THE RED RIVER BOUNDARY DISPUTE:

A NEW APPROACH TO AN

OLD PROBLEM

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To my thesis committee, for staying with me on this the entire time. For not letting me stray off course, and for guiding me throughout, I thank you all. And to my wife Christie, who deserves more thanks than anyone. I love you my dear.

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Introduction

The Red River, which serves as the boundary between Texas and Oklahoma, has historically been a source of dispute between the two states. Since the river was proposed as a boundary by the Adams-Onis Treaty in 1819, landowners on both sides have been confronted with the familiar problem of determining the boundary separating their properties as confirmed by the location of the middle, or banks of the river. The importance of this issue cannot be underestimated since the location of the boundary has economic consequences related to the water itself, the riverbed, and land adjacent to the watercourse.

Disputes concerning the river frequently result in litigation fixing the location of the boundary only until a subsequent change in the river's course occurs. Solutions to these disputes fall short because they are unclear, narrowly fashioned, and usually short lived. To date, there has been no method proposed that renders a permanent solution to this or other similar disputes.

Issues such as the Red River boundary dispute are national and local, and concern both public and private rights. It follows then that decision-making in the form of laws are fundamentally intertwined with and dependent upon geographic processes. It is the changing geography of the region that generates such disputes, therefore, without a thorough knowledge of laws and the geographic processes which govern them, landowners and all those with a vested interest in areas associated with river boundary issues face difficulties in making viable management decisions.

Purpose of the Study

With a comprehensive approach that reflects both geography and law, this study presents an alternative to past methods; techniques which relied heavily on imprecise procedures. Recent innovations such as the Global Positioning System (GPS), software programs capable of generating stream channel data, and geographic information system analysis and mapping procedures introduce a new set of tools for addressing boundary problems. The goal of this study is to evaluate GPS as a procedure that has the potential to locate and demarcate a river boundary at any specific point in time by incorporating GPS data within the framework of a model. Does this method promises to equip riparian landowners with the information needed to more effectively manage subsurface minerals, personal property, and natural resources?

This study also provides a review of case law which acts as a chronology to explain the Red River situation. In addition, it also serves as a timeline for the development of case law which has been forced to adapt to changing geographic forces of the Red River region.

To date, there is an absence of work pertaining to the application of GPS in resolving river boundary disputes. This study will serve as a starting point for incorporating GPS to accurately demarcate a river boundary. In addition, it will illustrate the problems of using rivers as boundaries. The following are goals of the study:

1) to illustrate and discuss relevant case law regarding stream-formed boundaries and changes in bed ownership.
2) to discuss the application of these laws at the state and federal level and their application to the Red River boundary situation.
3) to identify the shortcomings of traditional surveying methods in resolving stream-formed boundary disputes.

4) to evaluate GPS techniques along the Red River boundary to help develop a new approach to demarcate boundaries along waterbodies that are not geographically stable over time.
5) to discuss the incorporation of GPS data within the framework of *Discalc* or another suitable model to determine the banks of the Red River.
6) to compare this new technique with traditional survey methods of the past.

Justification for the Study

In order to make proper management decisions regarding property along the Red River boundary, knowledge of the geography and laws of the region are necessary. Without an understanding of how the stream-formed boundary impacts property, making sound decisions concerning a state's ability to tax, and the extent of a riparian landowner's property, are difficult to determine.

Personal property between adjacent landowners is often in dispute. Questions arise regarding shared property lines and the ownership of subsurface minerals. The meandering boundary which constantly works to change the extent of the valuable property along the river leaves distinct property lines in question. When the boundary moves, state and federal interests concerning subsurface minerals and the extent of property become involved. The answers to these geographical questions are derived from complex and ambiguous legal principles.

A firm understanding of the way these laws are interpreted is very important, not only to better understand how they affect interests within the Red River boundary, but also to apply new techniques that could make viable management decisions feasible.

A new technology that has yet to be applied to a river boundary dispute is the Global Positioning System. The advantages that GPS offers will be discussed and demonstrated with the hope of fostering a new approach to keeping track of the constantly moving boundary and to avoiding confusion and delays in the legal system. Advantages of the GPS approach as compared to past methods will also be identified and discussed. However, while offering numerous advantages in data collection, GPS is not a solution by itself to the problems along the Red River.

Once GPS data has been collected, its use within a river flow model such as *Discalc* or a similar program will be explored. With this information, one can determine where the banks of the river lie with variable levels of water in the river.

An Overview of the Red River Boundary Dispute

The Red River boundary dispute has a well-documented history. Perhaps no other controversy between states has become so complicated. This and other similar controversies such as the disputes existing along the Mississippi, Sabine, Ohio, and Chattahoochee Rivers address the familiar problem of determining the middle and banks of the river. Attempts at bringing stability to dynamic river boundaries are complex issues and often end in litigation. As a result, the location of the boundary is fixed only until subsequent changes in the river's course occur. Although stability in jurisdictional zones may help prevent future conflict and suggest unitary management, moving rivers will continue to alter the surrounding land. The ideal manner with which to deal with such problems is to reach an agreement such as a contract or compact negotiated between the feuding parties. However, in many cases courts are asked to decide because agreement is difficult to obtain. Even if an understanding is reached, fresh issues can be created without allaying the original difficulty.[1]

The study of boundaries, especially those on the international level, has long been a central theme of political geography.[2] In contrast, debates along state boundaries usually engender less interest because people on both sides live under substantially the same constitutional regime.[3] But issues gain gravity when the boundary has significant economic value attributed to the water itself, the river bed, or land adjacent to the watercourse. Subsequently, in state boundary cases, the central issue has been and continues to focus on the banks and/or middle of the river.[4]

The situation has been a sensitive one for quite some time. Even though the Red River boundary was presumably fixed in an 1819 treaty with Spain, a "final" decision was not reached until 1923. Even so, the location is not completely clear. Due to the nature of the original treaty, the laws governing river movements, and the geography of the region, the boundary is in a continuous state of flux. To understand the conflict that presently exists in the region, a look at the forces involved in the territory's inceptive organization is necessary. Refer to the following timeline for a list of important events (Table 1.)

Both Texas and Oklahoma leased portions of the river: Texas to the middle of the river, based upon a liberal interpretation of the original treaty, and Oklahoma to the entire bed, on the grounds the river was navigable. Subsequently, the militia of Texas organized to enforce a

Table I. An Overview of Important Red River Events.[5]

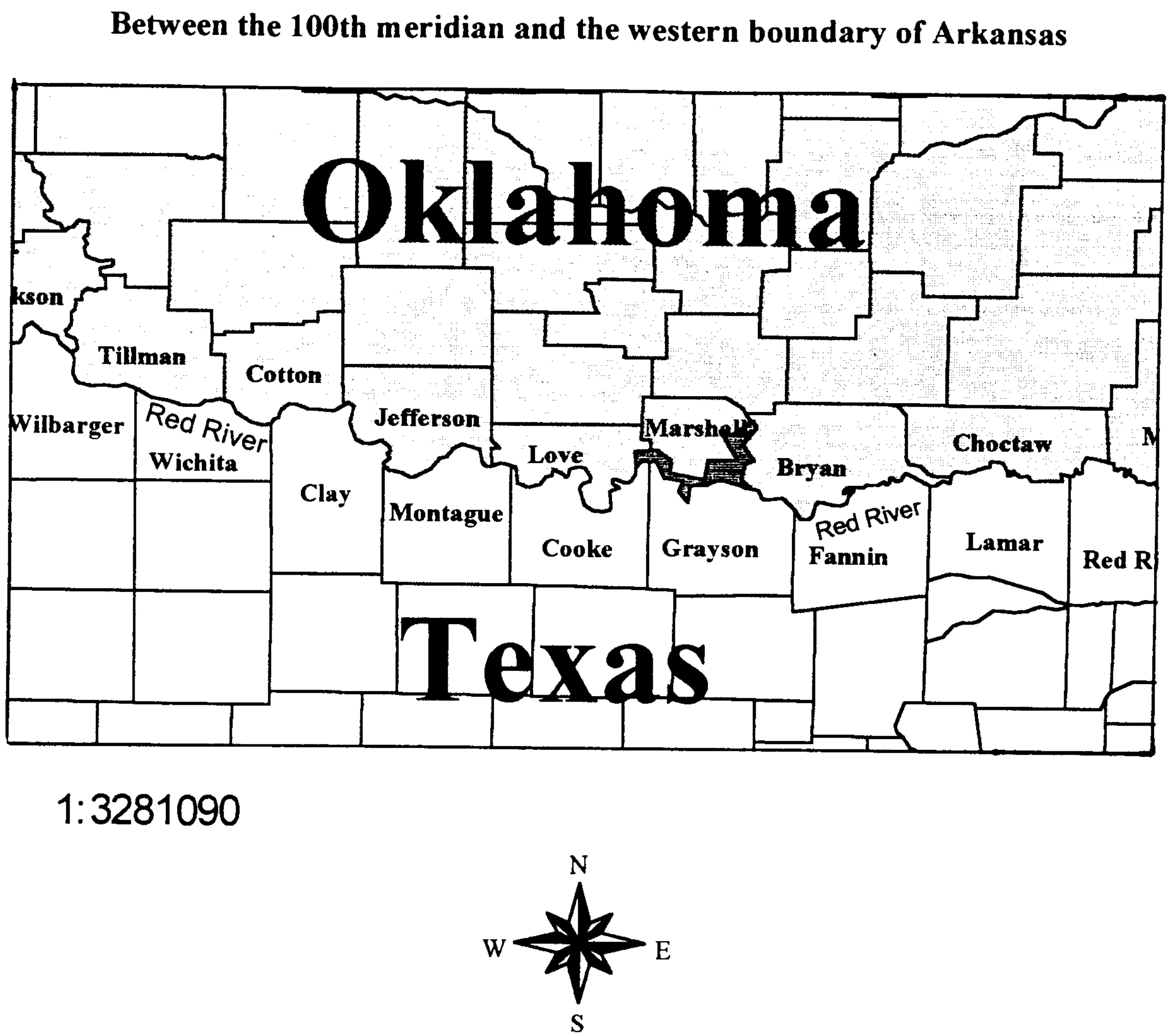
1800	*Treaty of San Ildefonso.* Ceded land commonly known as the Province of Louisiana from Spain to France.
1803	*Treaty between the United States and France (Louisiana Purchase.)* U.S. acquires title to the bed of the Red River and lands to the north.
1819	*Treaty of Amity (Adams-Onis Treaty.)* Set the western boundary of the U.S., and delineated the boundary between Spanish possessions and the U.S. at the southern bank of the Rio-Roxo (Red River.)
1828	*Treaty between the United States and Mexico.* Reaffirmed boundary set in 1819 treaty.
1838	*Convention between the United States and the Republic of Texas.* Acknowledged 1828 treaty as binding upon the Republic of Texas.
1845	*Texas admitted as a State.*
1867	*Treaty between the United States and the Kiowa, Comanche and Apache Tribes.* Territory north of the "middle of the main channel" of the Red River between the 98th meridian and North Fork set apart as a reservation.
1873-4	*Northern Bank of Red River Surveyed.* Boundary surveyed by General Land Office (GLO.)
1890	*Act of May 2nd Organized Oklahoma Territory.* The portion of the Red River between the 98th meridian and North Fork included in the Oklahoma Territory.
1896	*United States v. State of Texas.* Reaffirmed that the Texas boundary lies along the south bank of the Red River.
1907	*Oklahoma admitted as a State.*
1919	*Oil discovered in Red River.* Texas issues oil and gas permits for the south half of the river, while Oklahoma issues leases for the entire riverbed.

mandate of a Texas court, while the Oklahoma militia gathered to carry out the similar decree of an Oklahoma court. As a result, Oklahoma filed suit against Texas to again define the south bank as the boundary between the two states.[6]

Perhaps the most important factor the U.S. Supreme Court had to determine was whether or not the river was navigable. Normally, title to the bed of navigable rivers goes to states upon their admission to the Union. Oklahoma's contention, that it was navigable, was vital to justify their leasing the entire riverbed. After much testimony from both sides, the river was judged to be non-navigable, meaning that Oklahoma did not gain title to the riverbed. As a result, neither Texas nor Oklahoma possessed title to the bed.

When the federal government grants title to riparian lands, ownership by convention, in most cases, stops at the medial line between cutbanks of the river.[7] Therefore, ownership of the north half of the river was incidental to the riparian landowners on the north bank. Since the boundary between the two states was still the south bank, Texas could not claim ownership of the riverbed, however, citizens of Texas did have a right to reasonable access to

Figure 1. The Red River



the waters along the boundary, but this was a small consolation.[8] What was left is a piece of land between the medial line of the river and the south bank. Since no part of the river within Oklahoma's boundary was judged to be navigable, ownership of the bed did not pass to the state at the time it was admitted to the Union. Therefore, full title and ownership reverted back to the United States, thus introducing another player into what was an already complicated situation. Ultimately, ownership of all parts of the riverbed relied upon a common understanding of the location of the middle and banks of the river.

The 1923 Supreme Court case *Oklahoma v. Texas* aimed to define features of the river. The south bank was defined as:

> ...the water-washed and relatively permanent elevation or acclivity at the outer line of the riverbed which separates the bed from the adjacent upland, whether the valley or hill, and serves to confine the waters within the bed and to preserve the course of the river, and the boundary intended is on and along such banks at the average or mean level attained by the waters in periods when they reach and wash the bank without overflowing it.[9]

The bed of the river which contained the channel(s) of water also received a more precise definition:

> ...all the area kept practically bare of vegetation by the wash of the waters from year to year, though parts are left dry for months at a time, but not lateral valleys having the characteristics of relatively fast land, and usually covered by upland grasses and vegetation,

> though temporarily overflowed in exceptional instances, when the river is at flood.[10]

As a result, the boundary between Texas and federal land was again set along the south bank of the river following a rather peculiar feature known as the cut bank.

The cut bank is a highly transient, ephemeral, intermittent bank that ranges in height from two to ten feet.[11] Isaiah Bowman witnessed, "...the cut bank of the river is made almost everywhere of loose material, easily eroded, and constantly shifting from side to side..."[12] It is more pronounced as one moves east owing to a greater volume of water. In places where the river is exceptionally wide, the bank is sometimes barely visible. Since political boundaries should be as rigid as possible, subsequent Court decrees applied additional guidelines to further strengthen these definitions:

> At exceptional places where there is no well defined cut bank, but only a gradual incline from the sand bed of the river to the upland, the boundary is a line over such incline conforming to the mean level of the waters when at other places in that vicinity they reach and wash the cut bank without overflowing it.[13]

Since the point where the bed of the river ends and the adjacent benchland begins is at times questionable, disputes arise. However, these are not the only source of conflict on the river.

