

DETERMINING THE UTILITY OF GIS IN BORDER DISPUTES  
CASE STUDY: SUDAN AND SOUTH SUDAN

By

Chandra Dawn Baker

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## **DEDICATION**

I dedicate this thesis to my family, especially husband Derek and son Nico who have inspired and motivated me throughout this entire process.

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I will be forever grateful to my advisor, Dr. Warshawsky. I would also like to thank my family and friends, without whom I could not have made it this far.

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## **LIST OF ABBREVIATIONS**

ABC	Abyei Boundary Commission
CPA	Comprehensive Peace Agreement
IBRU	International Boundary Research Unit
SDBZ	Safe Demilitarized Buffer Zone
SPLA	Sudan People's Liberation Army
SPLM	Sudan People's Liberation Movement
TFDD	Trans-boundary Freshwater Dispute Database
UNAMIS	United Nations Advanced Mission in Sudan



## ABSTRACT

Almost every country in the world has experienced a border dispute to varying degrees of conflict and the Sudan – South Sudan border region is no exception. Distribution of spatial information to all sides in border negotiations may help to ensure a smoother functioning negotiation, and thus avoid armed conflict. In this thesis, the likelihood of border conflict is measured by adapting the *opportunity* and *willingness* framework, and then determining the *conflict border* (Starr 2002; Starr and Thomas 2005). Conflict occurs where the border region has infrastructure in place to mobilize militarily and the area is salient, but not so salient that mutual cooperation between states has occurred. This thesis demonstrates the utility of a GIS analysis for border placement negotiations between Sudan and South Sudan by developing a conflict border index based on the opportunity and willingness distribution within a 100 kilometer border region. The opportunity and willingness analysis proves effective in determining the utility of GIS in border determination. Areas with medium levels of opportunity and willingness were located and therefore could be avoided in border placement as a way to reduce potential future conflict.

## CHAPTER ONE: INTRODUCTION

Borders are a fluid concept. A border can divide or unite, provide security or create vulnerability, provide or strip identity. Frequently, borders are determined, not by the people who reside or do business in the region, but by politicians and special committees far removed from the area.

When delimiting a border, the interests of the people are not always in line with the interest of the state(s). Moreover, the interests of the people are not always in line with each other throughout the border region. When this misalignment happens, border issues arise and sometimes result in conflict. One example of this misalignment can be found along the border of Sudan and South Sudan. A long and tangled history of pastoral tribal conflict, struggles over natural resources and a difference in cultural identity between the south and the north set the stage for South Sudan to secede from Sudan in 2011; however the border conflict continues to plague the region.

The nature of a border vastly impacts the population, economy, and security of a state. Because of this, much research on border dynamics has been done by the international relations and geopolitical community. More recently, border research has reemerged as a rebuttal to the idea that physical borders and geography do not matter due to globalization (Anderson and O'Dowd 1999; O'Dowd 2001; Furlong et al. 2006; Starr 1999; Robinson 2007). Recent border concerns within the international relations and geopolitical literature center around concepts such as the interdependence between states, regional integration, the probability of war, diffusion of war, peace, democracy, opportunity and willingness, borders and alliances, etc. (Starr 2002; Siverson and Starr 1990).

Although physical and cultural features have long been considered in border research, GIS has not been explored to any great extent. Vanzo (2002) examined compactness strategies in

