workers, 459 areas were located over a two-year period. An extensive survey was completed about each of these areas and entered into a GIS system. A ranking system was also developed to categorize the environmentally sensitive areas in terms of which areas would be in most danger of environmental damage. With the help of a contractor, economic data was also gathered about these sensitive areas and it was determined which river segment would be most economically affected by a product spill. With this study, a pipeline company can now make informed decisions about which areas would be more affected environmentally and economically, as well as which river segments would be in greatest need of protection in the case of a single or multiple pipeline spill across the state of Oklahoma. With this information, the areas surveyed may now have a better chance of being protected, but the potential of environmental and economic damage is still there.

Although no definite answer was given as to which river is the most environmentally sensitive or which 10 mile section of river in the state of Oklahoma would be the most impacted by a spill, this study did prove that there are areas out there that are in more danger than others. It was also found that in most of the statistical tests performed, the Cimarron River would be the river most in need of protection, in the event of multiple pipeline spills in Oklahoma. In terms of economic destruction, the majority of the data suggests the Grand Lake would be the most economically impacted; however, in the event of a worst-case spill, the Cimarron River would be the area most impacted. With this information a pipeline company can now make more educated decisions about what areas need protecting and where more maintenance of the pipeline system might be warranted.

Limitations of Research

There were several limitations that restricted this study. First was a lack of background literature about the subject of petroleum spills in rivers. Most of the literature found dealt with marine spills and was not relevant to this study. With little background information, most of the data that was used came directly from the pipeline company that funded this study, thus offering some bias as to how they would perform this study as compared to how other pipeline companies might do something similar. While the 12 categories of environmentally sensitive areas that were included in the survey data were of importance to the pipeline company, other businesses or environmental agencies might have chosen other types of environmentally sensitive areas to be included or excluded from this survey. With the addition of other areas, the results of the ranking system could have been much different, thus changing the overall outcome of a river being listed as more or less environmentally sensitive. In order to get a clear picture of a river, all areas would have to be surveyed and a ranking system developed, based on the entire findings of the survey. Another limitation was lack of access around the river segments. The field workers located as many environmentally sensitive points as possible. However, they were certain that there were more points that they were not able to gain access to, either because of lack of road access or because boundaries prohibited access. The field workers were also limited by the time that they could spend looking for the specific areas due to the fact that the survey had to be completed during the summer months. These are a few of the limitations that may have restricted the accuracy of this study.

Further Research

This study could be furthered several ways. As mentioned above, a study could be performed that took into account other environmentally sensitive areas, which may change the outcome of the ranking system. Further long-term studies could also be performed to see how the rivers change over time, thus shifting their vulnerability one way or another. As rural areas become more urban, the environmentally sensitive areas may move to be more economically sensitive and vise versa. In terms of the economic aspect of this study, if an economic price was placed on each of the environmentally sensitive areas, as well as a price to protect each specific area, this study could be furthered by allowing a pipeline company to know specifically how much it would cost to clean up and protect each specific area. Because of the limited published literature found on this topic, any research that could be performed would greatly enhance the knowledge of how petroleum products react with river environments, thus helping to protect nature and the human populations for generations to come.

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