Another dilemma arises when considering the medial line between the opposing cut banks. Ownership and title to lands in the bed of the river depend upon the precise location of this line. The medial or middle line is imprecise unless defined to a greater extent then previous attempts.[14] In a supplement to the partial decree of the 1922 case *Oklahoma v. Texas*, the Supreme Court added:

> ...the medial line of the river is a line drawn midway between the northerly and southerly banks of the river, commonly called cut banks, save that, under a stipulation between the parties affected, to which full effect must be given, this line, in so far as it reaches and is in contract with patented or allotted tracts which are within what is now the bed of the river, shall be regarded and treated as falling no farther north than the southerly line of such tracts as the same were represented by the official survey according to which they were patented or allotted.[15]

Considering this as well as other definitions the Court used to add resilience to the jurisdictional lines involved, the cut banks and the medial line are still subject to continual movement. Such movements of the river were controversial considering the oil wells drilled in the bed. Location became important down to the last foot as shifts in the river could force oil claims to change hands as often as twice a day.[16] These shifts are natural in occurrence and affect the size and position of the river; subsequently, the boundary moves because the river does.

Figure 2 illustrates this problem chronologically. At point "1" the river is in a rather typical state of flood. Four hours later "2" represents its new position. During this brief epoch of time, the oil well has transferred from Texas to Oklahoma, since the river is unnavigable, the oil well is owned by the United States even though it is in Oklahoma territory.

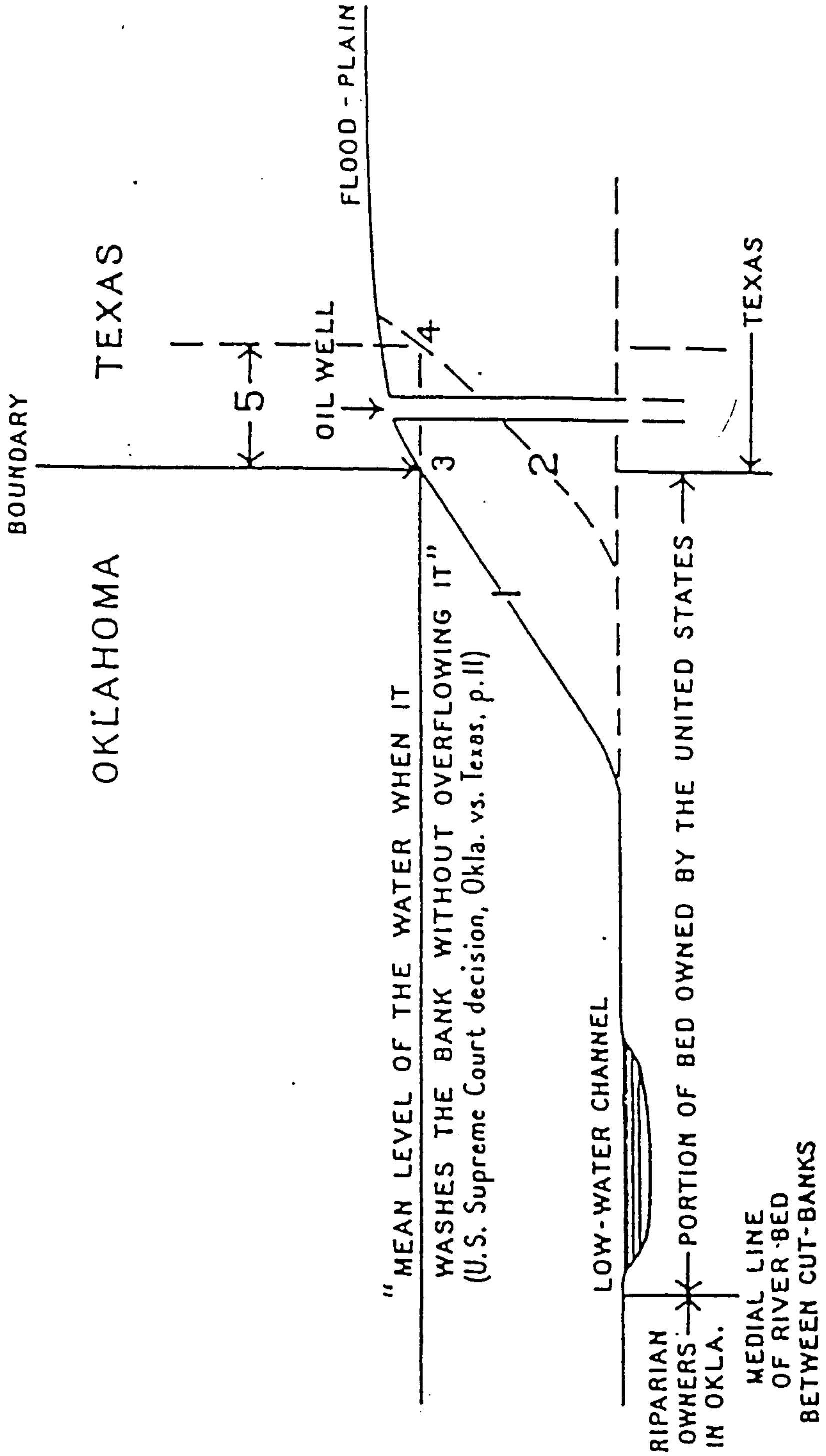
There are several terms that describe the processes by which rivers move from one side to the other. Pertinent here are two distinct processes, avulsion and erosion.

Avulsion is a change in a water boundary that is not gradual or imperceptible and may happen as a result of flooding, whereas erosion, represented by accretion and reliction, is gradual.[17] According to Stephen B. Jones in *Boundary Making*,

> Accretion may be defined as a lateral movement continuous in the space sense. It need not be continuous in the time sense. If the stream shifts bodily, taking a new course without removing piece by piece from its bank, it is said to shift by avulsion....Avulsion may be defined as a lateral movement discontinuous in the space sense. In the time sense, the actual avulsion is almost instantaneous.[18]

When a watercourse changes position by an avulsive action, the result works no change in the boundary.[19] This doctrine is used to maintain boundaries at their position before the sudden change in the river occurred. This minimizes the

Figure 2. How the Boundary Changes Owndership



Source: Bowman, Isaiah. "An American Boundary Dispute." *Geographical Review* 27 (1937): 445-57.

hardship that would result to landowners if the accretive doctrine was followed.[20] In contrast, when the gradual processes of erosion and accretion change the course of the river, the boundary changes with them.[21] Since these natural occurrences cause a continual migration in the banks of the river, the derived medial line will also shift, and possibly bring about a change in bed ownership. An in-depth look at these unique processes will be provided in a later chapter.

At stake in the delimitation of jurisdictional lines are public and private rights. Both Oklahoma and Texas coveted the valuable oil reserves located within the bed of the river. The huge quantities of oil are not only valuable because of the money that can be made by individuals and private drilling companies, but also because of the large taxes to be collected by each state. The lure of wealth has enticed others to stake claims over the years. The Comanche Indians claimed title to the north half of the bed by virtue of a treaty with the United States government in which the medial line was designated as the boundary line. Citizens of both states claimed the riverbed was open to placer mining because the area had become federal land after the opening of the Big Pasture Indian Reservation in 1906 (at the time, oil was developed as a placer claim on federal land). Private land owners have also claimed ownership.[22]

Since the placer mining claims were not reasonable from a legal standpoint, efforts were made to come to terms with the Kiowa, Comanche, and Apache tribes. The treaty of 1967 gave Indians title to lands north of the middle of the North Fork and longitude 98° west. On June 6, 1900, 160 acres were granted to each tribal member, 2,480,000 acres were reserved for cooperative uses, and four sections were allotted for schools and like purposes. The remaining land fell under public control. Because the reserve land was apportioned by the act of June 5, 1906, some of this land became Oklahoma school land, another portion was open to white settlement, and the remainder was distributed to the Indians. All riparian claims north of the river derived from such allocations.[23] Title to the remaining land was left to be decided between the two remaining claimants, the United States and the state of Oklahoma as mentioned earlier. More recently, conflicts have been on a smaller scale, between adjacent landowners.

Problems concerning ownership of the river bed continue. In contrast to conflicts that once occurred as bitter disputes over giant oil reserves, contemporary problems now exist between private land owners. Two recent cases illustrate: 1) the problem of defining and locating the south bank and medial line, and 2) the type of river movements affecting such delimitations.[24] Conflict generally arises between adjacent landowners who are located on opposite sides of the river. The source of contention usually emanates from an alleged movement of the river (i.e., avulsion, erosion, or accretion) that if upheld would establish a change in ownership of the bed or land nearby. Such a change could mean that property and subsequent mineral rights may be given to one landowner at the expense of another. Worse yet were problems created by decisions handed down by the courts. Each court determination resulted in an exact delimitation of the banks, bed, and medial line of the river that lasted only as long as subsequent changes in the river's course remained. Consequently, each new court delimitation can be different from the last.

Even though the 1923 case *Oklahoma v. Texas* is looked upon for guidance in dealing with these disputes, relying on methods employed in the past inevitably perpetuates the same dilemmas. This is true not only in the case of the Red River boundary dispute, but in other river boundary conflicts as well. While there will likely never be a solution that permanently delimits the boundaries of a river since rivers are so dynamic, possibilities do exist for locating the middle of the river, the boundary, or any jurisdictional line for a specific point in time.

Recent innovations including the Global Positioning System (GPS) allow for real-time location of geographical features. At the very least, such technology helps to locate jurisdictional lines more accurately and quickly than any method previously employed. But attempts should be made to go beyond merely locating political boundaries. If identifying such features does not offer a new perspective or put into motion some sort of unconventional thinking about the boundary issue, the result would be merely repeating the past efforts which have proved futile in resolving disputes. While GPS is outstanding for locating features on earth, it alone cannot identify the banks of the river because of a river's meandering nature.

The Red River moves and the amount of water in the river changes regularly. At times the river may be only a few meters wide while at other times it may be in excess of a mile wide. Because of this, the banks of the river change too. To accommodate this wide ranging personality, we need to consider the GPS data within a model; a model that can account for river's varying flows, widths, and volumes. *Discalc* may be one such tool to help arrive at a solution.

Even though the Red River meanders regularly which works a change in the river's banks, a permanent bank has been set as the result of litigation between disputing neighbors. Using that bank as a starting point, and by making use of *Discalc*, we can mechanically "fill" the river to this bank and quantify the volume of water used to do so. Once this is done, that same volume of water can be used to fill the transects collected by GPS. This means that the banks of the river, at each transect, can be identified.

According to Stephen B. Jones, "Any argument against dividing a river basin is, necessarily, an argument against employing rivers as boundaries."[25] Given the fact that we cannot circumvent the use of the Red River as a boundary, we can at least make attempts at better ways of defining its use as a boundary. Unitary management, where states supervise the river boundary jointly, is a possibility that may bring stability to this situation. This approach will help to allay future problems that may be caused by the continued movement of the river because the states will be dealing with the problem as a whole instead of its many separate parts. If this is accomplished, better management of pollution, navigation, irrigation, as well as boundaries may be a bit closer.

In view of the enormous impact the Red River has on the local environment, manipulation of such a boundary will likely have far-reaching consequences. The boundary itself not only determines who owns the surface, but also who owns the minerals beneath. A working knowledge of both geography and law is necessary to make sound decisions concerning the dynamics of the current situation. But the interface between the two fields becomes even more important when considering administrative alternatives, such as decisions regarding unitary management of land and resources.

Since every river is unique, it is difficult to compare one boundary conflict with another or to apply the decisions handed down in one case for the purpose of resolving another. However, the uniqueness of these boundary disputes does not prevent one from applying legal theory to future disputes. There are consistencies in law that need to be understood so the next step can be taken. Without understanding a single dispute there is no way to even begin to comprehend the problems of others. Eventually, attempts can be made to apply these concepts to other river boundary disputes to see if this approach may offer additional insight.

Geographic Literature Review

As noted earlier, it is important to have a thorough grasp of both geography and law when considering a dispute of this nature. Here, they are intertwined. However, geographers have paid little attention to the law when it comes to understanding resource and landscape movements.[26]

It follows too that a mere legal understanding of such matters is only half the story.

Lawyers have relied heavily on the material collected, described, and classified by geographers. One of geography's founding fathers, Friedrich Ratzel, authored some of the most famous theories on boundaries.[27] Many other geographers have also written about boundaries. Bringham,[28] Cohen,[29] Platt,[30] Harthsorne,[31] and de Blij[32] have all made substantial contributions in the discussion of boundaries as social, political, and physical barriers. Pertinent to the Red River discussion are two geographic subdisciplines, physical and political geography.

One of the best analyses of the Red River boundary dispute within a geographical context is Isaiah Bowman's, "An American Boundary Dispute."[33] Perhaps best known for his work in the application of geographical methods to formulate policy, he begins with a discussion entitled "Geography of the Disputed Zone." In it he reviews topics such as the spatial distribution of counties and populations within the immediate locale, rainfall and climate, and transportation. In addition, he provides a complete overview of the legal-geographic repercussions of U.S. Supreme Court decisions. The premise for an analysis of conflict is a firm understanding of the geography of the region; without such knowledge the reader is unprepared to follow the next phase of the discussion.

Bowman goes further to explain the nature of streams and the processes involved in this controversy, namely erosion, accretion, and avulsion. A thorough discussion of the physical characteristics of the Red River and Red River Valley are included, including detailed explanations of tributaries, vegetation, variance in river flow patterns, the question of a permanent bank, and the "detachment" of the people of Texas from the rest of the United States. In his conclusion, he asks what the Court might have decided had they recognized the essential and profound difference between the upper and lower sections of the river. Instead the Court treated the river as a single unit, with their decision based on rules of law instead of scientific evidence, which hardly seem applicable to so specialized a case.[34]

Perhaps the single most important work pertaining to a basic understanding of boundaries as a whole, and water boundaries in depth is *Boundary Making* by Stephen B. Jones.[35] This seminal work serves as a backbone of geographic information concerning water boundaries. The first portion of the text discusses different types of boundaries, their classification, function, and friction. Included are human and physical factors such as mineral and water resources that directly pertain to understanding the Red River boundary. In addition, discussions about native peoples and their resettlement after territorial transfer are included. The most important portion of the text however, is the discussion of river boundaries and their delimitation.

Jones writes about the pros and cons of rivers as boundaries. The disadvantages, more numerous than the advantages, are noted, especially with regard to politics. Also significant is his discussion of the type of boundary lines that can be employed: the middle or median line, the channel, the thalweg, bank, or an arbitrary line between turning points. Included is a discussion on why each may be utilized to suit specific geographic need. Finally, Jones covers the application of avulsion and accretion doctrine and the problems presented by islands. In short, this book is vital to understanding many complex river problems.