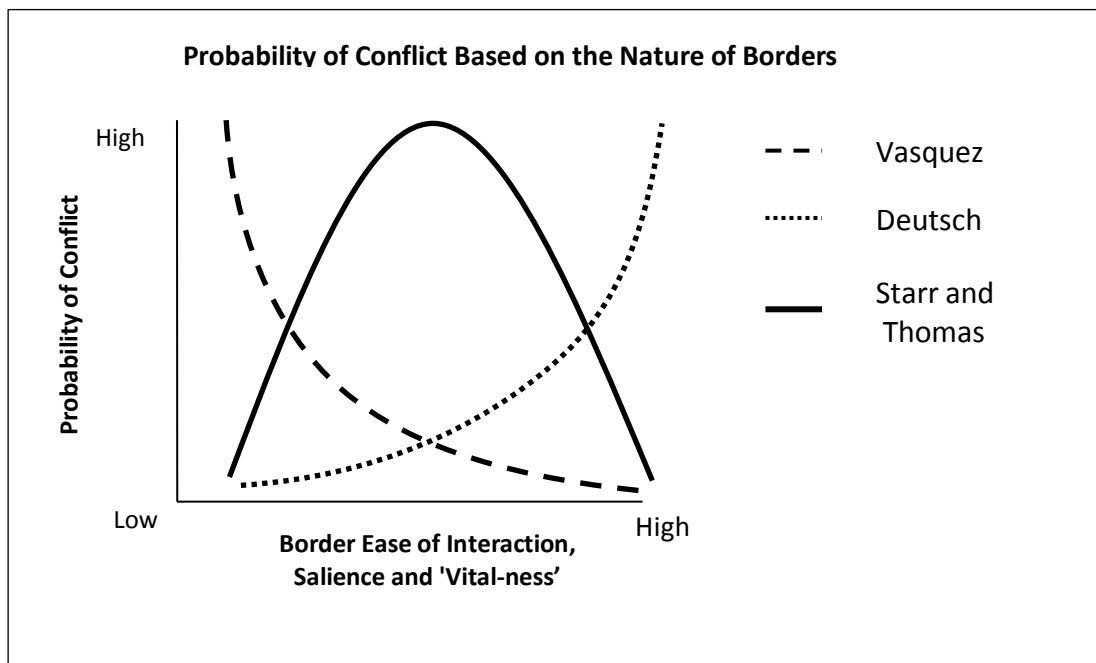
German and Israeli border configurations using GIS as a tool. Starr (2002) used GIS as a tool to revise how borders are seen and measured. Wood (2000) lays out ways GIS can be used as a tool in territory negotiations; however, the author does not undertake GIS border analysis. A large research gap exists in the GIS border research and the goal of this study is to present a way of determining a border using GIS. This thesis will focus on the *opportunity and willingness* framework as developed by Starr (2002) and Starr and Thomas (2005) to present a way of determining a border using GIS.

Siverson and Starr (1990) describe opportunity, or ease of interaction as: Possibilities that are available to any entity within any environment, representing the total set of environmental constraints and possibilities” (48). In this thesis, it is measured more narrowly as the spatial distribution of existing transportation infrastructure between two land-based territories. Willingness is defined as the motivation, desire, or reason to engage or not engage in territorial conflict based on the perceived value, or salience of a territory and is, “Related to a decision maker’s calculations of advantage and disadvantage, cost and benefit” (Siverson and Starr 1990, 49).

The connection between opportunity and willingness of a state(s) and conflict in border regions has been recognized in the international relations literature; however the interpretation by scholars differs greatly. Deutsch (1970) claimed easier border crossings (high opportunity) and an increased saliency (high willingness) of the border region, the *less* likely a border will experience conflict (Starr and Thomas 2005). Deutsch based this claim on the idea that interdependence and integration can be facilitated through highly permeable and salient borders thus making conflict less likely (Starr and Thomas 2005). On the contrary, Vasquez (1993) claimed easier border crossings (high opportunity) and an increased saliency (high willingness)

of the border region the *more* likely a border will experience conflict (Starr and Thomas 2005). Vasquez based this claim on the idea that border regions with a great deal of access between populations paired with high value of the border region land and resources, would result in a greater likelihood of conflict.

Starr and Thomas (2005), noticing the contradictions between Deutsch and Vasquez but realizing both claims had value, developed their own claim. As shown in Figure 1, Starr and Thomas claim that conflict was more likely to occur at neither the highest level of opportunity and willingness nor the lowest levels of opportunity and willingness, but rather right in the middle (Starr and Thomas 2005). Starr and Thomas propose that the middle range of (high) opportunity and salience should have proportionally the highest incidences of conflict (Figure 1) (Starr and Thomas 2005). This claim is based on the cost of militarized dispute. Where borders have less opportunity and less salience, there will be less conflict because there is neither the



**Figure 1 Probability of Conflict Based on the Nature of Borders (Starr and Thomas 2005)**

means nor the desire to create conflict. Concurrently, where there is more opportunity and more salience, there is increased cooperation between states and therefore less conflict. According to Starr and Thomas, conflict occurs is where the border region has infrastructure in place to mobilize militarily and the area is salient, but not so salient that mutual cooperation between states has occurred (Figure 1) (Starr and Thomas 2005).

The opportunity metric is based on proximity. Proximity, as it relates to border conflict, has its roots in the loss-of-strength gradient (Boulding 1962) and been measured many ways. Contiguity, inter-capital distance, minimum distance between relevant dyads (Furlong et al. 2006), and military reach (Vasquez 1993). Starr quantifies the opportunity as the number of roads, railroads and steepness of terrain as factors leading to the opportunity for interaction, either facilitating or hindering interaction (Starr and Thomas 2002). States that are nearer each other have more opportunity for interaction yet mere proximity does not absolutely give rise to conflict alone, the willingness to go to war must also exist (Vasquez 1993; Starr 2002).