An excellent companion to Jones' text is his article entitled, "Boundary Concepts in the Setting of Place and Time."[36] In his article, boundaries are conceptualized according to their relation to geographical and historical milieu. He further presents an historical account of boundary concepts, and examines them with respect to time and place.

"Problems of Water-Boundary Definition," by S. Whittmore Boggs,[37] examines ambiguities that arise when defining political boundaries along watercourses. Specifically, Boggs offers three common definitions of a medial line: 1) a line being at all points equally distant from each shore; 2) a line following the general lines of the shores and dividing the surface water area as nearly as practicable into two equal parts; and 3) a line running along the mid-channel dividing the navigable portion of the lake or river, and being at all points equally distant from the shoal water (a sandbar or point where a body of water is shallow) on each shore. These concepts have been imprecise and nonspecific and, as an alternative, Boggs suggests his own delimitation: a median line as the line every point of which is equidistant from the nearest point on opposing shores of the river. Since this results in only one continuous line, it is more precise than other methods.

"Boundary Studies in Political Geography,"[38] by Julien Minghi, presents a political geographical approach to boundary controversies. Although river boundaries are not discussed in depth, Minghi offers a review of many different types of boundary studies, which is important because it presents a discussion of boundary problems from a political perspective. According to Minghi, such an analysis is beneficial in identifying problems common to all boundaries and may ultimately foster a new philosophy, a trend away from the earlier thought-restricting boundary concepts based on the artificial-vs.-natural dichotomy and towards more function-oriented studies.

Part of developing a new philosophy and as a means of assisting in the comprehension of the technical and statistical element of Minghi's research, Bruce Rhoads' "*Discalc*: A Computer Algorithm for Computing the Flow Characteristics of Flood Discharges in Stream Channel Cross Sections[39]" proves invaluable not only because it is the only information outlining the proper application of the software package, but it also evaluates river flow. *Discalc* is a computer program that calculates uniform-flow characteristics of flood discharges within stream channel cross-sections. *Discalc* is capable of manipulating data for various types of rivers, including those that shift frequently, such as the Red River. Along with being able to estimate hydraulic roughness characteristics in order to express quantitatively the degree retardation of flow, *Discalc* can yield desired flow estimations which can be used in boundary delimitation. Further, a discussion will follow about *Discalc*'s, or another program's viability in providing a solution.

Critically important in bridging the gap between geography and law are the contributions and connections made by Olen Paul Matthews. His monograph entitled *Water Resources, Geography & Law* illustrates water resource problems from a geographical perspective, particularly with respect to boundary changes. Considered also are jurisdictional conflicts involving rivers. The text not only fundamentally links geography and law, it demonstrates how laws interact with natural and cultural processes to provide a better understanding of resource use and landscape evolution.[40]

The Global Positioning System

The Global Positioning System (GPS) has experienced a monumental explosion in popularity of late. Among surveyors, cartographers, and facility managers, GPS offers increased speed and accuracy.

Trimble Navigation is one of the most familiar names in GPS technology. This is due to trend setting technology and valuable publications they have produced on the subject. One of the most important contributions to a basic understanding of the inner workings of GPS is a series of works beginning with *GPS - A Guide to the Next Utility.*[41] A stalwart in introducing GPS to students, it also covers subjects such as differential GPS, errors caused by factors such as atmospheric delays. Furthermore, it describes the basics of good field work. In short, no other text is as valuable for presenting a rudimentary, concise, and accurate account of GPS.

Little has been published concerning the use of GPS for the delimitation of moving river boundaries. Furthermore, what has been published has been of limited use. For instance, the Mississippi River, in reaction to devastating floods of recent years, has been the topic of GPS boundary studies. An article discussing GPS as an approach to helping prevent future disasters was very informative. However, this research involved equipment and resources unavailable to students because of cost alone.[42] This article does serve to aid in the planning portion of such a river project and becomes invaluable should a similar approach be made along any other river, like the Red River.

The remainder of the literature reviewed here is discussed in greater detail in later chapters of this study. The bulk of legal material is comprised of United States Supreme Court documents, individual State Supreme Court testimonies, and articles written by lawyers. Considering their approach and the rather heavy legal underpinnings of understanding this perspective, a discussion of the legal literature will be made in an appropriate chapter of this thesis where river boundary problems of different kinds will serve as necessary background to make sense of the sometimes unorthodox legal approach. To elaborate on them here would create a duplication of material.

Methodology

There are many ways to study river boundary movements and the legal repercussions of such movements. At this time, there has been no study which uses the Global Positioning System (GPS) for the purpose of demarcating river features to establish boundaries of ownership. Nor has there been any work published on establishing permanent river boundaries using GPS data within a model to render some longevity to the river boundary. This study, in addition to the purpose outlined earlier, will discuss the utilization of GPS within *Discalc* or a similar program.

Complementing legal and geographic methods for examining rivers are the data collection capabilities of GPS. In an effort to test a portion of the hypothetical approach being presented here, field work was conducted on a small portion of the river. It consisted of transects made across the river, as proposed by others.[43] The study area was located along six miles east and west of the Byers-Waurika bridge which passes over the Red River near Waurika, Oklahoma. The bridge not only provided easy access to the river, it also included all the players involved in the most recent disputes: a tributary, the Wichita River, and a portion of the Red River involved in the most recent litigation. The study area was contained within Jefferson County in Oklahoma and Clay County in Texas.

Data was acquired using a GPS unit. This rover receiver was capable of collecting latitude, longitude, and elevation for any spot on the globe by measuring the user's distance from a group of satellites. In this case, the GPS receiver served as a roving data collector, while another receiver known as the base station collected data at a known location (atop the Geography Building at Oklahoma State University). The rover receiver was used to collect data along transects of the river. These transects were walked at two places within the research area, and ran perpendicular to the predominant bank of the riverbed. They included the river, riverbed, the 100-year flood plain, and all areas prone to submergence due to the natural meandering of the river channel. The data collected were then differentially corrected to eliminate error. To illustrate how this process is completed, three transects were collected and analyzed.

Since the exact coordinates of the base station are known, removing the error from the rover is simple. By comparing the readings received by the roving unit to the base station, errors could be identified and eliminated.

Differential correction will result in latitude and longitude values within the transects that are within 2-5 meters of the rover receiver's true location on the globe horizontally, and 1.7 times this vertically. In high accuracy mode, horizontal accuracies of about one meter can be obtained.

After obtaining the data, it may be possible for the information to be entered into a program such as *Discalc* for further manipulation. Such programs are capable of providing cross-sections of the river at each transect and can be used to simulate the river. It can "fill" the river to different levels, and thereby display the moving boundary.

The appropriate boundary to consider first will be the "wheatfield" bank set and defined by the courts in *James v. Langford.*[44] *Discalc* can fill the transect to the level of this bank, and can use that same volume of water to fill the other transect. This will allow one to determine where the cutbank will be on either side of the river at each transect. As mentioned earlier, the cutbank has been defined as the point where the waters reach and wash that point without overflowing it[45]. Once the cut bank has been identified, the boundary and the medial line can be located.

This method not only allows one to manipulate the amount of water in each cross-section, but it also permits one to delimit the boundary and middle of the river for different volumes of water. The speed and accuracy that GPS affords is a clear advantage over past attempts similar to this in that it yields more accurate readings in near real-time, and programs like *Discalc* help to locate important boundaries.

The court cases pertinent to the Red River and the boundary dispute are vital in that they reflect the thinking of the courts. By analyzing these cases in the context of this research and the subsequent findings, a better understanding of how law may interpret such conclusions, or possibly be improved by them can be ascertained.

By using techniques such as GPS and computer software such as *Discalc*, we can deal more effectively with the problems the meandering Red River causes. We have seen that past attempts have fallen short because of their limited longevity. The river has been known to shift its position by over 2000 feet in a single flood occurrence. It is not unlikely for the river to move 100 feet year to year. By understanding the geographical and legal matters involved, a new application may be considered, one that elucidates the limitations of traditional surveying methods, but more importantly, offers insight to a more effective solution.

[1] Isaiah Bowman, "An American Boundary Dispute," *The*

Geographical Review 13 (1923): 161.

[2] Olen Paul Matthews, *Water Resources, Geography and Law* (State College: Commercial Printing Inc., 1984) 55.

[3] Bowman 162.

[4] Matthews 55.

[5]Waits, David. "The Red River Historical File." Part of this unpublished work was used as an aid for completing this timeline.

[6] Welbourn 94.

[7] *Archer v. Greenville Sand & Gravel Co.*, 233 U.S. 60 (1914); *Butttenuth v. St. Louis Bridge Co.*, 123 Ill. 535, 537, 17 N.E. 439, 445 (1888); *Strange v. Spaulding*, 17 Ky. L. Rptr. 305, 29 S.W. 137 (1895); *Krumweide v. Rose*, 177 Neb. 570, 129 N.W. 2d 491 (1964); *Mariner v. Shulte*, 13 Wis. 775 (1861).

[8] *Oklahoma v. Texas*, 261 U.S. 342 (1923).

[9] *Oklahoma v. Texas*, 260 U.S. 429 (1923).

[10] *Oklahoma v. Texas*, 260 U.S. 429 (1923).

[11] Welbourn 103.

[12] Bowman 169.

[13] *Oklahoma v. Texas*, 261 U.S. 342 (1923).

[14] Jones 114.

[15] *Oklahoma v. Texas*, 261 U.S. 346 (1923).

[16] Bowman 166, 185.

[17] Matthews 58.

[18] Matthew 58, Jones 120.

[19] *Arkansas v. Tennessee*, 246 U.S. 158, 173, 62 (1918) L. ed. 638, 647, L.R.A. 1918D, 258, 38 Sup. Ct. Rep. 301, *Nebraska v. Iowa*, 143 U.S. 965 (1965), *Jeffries v. East Omaha Land Co.*, 134 U.S. 178 (1890), *Bauman v. Choctaw-Chickasaw Nations*, 333 F.2d 785, 789 (10th Cir. 1964), cert denied, 379 U.S. 965 (1965), *Smith v. United States*, 593 F. 2d 982 (10th Cir. 1979), *Denny v. Cotton*, 22 S.W. 122 (Tex. Civ. App. 1893).

[20] John C. Cabaniss, "Federal Common Law and its Application to Disputes Involving Accretive and Avulsive Changes in the Bounds of Navigable Waters," Land and Water Law Review, vol. 17, no. 2, (1982): 336.

[21] *Nebraska v. Iowa*, 143 U.S. 159, 368 (1892), 36 L. ed. 186, 190, 12 Sup. Ct. Rep. 396, *New Orleans v. United States*, 35 U.S. (10 Pet.) 662 (1836), *State v. Bali*, 144 Tex. 195, 190 S.W. 2d. 71 (1945).

[22] Welbourn 99-100.

[23] Welbourn 104.

[24] *James v. Langford* (10th Ct. 1983), *Currington v. Henderson* (W. D. Ok. 1986).

[25] Jones 110.

[26] Matthews, foreword.

[27] Strassoldo 89.

[28] A.P. Bringham, "Principles in the Delimitation of Boundaries," *Geographical Review* 7 (1919): 201.

[29] S.B. Cohen, *Geography and Politics in a World Divided* (New York: Random House, 1963).

[30] Rutherford H. Platt, "*Land Use Control: Interface of Law and Geography*," resource paper no. 75-1, Washington, D.C. (1976): Association of American Geographers.

[31] Richard Hartshorne, "Geographic and Political Boundaries in Upper Silesia," *Annals of the Association of American Geographers* 23 (1933): 195. "Suggestions on the Terminology of Political Boundaries," *Annals of the Association of American Geographers* 26 (1936): 26-57. "The Tragedy of Austria-Hungary: A Post-mortem in Political Geography," *Annals of the Association of American Geographers* 28 (1938): 49-50. "A Functional Approach in Political Geography," *Annals of the Association of American Geographers* 40 (1950): 95-130.

[32] H. deBlij, *Systematic Political Geography* (New York: John Wiley and Sons, 1973)

[33] see note 1.

[34] Bowman 189.

[35] see note 10.

[36] Stephen B. Jones, "Boundary Concepts in the Setting of Place and Time," *Annals of the Association of American*

Geographers 49 (1959): 241-255.

[37] S. Whittmore Boggs, "Problems of Water-Boundary Definition," *Geographical Review* 27 (1937): 445-457.

[38] Julien V. Minghi, "Boundary Studies in Political Geography," *Annals of the Association of American Geographers* 53 (1963): 407-428.

[39] Bruce L. Rhoads, "Discalc: A Computer Algorithm for Computing the Flow Characteristics of Flood Discharges in Stream Channel Cross Sections," *Computers and Geosciences* 13 (1987): 495-?.

[40] Matthews 1-81.

[41] Jeff Hurn, *GPS - A Guide to the Next Utility* (Trimble Navigation, Sunnyvale, CA, 1989) 2-76.

[42] In this study of the Mississippi River, two Ashtech dual-frequency receivers, two stereoscopes, two L1/L2 dual frequency antennas, two airplanes, and the associated software. "Mapping the Mississippi: A Young Technology Takes on Ol' Man River," *GPS World*, Feb. 1996: 20-28.

[43] Dr. David Waits 1994, and Bruce Whitesell 1995.

[44] see note 29.

[45] see note 19.

Chapter II

Legal Implications of the Red River Boundary Dispute

For riparian landowners, titleholders to subsurface minerals, and the states of Oklahoma and Texas, the Red River controversy has been, and will continue to be, a management problem. The meandering river has been the source of contention for all those with a vested interest in the riverbed and land adjacent to the river. If the volume of litigation is any indication of the current state of affairs, many complex issues have yet to be resolved. These matters have distinct economic consequences tied to subsurface minerals and the values attached to private land rights. Perhaps most responsible for this relationship is the troublesome behavior of rivers.

The Allure of Rivers

Rivers have long been used as boundaries. They are conspicuous on large maps, and even small ones. The earliest maps used by explorers and traders had more details about rivers than other features, and these were used to explore the lesser known territories. But in these newly discovered places, settling trends applied, namely the attraction of living along a river frontage. This has held an attraction similar to that of a sea frontage settlement.

Access to the water has been extremely important to settlers throughout the development of the United States. The ability to navigate and fish have been pivotal to the growth and sustainability of settlements adjacent to water bodies. As early frontiersman formed villages and towns grew in size and became cities, the unifying effects of rivers increased as a method for travel and commerce. Ferrying, irrigation, and flood-plain farming became prevalent and increased the use (and abuse) of river resources. Today bridges, dams, large-scale irrigation, flood control, and navigational improvement are commonplace on all but the smallest of streams.[1]

As a result of the enormous interest inherent to possessing access or holding the right to use water, conflicts of all sorts have developed and will continue to persist in the future. Issues revolving around the ownership of property are particularly contentious in nature. The bitterness between landowners often results in lawsuits filed by one party against another. This is not surprising given the manner with which the legal system deals with continuing litigation[2]. In the case of the Red River, questions abound regarding the extent of property: 1) is land being removed by erosion or gained by accretion? And 2) where is the state boundary? Other obvious issues exist when considering the authority and jurisdiction of the territory in question. A firm understanding of the legal principles involved is necessary to answer questions concerning ownership.

The Federal Concept of Navigability

One of the underlying management problems along the Red River is the concept of navigability. Navigable rivers may be controlled by the federal government, which leads to conflicts between states and private landowners. Both federal and state governments have developed definitions for navigable rivers. During the mid-nineteenth century, navigable waters were identified using three criteria: the extent of admiralty jurisdiction, the right to surface use, and the title to beds.[3] However, there was a great deal of confusion as a result of the ambiguity concerning tests for navigability. At the federal and state levels, many navigability tests were developed that were similar, but not identical. As a result, a body of water could be navigable under the criterion of one test and not for another,[4] depending on the test that was used. It is generally accepted that four tests for navigability exist at the federal level: 1) the public trust doctrine, 2) the federal title test, 3) the commerce test, and 4) the federal test of locational admiralty jurisdiction.

In the case *Martin v. Wadell,*[5] the Supreme Court decided it was a federal matter to resolve submerged bed ownership. This was a landmark case for two reasons: 1) the birth of the "public trust doctrine," and 2) the complete lack of authority exercised in prompting such an opinion.[6] The "public trust doctrine" which applied to the thirteen original colonies, was extended to apply to all states admitted to the Union.[7] In essence, it meant that, while the beds of rivers are conveyed to the state upon admission to the Union, they are held subject to a public trust and cannot be transferred unless a purpose beneficial to the public is being served.[8]

Since *Martin v. Wadell,* established state ownership of the beds of rivers under navigable waters, the obvious problem became defining navigable waters. *The Daniel Ball* case was the first in a surprisingly small number of U.S. Supreme Court cases to define navigable waters for the purpose of determining who owned the riverbed.[9] This federal "title test" contained five components, all of which needed to be met. First, it is sufficient for a river to be "susceptible" to navigation, but actually not navigable. Second, the water body must be capable of navigation "for commerce." Third, the river must be capable of navigation in its "natural and ordinary condition."[10] Fourth, the commerce may be by any "customary mode" of travel.[11] The fifth and last element is the most troublesome: navigability for title purposes relies on the condition of the river at the time the state to which it belongs enters the Union.[12] This last component fosters controversy because such records may not exist.[13] It is immaterial that the river may have once been used for commerce.[14]

Along the Red River, geographers played a key role in helping to understand the prevailing condition of the river at the time of statehood.[15] But attempts at tracing the changing course of the river to 1821 (Adams-Onis Treaty ratification), or 100 years prior to the time the Court was to decide (the time when the Red River was first used as a boundary), did not lead to a very convincing, nor concrete solution.[16]

A federal test more comprehensive than the title test is the commerce clause test. This test is not usually dependent upon the navigability or nonnavigability of waters, and therefore hinges only upon its "effect" on interstate commerce.[17] Under this test, it is also possible for a body of water to be navigable if it can be made navigable-in-fact with "reasonable improvements," whether or not those improvements are carried out.

The commerce test is similar to the federal test for locational admiralty jurisdiction. Originally a tidewater concept, the Court has since moved towards a navigable-in-fact concept ever since the 1851 case of *The Propeller Genesee Chief v. Fitzhugh.*[18] A significant provision of this test that is different from the commerce clause test is that, under the commerce test, a water body is navigable if it has ever been navigable in its lifetime, or can be made navigable by some practical means.[19]

Even though early federal court decisions did not clearly outline the role of the legal system when dealing with title to beds of navigable waters, nine Supreme Court cases can be looked upon for guidance when dealing with such questions.[20] Understandably, these cases have solidified the Court's stance, although difficulties still remain when applying these concepts to a specific watercourse such as the Red River. To add to the uncertainty, states too had tests for navigability.

The State Concept of Navigability

At the state level, tests for navigability have been concerned with usufructuary rights (or, rights of use) at the surface and ownership of the underlying bed. But questions abound regarding the role these tests play with regard to the various federal tests. Since states had begun to develop tests for navigability before the Supreme Court had honed its own definition of navigability, numerous doctrines were already being applied to water bodies in the United States. As a result, in the absence of a firm set of rules to follow besides their own, states assumed that their tests were the ultimate arbiter in determining navigability.[21] However, between 1922 and 1931, three U.S. Supreme Court cases declared the federal title test to be controlling.

Brewer-Elliot Oil & Gas Co. v. United States, *United States v. Holt State Bank*, and *United States v. Utah* changed the way states dealt with navigability determinations.[22] These cases held that it is a federal question whether title to submerged beds may pass a the state upon its admission to the Union.[23] As a result, the federal title test must be looked upon to determine if the state owns title to the bed by way of its admission to the Union. Yet confusion remains.

In addition to the rather confusing dilemma of separating uses of the bed from usufructuary interests of the surface, navigability "...still suffers from the inescapable ambiguity of practical application."[24] Even though the federal title tests prevails, the state test for navigability still plays a role in some cases involving title to submerged beds. This role has been the source of further confusion.[25] Consequently, calling a water body navigable may mean all sorts of things, depending on the applicable test on which the definition relies. In addition to multifaceted and ambiguous legal definitions, what makes the Red River situation even more controversial is its timing. During this period in history, laws describing the use of water and its navigability were understood by few at best, and were open to varying interpretation.

To those parties with a vested interest in the submerged bed of the river, a clear definition of navigability was essential to manage the regions of property dependent upon such a determination. After reaffirming the boundary between the two states as the south bank, it became necessary to determine ownership of the remaining land between Oklahoma and the United States. Oklahoma claimed title to the riverbed on the basis of the act which admitted the state to the Union, and on the assumption that the river was navigable.

Attorneys for Oklahoma presented evidence to prove the Red River was indeed navigable. In much the same manner, lawyers representing the United States demonstrated information to the contrary. On May 1, 1922, the Court ruled that no part of the river within Oklahoma was navigable and, therefore, ownership of the bed did not pass to the state of Oklahoma at the time it was admitted to the Union.[26] This vitally important decision was handed down at a time when the development of navigability theory was still nebulous.

Since only a handful of cases have been decided by the U.S. Supreme Court regarding navigability for title purposes, many questions have been left unanswered. Part of the problem is the lack of a clearly drawn definition of navigability. The other uncertainty is applying this vague formula to the plethora of unique geographical features that the Red River presents.[27]

The Geography of the Red River

The source of the Red River is in the Llano Estacado, or Staked Plains, of the Texas panhandle. From this very flat, relatively high elevation, the river runs generally eastward between Oklahoma and Texas, into the southwestern corner of Arkansas and finally into Louisiana. Since the river rises in one climatic region and flows into another, it presents a myriad of geographic variability.

In its upper portion, the river has an ever-changing character. The banks are a mere formality with which the river toys daily. From day-to-day the river changes its form and position; sometimes braided and sinewy, and at other times forming a single channel. During times of low water the river resembles a meadow brook, while at other times its volume is as great as that of the Colorado. The land on either side offers little resistance to the constant remodeling and building effects of the water. The river possesses these same qualities in the study area.[28]

Everywhere the river is comprised of loose, sandy material. The Red is braided and constantly moves huge amounts of alluvium giving it a red hue. At many places the current is weak and almost stagnant, while at other locations it is very brisk making it almost impossible to cross without assistance. The bed of the river in its current state is covered with sand and in the warmer months some grass is present. In most instances it is nearly a half mile in width.

While water is the prime mover of material in the bed, the wind plays a very significant role. At times the wind blows in excess of 40 miles per hour and forms great clouds of dust hundreds of feet high. Great quantities of sand sweep along the surface to change the shape of the dunes in the Red River Valley. As a result the various channels meander regularly here, between the bank on the Oklahoma side and the steady incline on the other.

Perhaps the best way to understand the nature of the floodplain area is by describing it along the course of a cross-section. In this case, a transect was walked from the Oklahoma bluffs which rise approximately 70 feet above the river valley. The bluffs are steep and in places difficult to descend. Upon reaching the bottom, the land everywhere is engraved by the remnants of past river channels. This portion is known as benchland and is covered with trees and shrubs. Here the ground is mostly muddy and resembles a quagmire with pecan trees scattered throughout. Closer to the river the damp soil gives way to sand. The cut-bank on the Oklahoma side is an acclivity of approximately 6-10 feet. In this case the main channel of the river was immediately adjacent to it. The meander abutting the cutbank was the deepest channel along the transect at four feet. Upon crossing the channel and three other more shallow braids, the bed continued for about a quarter of a mile to the cutbank on the Texas side. From the bank to the Bureau of Land Management land markers, the land is covered with dense, virtually impenetrable patches of chaparral and woodlands. This area too showed signs of past river channels.

During flood stage the river has an enormous volume, but this is tied to its width rather than its depth. At these times, the river is very wide while and only a few feet deep. At peak flow, the river may extend from the Oklahoma bluffs beyond the BLM land and onto the agriculture land of Texas landowners. In extreme cases, the river may be as many as two miles wide. When the river recedes to this "normal" capacity, it is never in the same location as it was previous to a flood. With each new river location comes a host of new problems.

Fitting a uniform definition of navigability to the Red River is a major concern. Subsequent management problems encountered by the states of Texas and Oklahoma and their private titleholders underscores the importance of addressing the problem. The result is a boundary which is difficult to maintain, nearly impossible to locate in the real world, and one that moves constantly.

Settling on a Boundary

As mentioned in the previous chapter, ownership of the bed of the Red River was decided by the U.S. Supreme Court. The peculiar result is as follows: Texas possessed no claim to any part of riverbed nor jurisdiction over it;[29] Oklahoma did not, by virtue of its admission to the Union, acquire title to the bed, except as incidental to ownership of lands on the northerly bank of the river.[30] However, Oklahoma did have jurisdiction over the river to the south bank. And because neither state had any claim to the portion of the river bed between the medial line and the boundary between the two states, title and ownership fell into federal hands.[31]

The next course of action was boundary demarcation and delimitation. The meanings adopted for each were those assigned by McMahon,[32] and fervently accepted by Jones.[33] Demarcation, for the purpose of this study, refers to the physical marking of the boundary on the surface of the earth; and delimitation means the choice of a boundary site and its definition in any formal document. Serious errors frequently are made in boundary delimitation and demarcation. Mistakes such as unfamiliarity with the border region, unfamiliarity with the peculiar geographical features adopted as boundary sites, and a proliferation of the problems inherent to boundary definition may all contribute to future discord.[34] Rivers present additional problems.

It is generally unwise to employ compass directions in connection with rivers. Although the use of direction is unavoidable in some circumstances, rivers rarely run straight. Also, almost every topographic and hydrographic term is subject to various interpretations; the most common terms are often the most vague in meaning. For example, in the Adams-Onis treaty, the use of words such as "mouth" and "bank" and "islands" have greatly affected the delimitation of the boundary. As a result, boundaries along rivers require consistent maintenance and administration.[35]

The U.S. Supreme Court assigned the boundary between the two states along the south bank of the river, commonly called the cut bank. However, delimitation of bed ownership was also required to determine where the rights of Oklahoma riparian landowners were to end and where property titled to the United States was to begin. This meant that banks on either side of the river would have to be formally defined, and the medial line would also require an accurate explanation. Difficulties are intrinsic in defining such features on paper, but they pale in comparison to those created for titleholders to the riverbed and land adjacent to the river, especially when considering the movement of the boundary, which may change as often as the river does.

Meandering River, Meandering Boundary

The proprietary interests of the riverbed owner and the adjacent upland owner as well as those requiring federal consideration are at stake in the Red River. The movement of the boundary, as well as the lines of ownership that rely on its exact location are usually the center of disagreements among adjacent titleholders. The resulting friction is usually caused by the existence of overlapping territorial claims, claims that are vital to properly manage the boundary, regulate private and public lands effectively, and delegate authority to adequately govern each. Since a permanent location of the boundary line and other jurisdictional lines is not usually acceptable, legal terms have been adopted to describe the processes that occur. These are related to the rate of change by which a boundary moves and the method by which the change takes place.[36]

Accretion and Avulsion Theories

Since accretion and avulsion concepts will be discussed in detail, it may be helpful to give some basic descriptions to terms describing boundary movements. Accretion may be defined as the gradual and imperceptible process where soil is deposited to become dry, fast land. Very similar in nature but not in action is reliction, which occurs when water recedes, exposing new land. If soil is removed by the gradual encroachment of water, the process is known as erosion. When the water location changes suddenly or drastically as in a flood, the inundating process is known as avulsion and the baring of land is known as dereliction. Dereliction, a term that has fallen out of favor of late, is commonly replaced with reliction to describe such processes, whereas avulsion implies swift, instantaneous action.[37] For the purpose of simplifying the discussion hereafter, "accretion" will include the meanings of erosion and dereliction since they are a part of the accretion process. Furthermore, "avulsion" will include the inundating and baring of soil previously identified and defined. These terms are certainly not universally understood in the same way.

Compounding the already confusing methods for which to locate a boundary, are the rather subjective meanings attached to the accretive and avulsive definitions. The courts have only intensified the problem since their interpretations have been inconsistent. Various court cases have defined "imperceptible" differently: 450 acres "in a short time,"[38] two miles in 50 years,[39] 300 feet in three years,[40] and 140 feet in 22 years.[41] Defining these terms consistently is vital since in many cases, they determine when a boundary moves with a stream and when it does not. Subsequently, interpretations of accretion and avulsion may shift a landowner's rights to agricultural land. Taxes on property as well as ownership of subsurface minerals may also change with disparate interpretations.[42]

River Bed Ownership

The federal interest inherent in this river situation (because federal property is at stake) provides the necessity of using federal common law as the basis for the discussion. Typically, there are two alternatives to federal courts once a federal interest has been established: the adoption of federal common law, or the adoption of state law as the guiding federal rule of decision. Simply, federal common law is the portion of law developed by the federal courts that, except for cases governed by Constitution, United States treaty, or acts of Congress.[43] Because there is a distinct federal interest in the bed of the Red, federal common law reigns.[44]

The varied history of land titles among states has resulted in a diversity of legal rules for determining the ownership of lands under bodies of water such as rivers. However, bed ownership in most states depends on whether or not the stream is determined to be navigable.[45] In this case the bed was judged nonnavigable, and the private riparian landowners in Oklahoma own title to the middle of the bed.[46]

Federal and state law deals with accretive and avulsive changes along a boundary the same way. When a change is the result of accretion, the riparian landowner gains title to the land added.[47] By the same token, when erosion occurs, the riparian owner loses title to the land removed.[48] This is premised on the rationale that an upland owner should have access to the water whenever possible without creating a hardship on adjacent property owners. In contrast, when an avulsive action takes place, the boundary maintains its original location even if the river has changed its position completely, severing the owner's access to water.[49] This is necessary to diminish the hardship that would result to the adjacent landowner if the doctrine of accretion was followed.[50] It may go without saying that it is quite difficult to apply these concepts to the real world.