Willingness is defined as the motivation, desire, or reason to engage or not engage in territorial conflict based on the perceived value, or salience of a territory. Value can be measured many ways; however Starr (2005) uses: “Population concentrations, active civil and military airports, military camps, forts, oil wells and refineries, power plants, water tanks, factories, industrial complexes, hospitals, telecommunication stations, etc.” (Starr and Thomas 2005, 129) and their proximity to each other an indicator of value.

Starr expanded on the *opportunity and willingness* framework by analyzing past border data using Geographic Information Science (GIS) (Starr 2002; Starr and Thomas 2005). The opportunity and willingness concept has served as framework for determining the conditions leading to past border conflict (Vasquez 1993; Starr 2002; Furlong et al. 2006), but has not been

used as the framework to model future border placement based on the avoidance of known conflict conditions. The robustness of the opportunity and willingness framework allows for it to be applied to global and regional samples (Furlong et al. 2006) not only looking back to see past conflict conditions, but also forward to possibly mitigate future conflict.

The purpose of this thesis is to determine the utility of GIS in border negotiations by examining past research on what spatial and non-spatial factors increase border conflict based on the opportunity and willingness framework presented by Starr and Thomas (2005), and how this concept can be applied to current or future border negotiations. This thesis assumes both countries want to minimize border region conflict. If a GIS analysis of potential border locations can prove to be a useful tool for border negotiations, it is expected that border negotiations and ultimately the established border, will better reflect the needs of people in the border region and thus lead to less conflict. This thesis does not set out to prove or disprove Starr and Thomas (2005), but rather use the knowledge gained by their analysis of over 300 dyads applying it to a single case study for the purpose of demonstrating the utility of GIS in border negotiations.

Demonstrating the utility of GIS in border negotiations is accomplished by examining the Sudan – South Sudan border region and applying Starr and Thomas’ opportunity and willingness framework (Starr and Thomas 2005). After designating a study area by creating a 100 kilometer buffer around the present border as shown in Figure 2, I will locate areas in the border region where opportunity is high, medium, and low meaning there are conditions present or not present in the border region to facilitate interaction between two states (see Figure 2). Opportunity will be measured by creating a five kilometer buffer polygon around each road, railroad, and waterway, then counting the overlapping polygons to determine the levels of interaction opportunity.

Next, I will locate areas in the proposed border region where *willingness* is high, medium and low based on the value, or salience of the area. Value will be measured by locating settlements, air fields, mineral deposits and power plants within the border region as well their proximity to each other for the purpose of using this information as an indicator of value distribution within the border region. This will be accomplished by creating a ten kilometer buffer polygon around each feature and counting the number of overlapping polygons to determine the level of salience.

Finally, I will find areas that possess both a medium level of combined opportunity and willingness to determine the area within the border region to most likely experience conflict (Starr and Thomas 2005). This will be called the conflicted border area. This information will show negotiators areas of medium opportunity and willingness and thus areas to avoid placing the border for less conflict.

This thesis is organized in the following way. Chapter One provides a brief overview of the purpose and content of the thesis. Chapter Two will explore the existing literature pertaining to past border studies to include ways borders have been delimited in the past, the dynamics and history of the Sudan – South Sudan border, and how GIS has been used in past border studies. Chapter Three discusses the data and method used for this study. Chapter Four explains the results of the analysis. Chapter Five discusses the implications of the analysis and results.