Many reasons exist for the utilization of these principles. Most important among these is the ability to economically manage property effectively. Decisions regarding ownership, jurisdiction, and authority can be made because all property is accounted for whether land is being lost or gained.[51] Obviously this is not a fool-proof set of concepts, but if not for the continued use of these doctrines, riparian ownership would be difficult at best even though the boundary was originally set by treaty many years ago.

By virtue of the Adams-Onis treaty, the boundary was to follow the south bank of the river. However, because of federal interests, as well as those of the Texas and Oklahoma riparians, the delimitation of the medial line became vitally important. Two recent cases further define the types of problems that exist between landowners.

James v. Langford

This suit, which appeared in the U.S. Court of Appeals, pertained to a dispute over ownership of portions of the Red River.[52] The James', the plaintiffs in this case, were surface owners of land mostly on the Oklahoma side of the boundary. They claimed ownership of the bed to the south (west) bank. The Langfords were landowners on the Texas side of the river and claimed ownership of a portion of the river bed under application of the accretion doctrine and adverse possession. The State of Oklahoma claimed ownership of a portion of the bed from the medial line to the south (west) bank and certain mineral interests, and the United States also claimed the stream bed from the medial line to the south (west) bank. Various intervening parties owned mineral interests. The crux of the suit fell upon the resolution of two issues: the location of the south (west) bank of the river, and the nature of the changes in the location of the river since 1923.

In this case no fewer than four parties claimed ownership of the south half of the river bed, from the medial line to the southern (western) bank. The view of the court was that this matter be controlled by the application of the rules from *Oklahoma v. Texas*.[53] In that case the court described the standards to be applied in determining the location of the south bank of the river at any particular location. Important for this appeal are the following:

> 1. The south bank of the river is the water-washed and relatively permanent elevation or acclivity, commonly called a cut bank, along the southerly side of the river which separates its bed from the adjacent upland, whether valley or hill, and usually serves to confine the waters within the bed and to preserve the course of the river.[54]
>
> 2. The boundary between the two States is on and along that bank at the mean level attained by the water of the river when they reach and wash the bank without overflowing it.[55]

> 3. At exceptional places, where there is no well defined cut bank but only a gradual incline from the sand bed of the river to the upland, the boundary is a line over such incline conforming to the mean level of the waters when at other places in that vicinity they reach and wash the cut bank without overflowing it.[56]

The trial court applied these standards and identified the south bank as the "wheat field bank." It is a cut bank three to four feet in height and meets the requirements described in the 1923 case *Oklahoma v. Texas*.

The main channel of the river had run along this edge for a long time. Past records show extremely wide fluctuations in the flow of the stream, with very large volumes at flood stage. During these periods of high water, but not flood stage, the land in question is submerged and the bed is between one and two miles in width with variations in vegetation.

The second issue concerning the changes in the river since 1923 require the appropriate application of the doctrines of accretion and avulsion. The Supreme Court in *Oklahoma v. Texas* applied the doctrine as follows:

> Where intervening changes in that bank have occurred through the natural and gradual processes known as erosion and accretion the boundary has followed the change; but where the stream has left its former channel and made for itself a new one through adjacent upland by the process known as avulsion the boundary has not followed the change, but has remained on and along what was the south bank before the change occurred.[57]

The Court added that these changes would apply to "such changes as may occur in the future." The Court agreed that the trial court had correctly applied these doctrines and concluded that the changes since 1923 were the result of a number of very large floods.

The flood of 1908 caused a significant change as a new channel was created east of the original channel. The flood of 1935 moved the channel further east. Efforts to protect a bridge built in 1940 caused a change in the flow of the river. The railroad bridge was washed out by floods in 1941 and 1957.

The trial court determined that the portion of the stream bed in question "was not added to the land of the Langford's on the south (west) bank of the river by accretion or reliction as they contend." Therefore the Langford's claim to a portion of the bed based on a "bank" nearer to the center of the stream bed is not supported. Instead, the movement of the channel was the result of the avulsive movements of the various floods since 1923. Therefore no change in boundary location occurred.

Currington v. Henderson

This case is a declaratory judgment action to quiet title (to pacify) to property lying in the bed of the Red River between Jefferson County, Oklahoma, and Clay County, Texas.[58] This action was a binding declaration of rights and status of the litigants.[59] Currington, the plaintiff, owned land bordering the river in Jefferson County, and the defendant, Henderson, owns land bordering the river in Texas.

The issue in this case was the precise location of the south (Texas) bank which constitutes the boundary between riparian lands on the Texas side and lands owned by the United States; and the location of the medial line of the river bed, between lands owned by the United States and Oklahoma riparians. However, the banks on both sides of the river as well as the medial line would have to be delimited.

In this case the boundary exists primarily as it did in the previous case. The United States owns the portion between the medial line and the south bank, Oklahoma riparians own the portion of the bed from the medial line northward, and Texas riparians from the south bank southward. At the point of dispute on the river the bed exceeds one mile in width. The river is braided and the channel touches both banks. To identify the appropriate boundaries, the court ruled that the prior decision in *James v. Currington* is controlling. This is because the lands involved in this case directly adjoin the lands involved here. The banks, including the "wheatfield bank" are continuous features, readily identifiable along the river throughout the entire course of the land in dispute.

The cut bank on the Oklahoma side is a prominent bluff which is easily identifiable and extends over the length of the disputed area except where Whiskey Creek enters. On the Texas border, the prominent bank is the "wheatfield bank." Each of these banks is relatively permanent and meets the definition of the term "bank" outlined in *Oklahoma v. Texas*.[60]

It is important to note that the Oklahoma Supreme Court does not have the jurisdiction to delimit the state line. However, it does have jurisdiction to determine boundary lines for the purpose of resolving this dispute between landowners. The boundaries are determined in the following way: The United States Geological Survey issues a map upon which the boundary lines have been denoted. The river banks have also been plotted as reasonably as possible with a marker or thick pen. These boundary lines are intended to serve as the basis for any professional survey that may be needed in the future.

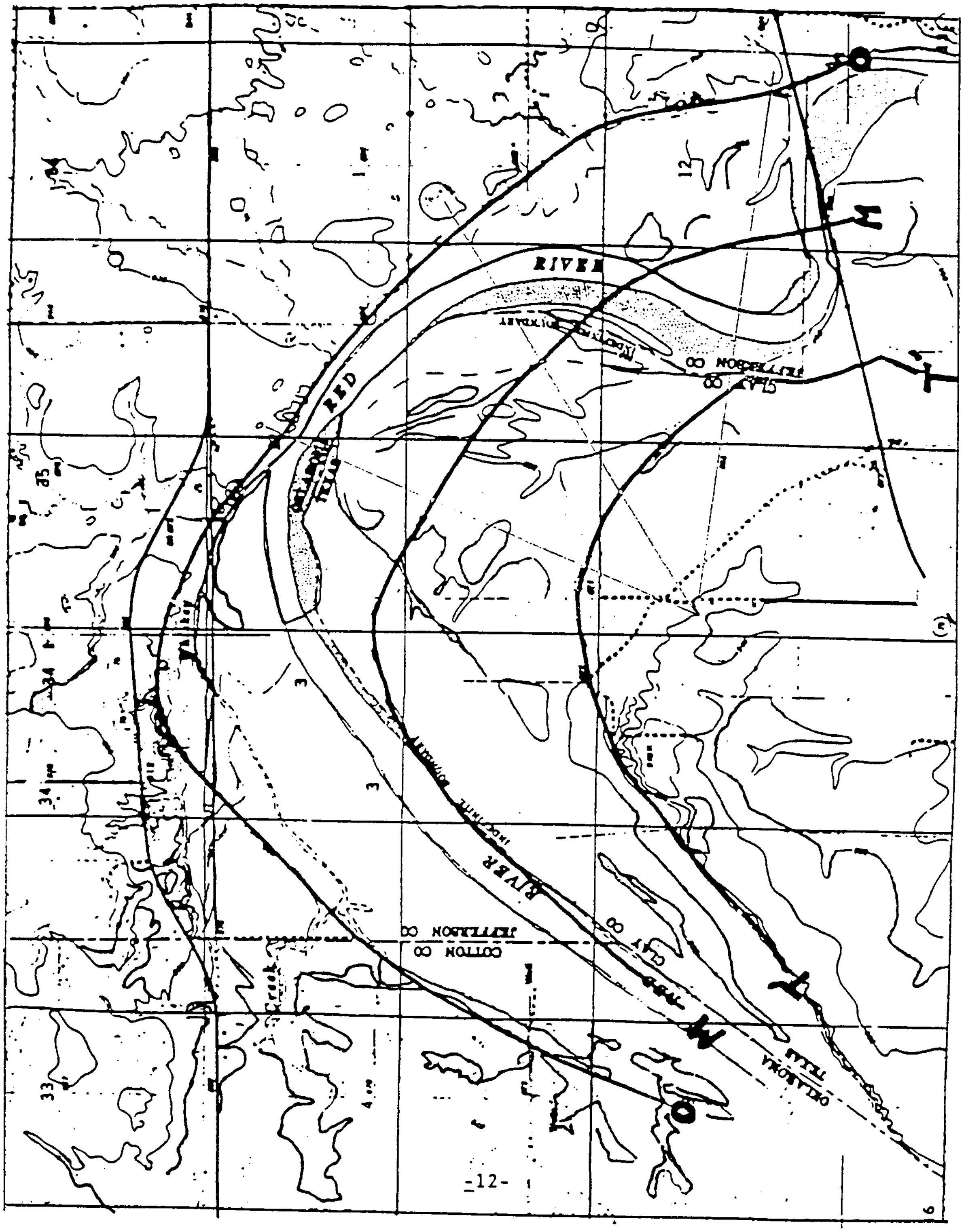
One of the problems in boundary delimitation is evident in figure 3. The line identified as T-T′ serves as the boundary between lands owned by the United States and the defendents, the Langfords. O-O′ does not mark a boundary but the Oklahoma cut bank which in turn helps to delimit the median line. The medial line is M-M′. Even with this method of delimitation and demarcation, the court could do no better than to draw thick lines on a map. These lines are so poorly drawn that they occupy some 20 to 30 meters of land.

Other Management Problems

In the course of completing the field work, numerous landowners had their own complaints and issues pertaining to the boundary. In many of these cases, landowners simply did not know where their land begins or ends because of the ambiguity of the property lines. One example is indicative of the dilemmas that exist in the area.

An Oklahoma riparian landowner has for generations owned land on the Oklahoma side of the river. Title to his property by law extended to the middle of the river. But in early 1974 there was a huge flood which resulted in the relocation of the river. Since a flood is an avulsive

Figure 3. The Court Drawn Boundaries from *Currington v. Henderson*



Source: *Currington v. Henderson*, W.D. Okla. 1-10 (1986).

movement, the boundary did not change. This presented an acute inconvenience. During the time preceding the flood, the landowner was operating a mining business on his property, extracting gravel and sand. As a result of the flood, his business was bisected by the water in the river, meaning that his operations were on his property on the Texas side of the river. Besides the obvious problem of a river running through his business, over time the boundary between his land and the federal land on the other side became more ambiguous. To this day, he does not know the extent of his property. Consequently, considerable discord exists between the landowner and the Bureau of Land Management.

A New Approach

One of the inherent problems in efforts made to determine the middle and banks of the river, or any of the boundaries or property lines in this dispute, is that such conclusions are useful for only a brief moment in time. The river moves so often and so randomly that court decisions meant to last for an extended period of time fall hopelessly short. While there may never be a method that provides a permanent solution, the Global Positioning System along with mathematical models such as *Discalc* offer new approaches.

By surveying transects along the river and deriving cross-sectional data, it is possible to "fill" the river to a court defined cut bank to determine where the cut bank, boundary, and all property lines are located.

By now many are familiar with the Global Positioning System (GPS) as a quick and easy way of determining where things are. The advantage GPS presents here is in its ability to both calculate exact coordinates for any position, and to quickly identify subtle boundary changes in the river and valley area, fluctuations that were impossible to detect quickly until GPS became a viable option.

Important in its own right is the ability to collect data much more quickly. In the past, efforts to manually survey the river consumed great quantities of time. In many cases the river was found to change its position many times before surveying could be completed. With GPS, the river can be surveyed with greater speed, owing to the fact that it can be performed day or night, rain or shine, with no line-of-sight required between base and rover receivers. Depending on the manpower and the particular GPS unit employed, surveying may be conducted in near real-time, meaning that accurate measurements can be made immediately in the field. Once this transect data is captured, the computer program *Discalc* can be used to simulatively "fill" the river which results in banks on both sides of the river.

The bank to which the river will be filled by Discalc will be that defined by the courts in *James v. Langford* as the "wheatfield bank." Once filled, the distinct volume of water at that point can be realized. By using that same volume of water to "fill" the other transects, the transient cutbank can be defined as the point where the waters reach and wash that edge without overflowing it. This method not only allows one to account for varying volumes of water, but allows the middle and banks of the river for each volume to be located. This method has a clear advantage over previous attempts that could not be completed as quickly or precisely.

It is important to reiterate that this approach can only locate the middle and banks of the river for a given point in time. After all, the river will continue to meander and change its course.

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[1]Stephen B. Jones, *Boundary Making* (Washington, D.C.: Carnegie Endowment for International Peace, 1945) 108-9.

[2]The litigation along the Red River continues to be "solved" by the application of methods derived by the Supreme Court

in 1922 (*Oklahoma v. Texas*, 256 U.S. 70, 258 U.S. 574) and 1923 (*Oklahoma v. Texas*, 260 U.S. 606). Recent cases such as *James v. Langford*, _F.2d_ 10th Ct. 1983, and *Currington v. Henderson*, _F.2d_ W.D. Ok. 1986, are examples.

[3]Glenn J. MacGrady, "The Navigability Concept in the Civil and Common Law: Historical Development, Current Importance, and Some Doctrines That Don't Hold Water," Florida State University Law Review, vol. 3:511, (1975): 587.

[4]In cases dealing with navigability the Supreme Court indiscriminately cites cases from the areas of admiralty, commerce clause regulation, and submerged bed ownership. Examination reveals that the Court relies on a relatively small number of cases for the definition of navigability: *United States v. Appalachian Elec. Power Co.*, 311 U.S. 377 (1940); *United States v. Oregon*, 295 U.S. 1 (1935); *United States v. Utah*, 283 U.S. 64 (1934); *United States v. Holt State Bank*, 270 U.S. 49 (1926); *Brewer-Elliot Oil & Gas Co.* v. United States, 260 U.S. 77 (1922); *Oklahoma v. Texas*, 258 U.S. 574 (1922); *Economy Light & Power Co. v. United States*, 256 U.S. 113 (1921); *United States v. Cress*, 243 U.S. 316 (1917); *Leovy v. United States*, 177 U.S. 621 (1900); *United States v. Rio Grande Dam & Irrig. Co.*, 174 U.S. 690 (1899); *St. Anthony Falls Water Power Co. v. St. Paul Water Comm'rs*,

168 U.S. 349 (1897); *Packer v. Bird* 137 U.S. 661 (1891); *The Montello,* 87 U.S. (20 Wall.) 430 (1874); *The Daniel Ball* 77 U.S. (10 Wall.) 557 (1870).

[5] 41 U.S. 234, 16 Pet. 367 (1842).

[6] Justice Roger Taney does make a brief reference to *Arnold v. Mundy,* 6 N.J.L. 1 (S. Ct. 1821) an earlier case that was cited in arguments to the *Martin* Court.

[7] *Pollard v. Hagan,* (44 U.S. (3 How.)212 (1845).

[8] David H. Getches, *Water Law* (St. Paul: West Publishing Company, 1990) 224.

[9] 77 U.S. (10 Wall.) 557 (1870).

[10] *United States v. Holt State Bank,* 270 U.S. 49, 56 (1926).

[11] *United States v. Holt State Bank,* 270 U.S. 49, 56 (1926).

[12] *Utah v. United States,* 403 U.S. 9 (1971).

[13] MacGrady 589-593.

[14] Johnson and Austin 16.

[15] Isaiah Bowman, "An American Boundary Dispute-Decisions of the Supreme Court of the United States with Respect to the Texas-Oklahoma Boundary," *Geographical Review* 63: 225-244.

[16] Bowman 167.

[17] *United States v. Rio Grande Dam & Irr. Ditch Co.,* 174 U.S. 690 (1899).

[18] 53 U.S. (12 How.) 443 (1851).

[19] See *United states v. Appalacian Elec. Power Co.,* 311 U.S. 377 (1940); *Madole v. Johnson,* 241 F. Supp. 379 (W.D. La.

1965).

[20] Oregon ex. rel., *State Land Board v. Corvallis,* 429 U.S. 363 (1977); 582 P.2d 1352 (Ore. 1978); 538 P.2d 70 (Ore. 1975); 536 P.2d 517 (Ore. 1975); 526 P.2d 469 (Ore. 1974); 439 P.2d 575 (Ore. 1968), *Bonelli Cattle Co. v. Arizona,* 414 U.S. 313 (1973), 495 P.2d 1312 (Ariz. 1972); 489 P.2d 699 (Ariz. 1971), *Utah v. United States,* 403 U.S. 9 (1971); 425 U.S. 948 (1976); 1976 *Utah Law Review* 245 Master's Report, *United States v. Oregon,* 295 U.S. 4 (1935), *United States v. Utah,* 283 U.S. 64 (1931), *United States v. Holt State Bank,* 270 U.S. 49 (1926), *Brewer-Elliot Oil and Gas Co. v. United States,* 260 U.S. 77 (1922), *Oklahoma v. Texas,* 258 U.S. 574 (1922), *Packer v. Bird,* 137 U.S. 661 (1891).

[21] Johnson and Austin 7. The state supreme courts in Arkansas, Idaho, Minnesota, North Dakota, Oregon, Texas, and Washington declared "local law" governed the determination of navigability.

[22] 260 U.S. 77 (1922), 270 U.S. 49 (1926), 283 U.S. 64 (1931).

[23] *United States v. Oregon,* 295 U.S. 4 (1934).

[24] MacGrady 613.

[25] MacGrady 598-99.

[26] *Oklahoma v. Texas,* 258 L.Ed. 772 (1921).

[27] Johnson and Austin 10.

[28] Bowman 173-6.

[29] *United States v. Texas*, 162 U.S. 1 (1896).

[30] *Oklahoma v. Texas*, 66 L.Ed. 1067.

[31] *Oklahoma v. Texas*, 67 L.Ed. 689.

[32] A. Henry McMahon, "International Boundaries," *Journal of the Royal Society of Arts*, vol. 84, (1935), p. 4.

[33] Stephen B. Jones, *Boundary Making* (Washington, D.C.: Carnegie Endowment for International Peace, 1945.)

[34] Jones 57.

[35] Jones 108-9.

[36] Olen Paul Matthews, *Water Resources, Geography and Law* (State College: Commercial Printing Inc., 1984) 55-57.

[37] Robert E. Beck, "The Wandering Missouri River: A Study in Accretion Law," North Dakota *Law Review* 43: 431.

[38] *Jefferies v. East Omaha Land Co*, 134 U.S. 178, 189 (1890).

[39] *McBride v. Steinweden*, 72 Kan. 508, 83 Pac. 822, 824 (1906).

[40] *Solomon v. Sioux City*, 243 Iowa 634, 51 N.W.2d. 472 (1952).

[41] *New Orleans v. United States*, 35 U.S. (10 Pet.) 662 (1836).

[42] Lowell W. Messer, "*Oklahoma Stream-Formed Boundaries: A Geographical Analysis of Legal Issues*," Oklahoma State University, 1991.

[43] Black, Henry Campbell, Black's Law Dictionary (West Publishing Co.: St. Paul, 1990) 610.

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[44] John C. Cabaniss, "Federal Common Law and its Application to Disputes Involving Accretive and Avulsive Changes in the Bounds of Navigable Waters," *Land and Water Law Review* vol. 17, no. 2 (1982): 331-2.

[45] *Provided new states were admitted on "equal footing" with those already in the Union, they acquired title to the beds of all navigable rivers within their borders. Shively v. Bowlby, 152 U.S. 1 (1894).*

[46] *Ottawa Shores Home Owners Ass'n. v. Lechlak*, 344 Mich. 366, 73 N.W. 2d 840 (1955); *Munninghoff v. Wisconsin Conservation Comm'n*, 255 Wis. 252, 38 N.W. 2d 712 (1949); *State v. Brace*, 76 N.D. 314 36 N.W. 2d 330 (1949); *Heimbecher v. City and County of Denver*, 90 Colo. 346, 9 P. 2d 280 (1932); *Allott v. Wilmington Light & Power Co.*, 288 Ill. 541, 123 N.E. 731 (1919).

[47] *Hughes v. Washington*, 389 U.S. 290, 293 (1967); *Arkansas v. Tennessee*, 246 U.S. 158, 169-77 (1918); *Jeffries v. East Omaha Land Co.*, 134 U.S. 178, 189 (1890); *Smith v. Whitney*, 105 Mont. 523, 74 P. 2d 450 (1937).

[48] *New Orleans v. United States*, 35 U.S. (10 Pet.) 662 (1836).

[49] *Philadelphia Co. v. Stimson*, 223 U.S. 605, 624 (1912); *St. Louis v. Rutz*, 138 U.S. 226, 245 (1891).

[50] Cabaniss 336.

[51] Matthews 58.

[52] *James v. Langford,* 10th Ct. 1-8 (1983).

[53] *Oklahoma v. Texas,* 67 L.Ed 428-39 (1923).

[54] *James v. Langford,* 10th Ct. 5 (1983).

[55] *James v. Langford,* 10th Ct. 5 (1983).

[56] *James v. Langford,* 10th Ct. 5 (1983).

[57] *Oklahoma v. Texas,* 261 U.S. 340, 345 (1923).

[58] *Currington v. Henderson,* W.D. Okla. 1-10 (1986).

[59] Henry Campbell Black, *Black's Law Dictionary* (St. Paul: West Publishing Co., 1990) 409.

[60] *Oklahoma v. Texas,* 256 U.S. 70, 41 S.Ct. 420, 258 U.S. 574 (1922), 42 S.Ct. 406 (1923).

Chapter III

The New Approach

Now that the problems of boundary delimitation have been identified and discussed from both an historical and analytical perspective, the advantages that the Global Positioning System (GPS) and programs such as *Discalc* offer can be discussed in detail. Each is important. GPS for the quick and accurate collection of data, and *Discalc* for modeling needed to identify the boundary. Only together is a viable solution possible.

First, a case will be made for GPS. How does GPS work? What advantages does it offer over traditional surveying techniques? How can it be used in the Red River boundary area? Second, *Discalc* will be discussed. Why do we need Discalc? How does it perform? Are there other software programs that are superior for this type of analysis? Third, how does GPS data work with one of these packages?

Critical to a new approach in collecting the data along the river is GPS. In the past, slow and less accurate surveying methods have limited the use of surveying information in helping to resolve river boundary disputes. A river may change its course several times before surveying information can be utilized effectively which only hampers an already complex situation.

The Red River has undergone many court ordered surveys which have resulted in short term results, if they may be called results at all. These surveys were painstaking endeavors. However, the results were prone to drifting and, as a result, were unreliable. To this day, the important boundary which separates Bureau of Land Management (BLM) property from private land is in question. Recent river meandering has changed the physical geography of the region to the point that earlier survey results are no longer valid for defining the landscape. Furthermore, requiring the land to conform to such surveying methods also works to confuse the location of parcel boundaries as well as all the surrounding land dependent on the accurate delimitation of such boundaries.

Since GPS receivers are more accurate and collect data faster than earlier surveying methods, the potential uses of the GPS data collection is broadened, especially adjacent to rivers that change their course frequently.

How the Global Positioning System Works

The Global Positioning System (GPS) has grown in popularity because of its ease of use and accuracy in locating positions. In this study it presents additional benefits. First, it is very mobile. The landscape along the Red River is comprised of a thick entanglement of trees and chaparral. Small and lightweight, the portability of the rover GPS unit is limited only by the user's physical dexterity. Second, GPS data can be collected much more quickly than data can be using conventional surveying methods. Since the river meanders so frequently, sometimes as often as a few times a day, speedy data collection is a necessity to process meaningful results. The river, in extreme, cases may change it's position a quarter mile in a week-long period. However, a change of six feet can be just as problematic as one of a thousand feet depending upon where one's property ends and his neighbor's begins. However, GPS involves more than collecting positions. The "system" is comprised of satellites in space and monitoring stations on earth operated by the Department of Defense (DoD). Careful planning and post-processing steps are also an integral part of GPS data collection. Before delving into the particular use of the GPS in this study, it is necessary to provide an explanation of how GPS works.

The Global Positioning System (GPS) computes positions using a concept called triangulation. Not unlike celestial observation of years past, GPS "stars" can be used to locate oneself on the face of the earth. While manual applications of triangulation may include a map and a compass, GPS triangulation occurs by measuring the distance between the rover receiver and selected satellites in space. Even more advanced methods of traditional surveying, using total stations, require line of sight between instruments. In the area along the Red River, line of sight along the ground is extremely limited by the dense thicket of trees and brush. Conversely, line of sight along the ground is not required in GPS. The rover and base receivers need not "see" each other. However, they need to have a reasonable view of the sky. By measuring the travel time of radio signals emitted from a group of four of more satellites, accurate positions on earth can be established. This is possible due to the way the satellites are operated.

Each of the satellites orbits the earth once every twelve hours at an altitude of about 12,600 nautical miles. The exact position of each is monitored by the DoD to ensure a consistent orbit, and to identify and eliminate "ephemeris" errors, errors in the predicted position of the satellite.[1] Each satellite possesses several high-precision atomic clocks and transmits a pseudo-random code for timing purposes to determine the distance from each satellite to the handheld (rover) unit. Since the satellites are in a precise orbit, each can be used as a reference point from which triangulation can occur.[2]

To obtain accurate measurements, triangulation using four or more satellites must be used. These satellites act as reference points from which receivers on the ground can compute their position. By "ranging" from a set of four satellites, we can identify one unique point on the face of the earth which is the true location. Of course, accuracy is a key component in obtaining acceptable results and there are a number of ways in which accuracy may be compromised. Errors include: satellite clock error, ephemeris error, multipath errors, receiver errors, as well as atmospheric/ionospheric inaccuracies, and "worst case" selective availability (S/A).[3] Selective availability accounts for the largest error in the overall error budget when, and if, it is implemented. It is introduced by the DoD to degrade the accuracy of GPS to avoid tactical advantages that high accuracy positioning could lend to

Figure 4. The GPS Error Budget

Error Budget

Typical Observed Errors:

- Satellite Clocks	2 feet
- Ephemeris Error	2 feet
- Receiver Errors	4 feet
- Atmospheric/Ionospheric	12 feet
- S/A	100 feet
Total	15-30 feet

Then multiply by GDOP (usually 4-6) which gives a total error of:

- Typical good receiver	60-100 feet
- worst case	200 feet
- with S/A	350 feet

Source: Trimble Navigation. 1989. *A Guide to the Next Utility*. Sunnyvale, CA: Trimble Navigation.

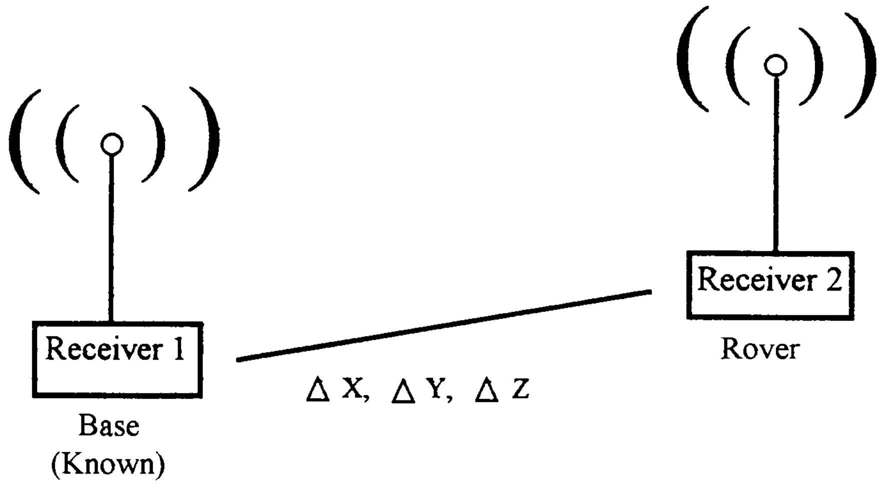
hostile forces. Satellite clock errors can occur when the satellite and receiver clocks are not synchronized. Ephemeris errors are caused by slight variations in a satellite's orbit. This is one of the reasons that the satellites are not in a geosynchronous orbit; every twelve hours a satellite orbits the earth and passes over DoD ground stations where adjustments can be made. Multipath errors are caused by the signal reflecting off objects before arriving at the hand held unit's antenna. Objects such as buildings and automobiles can cause this type of error. The receivers may have limitations too in that they may round-off mathematical computations which may introduce a few feet of uncertainty, and they are sometimes subject to electrical interference. Last, atmospheric and ionospheric propagation delays introduce the largest natural error. When a radio signal passes through the denser ionosphere, the signal is slowed down, disrupting the timing calculations. Fortunately, there are mathematical approximations that can be utilized to account for this type of error. Atmospheric errors are nearly impossible to correct, but since the average error is rarely in excess of a few feet and usually much less, such errors typically do not prevent accurate measurements.[4] With these errors and selective availability, a good receiver can expect an accuracy of +/- 300 feet.[5] Fortunately, the effects of these types of errors can be reduced with careful planning, and through post-processing of GPS positions.