# Study Area Reference Map

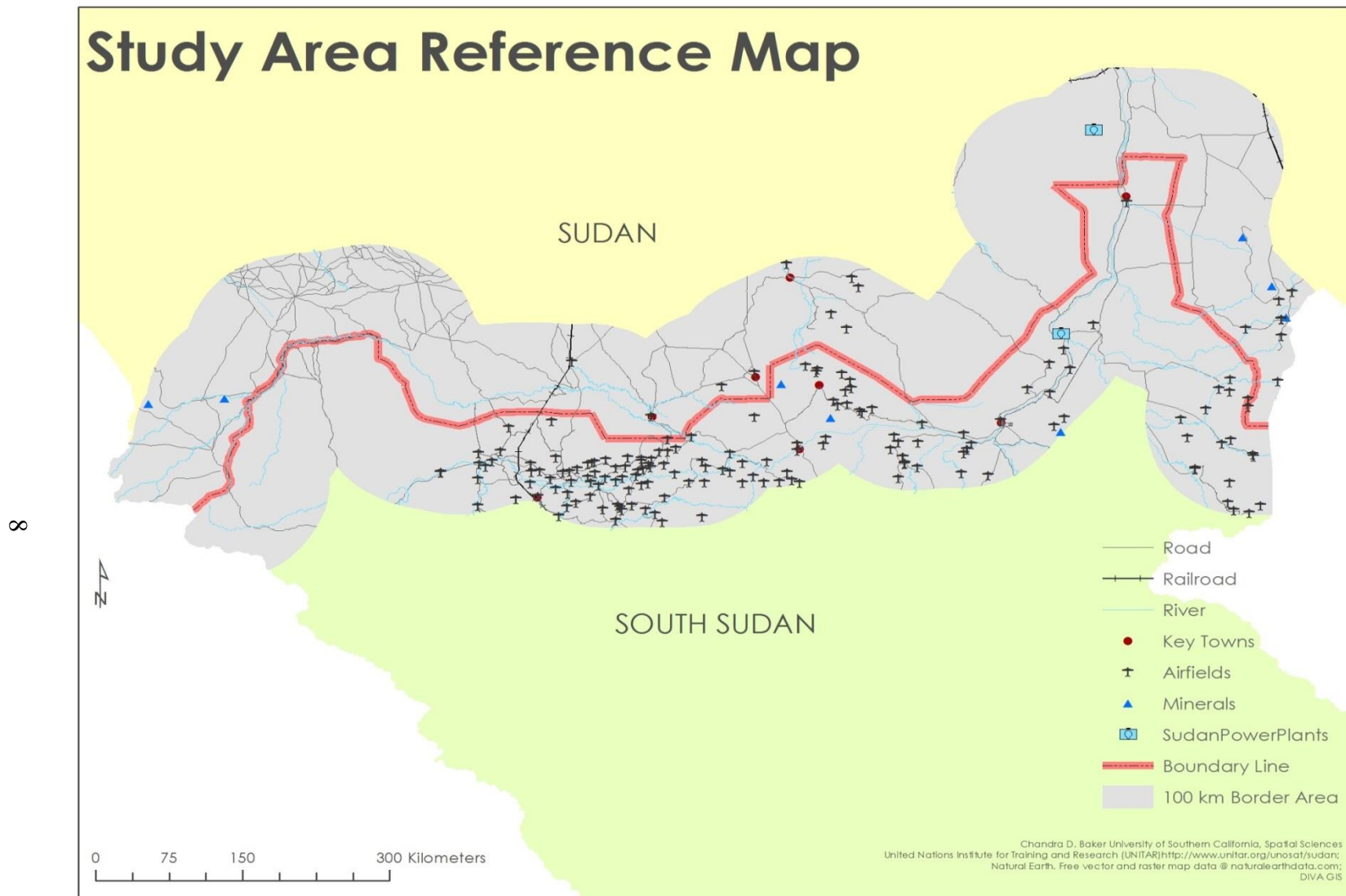


Figure 2 Study Area Reference Map



## CHAPTER TWO: LITERATURE REVIEW

Borders and boundaries are powerful phenomena. They evoke emotion, protect, contain, shape relations, facilitate trade, promote or deter conflicts, and define jurisdictions (Bonchuk 2012; Calfisch 2006, Brochmann 2012). For this reason, there are many perspectives on how to define borders. O’Dowd (2001) states: “Borders are the ubiquitous product of the need for order, security, and belonging in human life” (O’Dowd, 2001, 1). Newman suggests that classic border studies (prior to 1980s) in political geography focused on descriptive analysis of boundaries, their location, and the political and historical processes leading to their demarcation (Newman 2006). Anderson and O’Dowd (1999) argue: “The significance of borders derives from the importance of territoriality as an organizing principle of political and social life” (2).

### 2.1 Border Studies

Due to emergence of globalization concepts, border studies discourse has recently focused on the irrelevancy of borders. Newman (2006) asserts that the borderless world is exclusive to economist and information scientists as a discipline and Western European geographies. He maintains that borders do still matter, and states: “The process of bordering, rather than the border outcomes *per se*, which should be of interest to all border scholars” (148).