Differential GPS

Differential GPS (DGPS), also referred to as relative positioning, is accomplished by using two or more GPS units, one acting as a rover and the other operating as the base. The base is usually set over a known location such as a class A or B benchmark or surveyor's monument.[6] In the case of this study, it is a base station located atop a building. The base station used here is a static 12 channel GPS receiver that logs data to a personal computer. The computer collects the signals from up to twelve satellites simultaneously and saves the data to the computer's hard drive. The roving GPS unit is used in the field to collect data. Since we already know the exact location of the base station, removing S/A is quite easy. By comparing the positions received by the handheld unit to those received by the base station, the measurable error or the difference between the locations can be identified. Once this difference in the signal is realized, it can be removed from the measurements

Figure 5. Differential Correction

Differential Correction



Two or more receivers observe GPS signals simultaneously

Some errors are common (or similar) in the measurements made by all receivers

When solving for relative positions, these errors are eliminated or reduced

Relative positions are more accurately determinable than absolute positions

Source: Trimble Navigation. 1989. *A Guide to the Next Utility*. Sunnyvale, CA: Trimble Navigation.

collected by the rover.[7] Accuracies with GeoExplorer™ rover units, where positions have been post processed, are in the range of 2-5 meters.[8] To obtain the best results, careful planning prior to field data collection must take place.[9]

Pre-Fieldwork Planning

In addition to establishing a time period of warm weather and low water, additional planning was needed to collect data most efficiently. This meant making use of a software package called Trimplan™. Trimplan™ allows the user to query the location of visible satellites, satellite constellation availability, and PDOP (position dilution of precision) values. One can also determine satellite azimuth and elevation for any location as well as date and time up to 90 days in advance of data collection.

Knowing where satellites are in space is essential to collect data properly. Doing so allows the user to avoid periods of time when there is an unfavorable satellite constellation, or to manually select another satellite when one is blocked by a river bank or thick tree canopy. To aid in selecting the best group of satellites, PDOP values are calculated. This allows the user to collect data at times when satellites are in the best geometric position.[10]

Furthermore, knowing when data collection meets the preset values of a low PDOP and a minimum height above the ellipsoid (HAE) is critical for selecting satellites which give the best results.

The study area, located approximately six miles on either side of the Byers-Waurika bridge along highway 79, was chosen because it met key requirements. The first criterion was that this portion of the river had to have recent or ongoing litigation. This is because the result of this approach must be tested against real-world problems. A second criterion was accessibility. Compared to other areas of the Red River Valley, this region had the best access. Third, this area contained the boundary defined by the Supreme Court as the "wheatfield bank.[11]" Fourth, the water level of the river had to be low. All these factors had to be coupled with reasonable weather which effects sampling date and time. With these conditions in harmony, GPS data collection could be carried out.

By using the Trimplan™ program, the location of visible satellites, position dilution of precision (PDOP), and satellite azimuth and elevation, could be determined for the three day window. In addition to the pseudo-random code that each satellite sends, they also emit an almanac providing information about each satellite's orbit.[12] This data can be downloaded to the Trimplan software to plan effectively. By knowing the location of visible satellites (satellites above a predetermined height above the horizon) one can have an overview of the total picture of the sky and the satellites available on a particular day. This becomes important when obstacles such as bluffs and hills or a thick canopy of trees may interfere with the radio signal. PDOP values are significant because they help determine the total error inherent to data collected at a site. By multiplying the total error budget (root square sum) by the PDOP, the predicted accuracy is ascertained. It is good practice to set a PDOP mask of 6.0 so that positions exceeding the PDOP threshold are not recorded.[13] These positions are less reliable since their accuracy may be questionable. The azimuth and elevation of each satellite in the sky comes into play to ensure that satellites are at least 15° above the horizon. Below 15°, the atmosphere is very thick and causes considerable "noise" which interferes with receiving the radio signal from satellites. Here, the radio signal must pass through a substantially thicker portion of the atmosphere and is therefore much weaker. The radio signal from satellites above this threshold are more easily used by the receiver to compute a position. Knowing where all the satellites are in the sky is essential to capturing the best results. The collection of data must meet two criteria. First, the actual gathering of the data with the GPS unit must be possible, and second, the results must be both meaningful and useful to the landowner.

Data Collection

The data gathered along the river was in the form of transects. A transect, or transection, is by definition a cut across, or a transverse dissection. Here, each transect is a line formed by crossing the width of the 100-year flood plain.[14] Consisting of positions of latitude/longitude and elevation, each transect began on the bluffs of the Oklahoma side of the river and ran through the riverbed and river, and onto the Texas side. Even though transects are lines, the GeoExplorer collects most accurately in the form of point data that can be connected as lines later. To do so, each point is an average of 180 positions taken over the span of three minutes (at an interval of one point per second). This procedure was repeated at every appreciable change in elevation throughout the course of each transect. To ensure that a relatively straight course was made, a transit and flags were used. By placing a flag in the ground and ranging from it using the transit, a straight line is assured.[15]

This straight line that runs from one side of the river to the other proceeds through the river itself. The river maintains a depth of between three and four feet at times of low water. Within its configuration, the level at which the unit is held above the ground can be altered. In this case, the unit was held six feet above the ground so that it would not be submerged under water. This method was adopted each time the river was crossed.

After each transect was collected, the data was downloaded to a laptop computer. By using Pathfinder™ software, the data could be displayed immediately. This way, each point could be queried for integrity and errors could be corrected in the field. If a replacement transect needed to be collected, it could be done immediately. Once a transect was checked and the results verified, the data could be saved to the hard drive of the laptop computer, and files could be removed from the GPS unit.

Once the transect data was collected, it was downloaded and differentially corrected against base station data collected for the same time period. The data was then ready for further processing or display in any number of programs such as ArcView™, AutoCAD™, Intergraph™, or in this case, *Discalc*.

Discalc

Once the transect data had been collected with GPS, it was ready for use within a mathematical model. It is important to note that, even though GPS has numerous advantages it alone cannot arrive at a boundary solution.

The important factor that GPS cannot overcome is identifying which bank constitutes the cutbank. In the Red River area, many banks exist as a result of the meandering river. Because of this, no one knows which banks set the boundary. That is why the court defined bank in *James v. Langford* is necessary, because without it, we would have nowhere to begin analysis. And without *Discalc*, it would be impossible to identify other banks down the river on which the boundary relies.

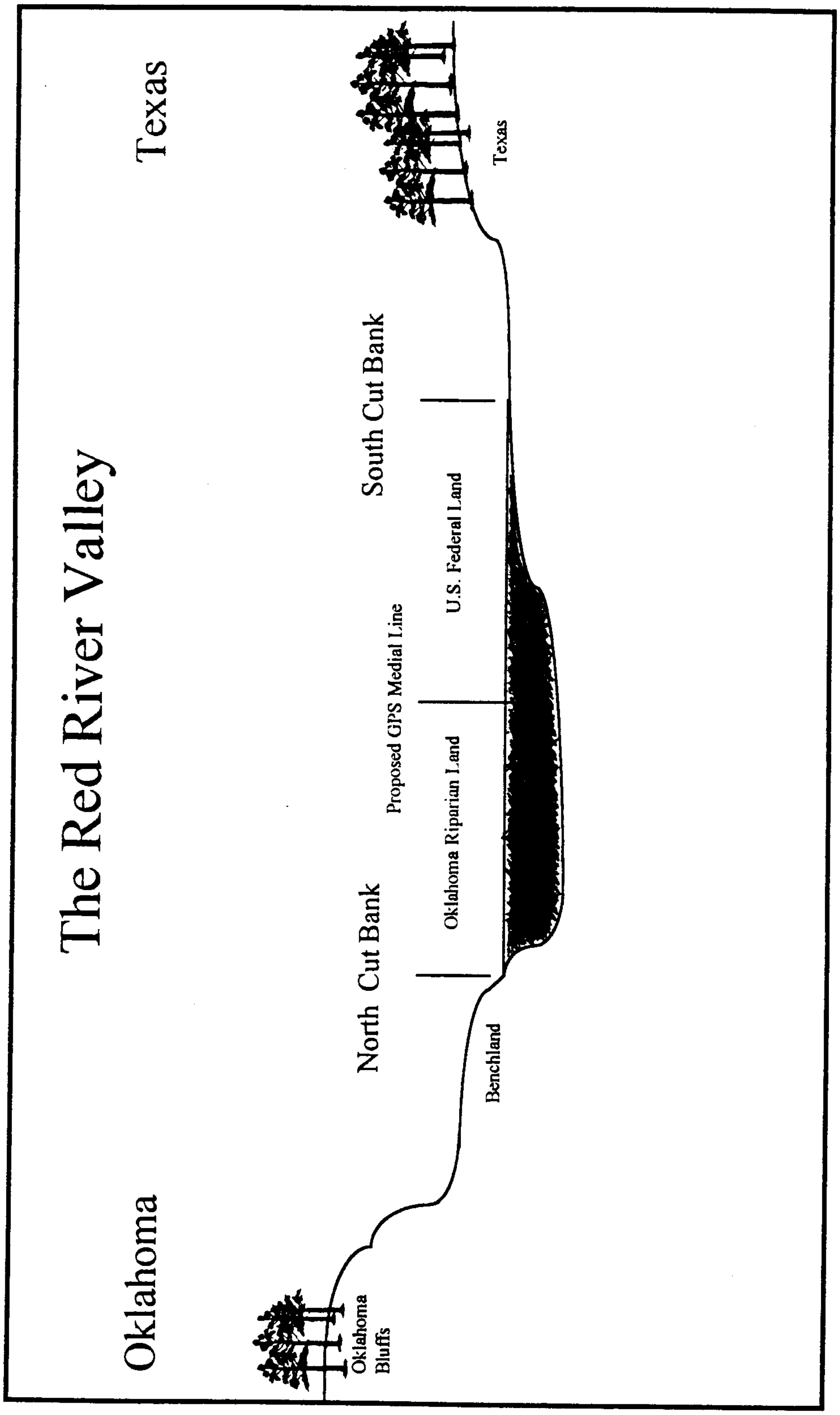
Discalc is a computer program that can estimate river characteristics for future and past events. It replaces manual methods for computing flow estimations which are time consuming. At the time it was developed, Discalc was the only program that could estimate the water level in a particular transect.[16]

Typical methods for estimating river characteristics such as mean stream power, cross-sectional stream power or stream volume, rely on actual streamflow measurements. However, in the Red River situation, it is necessary to work in the other direction. The Red River changes so frequently that actual stream measurements would be nonsensical. Discalc has the ability to use horizontal and vertical coordinates (x,y,z) derived using GPS to compute the cross-sectional dimensions and volume of the Red River at specific locations. (Figure 6 is a conceptual example of what such a transect might look like.) And with a resistance function, it is possible to determine mean velocity, mean depth, width, and other important information for those interested in how the river flow may be affected by the another adjacent river channel joining it. However, this procedure is "time consuming" and results in significant "computational bias."[17]

Discalc is capable of performing stream-channel cross sections for single thread channels and multi-thread channels up to 10 channels. Typically, the cross section data is entered from left to right, in order of increasing distance from the origin of the first coordinate. Once entered, the data may be displayed.

In this case, the volume of the river is most important. However, for each cross section the area (not volume) is of true importance since there is no intrinsic volume in a cross section of infinite thickness. Here, with the known control points, the calculated area may be identified and applied to other cross sections at locations

Figure 6: A Conceptual Transect



within the river. Simply put, *Discalc* puts a "lid" on the cross section and computes the area of the polygon at that point. In addition to the coordinates, the user must provide more information such as the water surface at the top of profile and the vertical exaggeration. While *Discalc* is designed to perform the functions necessary for this research, it does have shortcomings that prevent it from being a viable model.

The greatest drawback is the requirement that *Discalc* must run on an antiquated operating system. It will not perform properly on DOS (disk operating system) versions five and greater. Since most personal computers are equipped with newer incarnations of DOS, this is a rather severe limitation.

The program also has trouble with complicated transects. Transects with a large volume of water and with multiple depth changes (a large flat area adjacent to a single deep trough) do not process. Subsequent transects with a greater volume of water than an earlier transect are also problematic.

Other limitations include the requirement of having the data in only one format, meters. If a coordinate pair must be changed, one must know its sequence number or, the order in which it was entered from left to right. Also, *Discalc* cannot handle more than 10 separate channels in a transect.

Discalc is not much more than what it tries to be, a simple algorithm. It is not an intuitive, polished, or user friendly program. It is incapable of overcoming simple user mistakes such as entering an erroneous point. In light of these deficiencies, *Discalc* is not a viable model.[18] However, there are other programs that may be more suitable.

Quickflow™ is one such program that has the advantages of *Discalc* and more. It can use coordinates from any source, including GPS to compute areas and volumes. The environment is much friendlier too. It is used much in the same way *Discalc* is; simply plug in the GPS positions and simulate a river cross-section. Pull-down menus, easy import and export of DXF files, and compatibility with other software packages makes this program a viable alternative to *Discalc*.[19]

Surfer is another software package that can work with river transects. In fact, it is a contouring package useful for many operations. However, it is capable of computing transects. Options include user-specified contour levels and labeling, and the ability to use multiple views to see and analyze data. It states that it can import data in *any* format as well. A Windows platform is also an option with *Surfer*.

In short, all of three of these software packages can integrate GPS data. *Discalc* is the most limited however. Future research in this area would likely make use of programs like *Surfer* and *Quickflow*™ which offer many more options and are easier to use.

The Role of GPS in Boundary Disputes

Past methods of surveying along river boundaries for the purpose of resolving disputes between adjacent landowners have been long on efforts while resulting in very little progress. By the time a survey was completed, the river may have moved significantly, rendering the results of the survey obsolete. Landowners were often waiting while the courts deliberated, only to be granted a decree that could no longer be applied because the river had changed its position. Surveying methods employed in such court cases were a hinderance because they could not be accomplished in a reasonable amount of time, nor could they furnish the kind of accuracy possible with modern methods.

One of the most glaring problems was the colossal length of time needed to arrive at a "solution." Whenever the legal system is involved, typical delays inherent to such a process make the chances of resolution slim. For example, the survey ordered by the U.S. Supreme Court to be conducted by the Red River Boundary Commissioners began April 16, 1923 and was completed on February 17, 1924. The case itself wasn't decided until months later. This came at a time when millions of dollars were up for grabs between feuding parties. Making matters even less palatable, were the means by which the technology of the day hindered the accuracy of the survey. The "approved modern methods" of 1924 would fall short of today's standards in terms of technology because of the length of time it would take to perform a survey, and because the results would not be of utmost accuracy. Reference monuments and witness posts, used to record the survey, were located in the earth which, especially in the Red River Valley, were subject to frequent meandering of the river as well, particularly after years of use.[26]

It has been discussed earlier in this study that the U.S. Supreme Court is not able to effectively negotiate such disputes. A cursory look at the laws affecting river movements such as avulsion and accretion is confusing. It makes sense then, that any attempt to make the overall effort more efficient would be beneficial. In light of this, more responsibility falls upon the shoulders of the surveyor.

Courts at all levels that preside over boundary disputes have had to count on surveying as a tool. However, seldom has such a device been used as a tool to assist in settling disagreements between landowners. This may be attributed to many reasons, the most likely of which hinges upon the state of surveying at the time. It could not offer quick results, nor could it be thought of as a viable option, because it was so time consuming, to precede complicated legal interaction. Also important is that a comprehensive survey could not be completed without a considerable amount of manpower.

Other shortcomings existed. There was a profound absence of any manner with which to maintain the boundary. Once delimited and identified by surveyors and defined by law, there was no method in place to maintain and update fluctuations in the boundary as a result of the river's meandering. These changes made mapping of the boundary exceedingly difficult too. GPS, with its distinct advantages in accuracy and speed, offers new possibilities.

Advantages of GPS

As mentioned in the previous section, the speed with which surveying data can be collected is very important in a boundary dispute of this nature. After all, the river's position shifts regularly. GPS allows the user to overcome such changes with its ability to gather coordinates very quickly.

With the GeoExplorer GPS receiver used in this study, data was collected in the form of three transects consisting of over 100 points in less than one day. Depending on the scope of the survey, data collection could be completed significantly faster, especially when compared to past methods. All the post-processing was completed in the day following. More expensive models offer even more rapid results. Real-time data gathering with accuracy approaching a few millimeters is possible. This speed and accuracy is vitally important. It does not change the way features such as the cutbank and benchland are defined, but merely makes their location and demarcation easier. Therefore, we are not forced to redefine what has already been laid out in hundreds of years of testimony. Rather, we are going to apply those rules and decisions in a new way.

In the recent court cases *James v. Langford* and *Currington v. Henderson,* the court did not seek to redefine the physical appearance of the boundary. Rather, it merely sought to locate its position. Countless cases such as these defer back to *Oklahoma v. Texas* for the definition of terms such as cutbank, medial line, or bed of the river. If the location of these features can be accomplished using the definitions set forth in prior court cases, there may be an alternate mechanism to expedite court proceedings, or circumvent legal delays altogether. In some cases it may be as simple as walking the cutbank with a GPS unit to define its location.

What may be of greatest importance to all those who live adjacent to the river is the possibility GPS brings to maintaining the river boundary. Both Texas and Oklahoma operate boundary commissions whose duty is to resolve local disputes, and to keep in existence some semblance of order in hopes of avoiding future problems. One way of preserving order would be to map the boundary and the river valley, and to provide that information to the public. By using GPS in combination with another recent technology, the geographic information system (GIS), a viable method to determine the boundary becomes much more plausible.

Since GPS data is in a digital format, it is easy to import into any of the modeling programs and various mapping programs or GISs. Employing a GIS more easily facilitates an understanding for all those with a vested interest in the region because of the wide spectrum of ways that data can be presented. By updating a GIS with data collected with a GPS and manipulated by a model such as *Surfer* or *Quickflow*™, landowners can be presented with information that helps them to better understand the fluctuation of the river boundary.

And this is an advantage over the older, traditional methods of surveying.

GPS and GIS

After the GPS data has been collected and post processed, and after its analysis within a modeling program, the data can easily be used within another type of software for further analysis. Since the boundary between the two states does move, one way by which we are able to quantify and display such inevitable movements is within the framework of a GIS. A GIS can be interactive in this capacity and can be easily amended whenever appropriate. A GIS may include any number of layers to display the GPS data and to more easily facilitate consumption by the general public. Aerial photography, county and parcel boundaries, and classified Landsat TM[21] scenes may serve as layers that may be used to effectively show how the boundary changes.

Knowing where the boundary is at any given point in time has numerous advantages. To the respective boundary commissions from either state, it provides an accurate way with which to evaluate personal property and the taxes on such land. Business owners such as those who mine along the river will know the extent of their property. GPS offers river will know the extent of their property. GPS offers hope to local landowners who want to know where their property ends and where their neighbor's begins.

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[1]Trimble Navigation. 1989. *GPS: A Guide to the Next Utility.* Sunnyvale, CA: Trimble Navigation.

[2]Trimble Navigation 12-32.

[3]Trimble Navigation 46.

[4]Trimble Navigation 35-46.

[5]Thomas A. Wikle and Dean P. Lambert, "The Global Positioning System and its Integration into College Geography Curricula," *Journal of Geography* 95(5) (1996): 165-69.

[6]Generally, there is little difference between Class A and Class B benchmarks. Class A markers are typically comprised of a stainless steel rod driven in to the earth to the point of refusal below the portion of the earth that is prone to shifting the most, at or near bedrock. This rod is enclosed in a casing that minimizes friction between itself and the earth surrounding it. Class B benchmarks may exist as a stainless steel without the protective, friction-less casing, or may be set in concrete. In terms of accuracy, Class A markers are the most reliable. However, Class B markers may as accurate as the other but are not guaranteed to be since they are prone to a greater degree of movement.

[7] It should be noted that differential correction can be fraught with error if not averaged properly. A common mistake is to collect a series of points, average them, and perform the differential correction. Differential correction is only beneficial when the differential correction comes prior to the averaging process. If the prior method is adopted, observations will result in no real increase in positional accuracy over that which could be collected with an instantaneous position reading. Samuel G. Shaw, "Target Corrected GPS Point Features for Accurate Results," *GIS World* vol. 8, no. 5 (May 1995): 56-60.

[8] Although Trimble Navigation proclaims an accuracy of 2-5 meters on the GeoExplorer, tests in the field have exhibited an accuracy as low as sub-meter.

[9] The GeoExplorer GPS unit is a pocket-sized Trimble GPS receiver. It is a six channel receiver capable of tracking up to 8 satellites at once. It has a 1/4 megabyte of internal memory which allows for storage of up to 9,000 three-dimensional GPS positions. It is capable of differential GPS data collection and was chosen because of its simplicity of use, and lightweight design which made it easy to use in the field. It comes with GEO-PC processing software for differential correction computation, and PFINDER software which allows one to add attributes and descriptions to collected points. Trimble. Surveying and

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Mapping Division. *GeoExplorer- Pocket-sized GPS Mapping System.* Sunnyvale, CA. 1994.

[10]Generally, PDOP values of less than 6.0 are acceptable.

[11]*Currington v. Henderson,* _F.Supp._ W.D. Ok. 1986.

[12]Trimble Navigation 36.

[13] The PDOP acronym refers to the Position Dilution Of Precision. This refers to a change in a horizontal or vertical plane which may result in a degradation of accuracy. The lower the value of PDOP, the higher the precision.

[14]The width of the 100-year flood plain may be identified with a U.S.G.S 7.5 minute topo quad, or by other means. However, for the purpose of this thesis the exact limits of the flood plain were not identified. It was, in my opinion readily apparent where the flood plain exists.

[15]A second GPS unit can easily provide the user with bearings as well.

[16]Discussions with Bruce L. Rhoads.

[17]Bruce L. Rhoads, "Discalc: A Computer Algorithm for Computing the Flow Characteristics of Flood Discharges in Stream Channel Cross Sections," *Computers and Geosciences,* vol 13, no. 5, (1987): 495.

[18]In talks with Bruce L. Rhoads, he has expressed an interest in writing a newer version of *Discalc* that not only

operates on more contemporary operating system, but also corrects bugs in the original version.

[19]Rockware. *1996-7 Earth Science Catalog*. Golden, CO. 1996.

[20]*Oklahoma v. Texas*, 44 Sup. Ct. 571-604 (1924).

[21]A Landsat Thematic Mapper scene is a remotely sensed image. The image was classified to discern land use patterns.

Chapter IV

Summary and Conclusions

The Red River boundary dispute demonstrates that the legal problems associated with boundaries are complicated. There is ample evidence to make this supposition. Similar issues regarding the position of the boundary and bed ownership have been raised along many other rivers as well, between states and landowners. The Chattahooche River, which defines the boundary between Georgia and Alabama, the Savannah River, dividing land between the states of Georgia and South Carolina, and the Sabine River between Texas and Louisiana have long been the source of contention between states. However, these disputes affect individual landowners as well. The profound impact that meandering streams have on boundaries and areas in their vicinity cannot be underestimated.

One of the objectives of this study has been to discuss relative case-law regarding stream-formed boundaries. While the discussion presented here regarding the interaction of law and geography describes the typical course of action taken by the courts in boundary disputes, there is room for improvement.

If there was a way for courts to agree on how to deal with disputes such as these, there would be fewer problems demanding court action. However, concepts such as navigability and accretive and avulsive doctrines do change, and will forever suffer from the inescapable ambiguity of practical application. Similarly, rivers and their beds change ensuring continued controversy.

Courts will continue to be plagued with interpreting difficult concepts such as whether a particular river's movement is accretive or avulsive in action. What do words such as gradual and imperceptible mean? As suggested by many of these cases, it is apparent that considerable confusion has been created by courts ascribing different meanings to the same words. These problems will also continue until a uniform definition is accepted.

The second objective was to discuss the application of these laws at the federal and state levels. As we have seen, whether or not a river was navigable or not at the time it came under state jurisdiction may help determine if disputes are a state or federal issue. In extreme circumstances, geographers have been asked to trace historical records of a river's flow to ascertain whether or not the river was navigable or not. While this is atypical of recent issues, repercussions of such decisions are still being felt. Generally, a majority of the problems arise when the bounds of a water body change. Under both federal and state law, the first action is to decide what kind of movement the boundary has made; namely, whether it is an accretive, avulsive, or an erosional one. And once again we are back to defining and making practical applications of such words.

An attempt at a better application of the complex legal system is the goal of the next two applications. First, the shortcomings of past surveying techniques were addressed. They were time consuming, cumbersome, and labor intensive. Aside from the obvious complexities of applying legal principles to this river boundary, the resulting court decrees were slowed and often hindered by the speed of conventional surveying methods.

Since a river is prone to change position from time to time, the speed with which a survey can be completed is of utmost importance. Courts formulate a solution based upon the circumstances that exist such as the position of the river, the type of movement the river has made, whether the river is navigable or not, etc. However, by the time such a problem is addressed and studied, and proposals for a solution made, the conditions of the river may have changed. When this happens, it is exceedingly difficult to apply court derived solutions.

The only way that surveys can be completed more quickly and with equal or better accuracy than past techniques is by employing GPS. GPS helps the user to accommodate changes in the river's course because resurveying can be performed by as little as one or two individuals in a relatively short period of time. Even though coordinates can be collected quickly, GPS suffers no loss of accuracy. In short, it makes the delimitation and demarcation of river features much easier.

The fifth objective was to discuss the use of the GPS transect data within a model such as *Discalc*. At the beginning of this study, *Discalc* was the only model that was known to simulate river transects. What was discovered however, is that Discalc is not a suitable model for this purpose. Its reliance on an antiquated operating system and its general obsolescence place it far behind programs such as *Quickflow*™ and *Surfer*™. These programs are capable of calculating volumes at a specific transect and applying that same volume up and down the river.

The final objective was to compare this new approach to past methods of surveying. In the prior chapter, the advantages of GPS over traditional survey methods was discussed. On a surveying level, GPS has many advantages. But the true advantage to fostering a new approach to the Red River boundary dispute is using that data in a viable model. With such a model and a GIS many new possibilities exists that were never before possible. Information can be updated quickly and accurately. When the river moves appreciably, this approach is more proactive. It can adapt quickly to the river's changes. In addition, GIS can be used to overlay aerial photography and parcel boundary coverages as well as other layers.

What all this means is that new choices are possible. For the legal community, this may be an alternate solution to be employed by the courts which may help to expedite proceedings. Or, it may be used by local planners and tax assessors to iron-out rudimentary disagreements between landowners. Since many local planning offices use some sort of geographic information system or cartographic package to manage parcel boundaries, the data collected with the GPS can be easily integrated into their systems. This means that river boundary records can be updated regularly to reflect changes. In short, GPS can work to benefit the legal system and the local community when dealing with such disputes along a river boundary.

Call for Research

Further research studying the link between law and geography is not only wide open, but very important. Geographers can learn much from laws that govern geographic processes. Since the field work was performed for this thesis, there have been many innovations in the global positioning system. Receivers are becoming lighter and smaller. Less expensive, single frequency receivers collect data in real-time, making their use easier and more beneficial. Other new changes in GPS technology make it possible to collect data while on the move without a significant degradation in accuracy.

Including GPS data in a geographic information system presents more opportunities for continued research. A GIS could be employed which uses GPS data to display changes in the river's boundary, and how such changes affect ownership regarding riparian landowners, subsurface mineral deposits, and cadastral boundaries.

An excellent idea for continued research on GPS would be to determine how it may be used by the law. How does the legal community use such a tool? Can the use of GPS actually change the legal system's approach to boundary disputes? To date, there has been little or no research on the affect GPS has on the legal community.

Hopefully, these questions can spur continued research towards applying GPS in resolving river boundary disputes. It would be interesting to see how other river boundary disputes would be affected by the use of GPS. This paper serves as a starting point for future research in this area. By applying such a study on other river boundaries it may become possible to work a change in the manner with which boundaries along rivers exist. If this is possible, the riparian landowner, the subsurface mineral rights holder, and all those with a vested interest in property adjacent to a river may be able to better manage land.

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APPENDIX B
THESES CITED

Messer, Lowell W., "Oklahoma Stream-Formed Boundaries: A Geographical Analysis of Legal Issues." Thesis. Oklahoma State University, 1991.

VITA

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Master of Science

Thesis: THE RED RIVER BOUNDARY DISPUTE: A NEW APPROACH TO AN OLD PROBLEM

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