In this chapter I will discuss the various definitions of border and the methods typically used to delimit borders. Then I will narrow the discussion to the Sudan and South Sudan border history and conflicts. Next, I will discuss how GIS has been used in past border studies. Finally, I will discuss how the past application of GIS will be adapted to the case study of the Sudan – South Sudan border dispute, filling a critical research gap which lies in the application of GIS technology in such disputes.

### ***2.1.1 The Definition of Border***

The term “border” has been defined various ways depending on the defining entity. The Encyclopedia of Global Studies defines a border as: “Mark(s) that limit nation-states’ territory and legal jurisdiction, distinguish one state from another, and demarcate domestic from international realms” (McNevin 2012, 2). Political geographers tend to define borders as fundamental influences on the way a society develops and on the political options opened to it or physical outcomes of political decisions (Bonchuk 2012; Newman 2006). Lucius Caflisch, (2006) broadly defines a border as a way to identify areas where state sovereignty exists.

### ***2.1.2 Ways Borders have been Delimited in the Past***

There are several approaches to delimiting a border location between regions or countries. Geometry (Robertson 2008), geographical landforms (Caflisch, 2006), and re-visitation of previous borders (Carter and Goemans 2011), arbitration and mediation (Carter Center 2010) have been used in the past to settle disputes between borders. In many cases, combinations of several approaches have been used (White 2002; Bialasiewicz et al. 2009). Phenomena is not constant across a region where a territorial dispute exists therefore requiring different applications may be necessary.

#### ***2.1.2.1 Geometry***

Borders have been settled using geometrical lines on earth, such as parallels. The United States and Canada 49<sup>th</sup> parallel is a prime example of spherical geometry of earth used to determine all or a portion of a border (Robertson 2008). The Boundary Treaty of 1866 between Chile and Bolivia also utilized the 24<sup>th</sup> parallel south as the border between the countries and the countries would share tax revenues generated between the 23<sup>rd</sup> and 25<sup>th</sup> parallel (Farcau 2000). Earth’s spherical geometry has been used to define the geographic jurisdiction of The Antarctic Treaty,

the area south of 60 degrees latitude, and thereby defining a continent (Treaty 2012). The use of a parallel as a border line is common for water boundaries such as the border between Malaysia and the Philippines establish in the Convention regarding the Boundary between the Philippine Archipelago and the State of North Borneo, 1930 (Bautista 2009).

### ***2.1.2.2 Landforms***

Landforms such as rivers, watersheds and mountain ranges commonly serve as boundaries between countries. The Rhine River between Germany and France, the Rio Grande River between the U. S. and Mexico and even the Bahr el Arab River (Kiir River) along the Sudan and South Sudan border are examples of a river used as a border. Watersheds can also be used as landform boundaries as such the case where the Perlis River and Pujoh River watershed delimitate the Malaysian – Thailand border (Nordin 2006) and the Chile – Argentine border along the highest crest of the Andes established 1902 (Caflisch 2006).

Rivers as borders raise considerable questions when used to delimit a border. Brochmann and Gleditsch (2012) concluded that of the 299 contiguous dyads, all but 17 dyads share a river as derived from the *Trans-boundary Freshwater Dispute Database* (TFDD) (Brochmann and Gleditsch 2012). Typically a river border is established in the deepest channel in the river, or Thalweg, but can follow the riverbank, the median line between the river banks and change over time due to erosion, drought or floods (Gleditsch et al. 2006; Caflisch 2006; Carter Center 2010). The exact location of the Thalweg can be ambiguous as it may not lie in the middle of the river channel as one might expect (Caflisch 2006).

Rivers are perhaps the most debated type of boundary in the academic literature. Rivers can have negative effects causing conflict or positive effects and facilitate cooperation between states. Demonstrating the negative effects of river boundaries, it has been argued that countries

sharing a river have a higher probability of engaging in militarized disputes due to the natural shifting of the river (Gleditsch et al. 2006; Calfisch 2006; Carter Center 2010; Furlong et al. 2003). Also, river borders increase opportunity for interaction and willingness to fight over resources (Furlong et al. 2003; Gleditsch et al. 2006; Toset et al. 2000). On the other hand, Brochmann (2012) argued river boundaries have no effect on the risk of conflict (with the exception of the Middle East region) (Brochmann et al. 2012). However, once controlled for river basin proximity, Brochmann, et al. (2012), argued that dyads with an upstream/downstream relationship have increased risk of conflict due to the upstream state's decisions affecting the downstream states water quality and availability (Brochmann et al. 2012). Demonstrating a positive effect of a river boundary, Furlong et al. (2006) argued that river boundaries facilitate cooperation between states more commonly than cause conflict (Furlong et al. 2006).

Watersheds as boundaries share the same concerns as river and when used as boundaries can also lead to more disputes (Gleditsch et al. 2006). Erosion may change the watershed as the case with Chile and Argentina (Caflisch 2006). The watershed may cut across grazing land as the case with Siam and Cambodia (Caflisch 2006).

Mountain ranges as a border also raise considerable questions. The Chile – Argentina border was established in 1902 at the highest crests of the Andes forming the watershed line. However, over time, erosion caused the crests to shift (Caflisch 2006). Mountainous terrain does not always make for conflict-free dyads. Brochmann, Rod and Gleditsch (2012) assessed the effect of rugged terrain on the risk of conflict with rugged terrain defined as: “The length of border measured along the terrain, surface distance, divided by the horizontal projected distance” (179). They found rugged terrain does not decrease the risk of conflict as expected, but actually increases the risk of conflict (Brochmann et al. 2012). This study also found that swamp land

reduces the risk of conflict as swamp lands reduce interaction between dyads (Brochmann et al. 2012).

### ***2.1.2.3 Re-visitation of Previous Borders***

Many times, borders in dispute revert back to old borders. This has been the case for Croatia, Hungary, Bosnia and Herzegovina, Montenegro, Serbia and Slovenia as outlined by Andreja Metelko-Zgombić and Cosquer at the Applied Issues in International Land Boundary Delimitation/Demarcation Practices seminar, 2011. The Eritrea-Ethiopia border arbitration agreement mandated the neutral Boundary Commission: “Delimit and demarcate the colonial treaty border based on colonial treaties (1900, 1902, and 1908)” (White 2002, 346). The use of previous administrative boundaries has advantages such as transaction and negotiation costs are minimized and uncertainty is minimized due to the familiarity of the previous border (Carter and Goemans, 2011).

### ***2.1.2.4 Arbitration and Mediation***

Arbitration and mediation, usually administered by the United Nations International Court of Justice (ICJ), is a cooperative approach to border disputes (Carter Center 2010). According to The Carter Center’s report *Approaches to Solving Territorial Conflicts* (2010), the ICJ has seen 14 cases involving land disputes and is not consistent in its factors of consideration and thus not a very attractive option for resolving territorial disputes (Carter Center 2010). Sumner (2004) showed that nine factors needed to be considered in court for territorial claims treaty law, geography, economy, culture, effective control, history, “elitism”, and ideology. However, the factors the ICJ does seem to consistently consider are treaty law, and effective control. (The Carter Center 2010).

## **2.2 Sudan border**

Border delimitation between Sudan and South Sudan has been determined in different ways depending on the area. The Comprehensive Peace Agreement (CPA) 2005, between the Government of Sudan and the Sudan People's Liberation Movement/Sudan People's Liberation Army (SPLM/A) administered by the United Nations Advanced Mission in Sudan (UNAMIS) in Naivasha, Kenya identified an area known as the 'southern region' to hold a referendum in July of 2011 (Comprehensive Peace Agreement 2005). Excluded from this were the Three Areas known as the Abyei Area, Southern Kordofan and Blue Nile States, which were outlined in separate protocols under the CPA (Johnson 2008). On July 9, 2011, the people of southern region voted to succeed from The Republic of the Sudan to form The Republic of South Sudan. The CPA was the result of two civil wars in Sudan, the first 1955-1972 and 1983-2005. A combination of methods was used to establish a new border between Sudan and South Sudan, including using the Bahr el Arab River for a portion of the border and the re-visitation of previously administered boundaries for other portions of the border.

### **2.2.1 Abyei**

The Abyei Protocol commissioned the Abyei Boundary Commission (ABC) consisting of five members from the government, five from SPLM, and five international experts (Johnson 2008). Only Abyei can vote to become part of Southern Sudan. The ABC was given a specific mandate to define the Abyei Area from 1905 colonial rule not taking into consideration any developments since the area became disputed (Johnson 2008). The report was not accepted by the Sudanese government. The Sudanese government claims the territory belongs to Sudan based on the previous county borderlines from a 1902 Condominium.

### **2.2.2 Blue Nile States and South Kordofan**

The CPA (2005) states: “The Blue Nile State shall be understood as referring to the presently existing Blue Nile State. The South Kordofan/Nuba Mountains State shall be the same boundaries of former Southern Kordofan Province when Greater Kordofan was sub-divided into two properties” (73). These areas remained in Sudan despite a majority of the population identifying with the South Sudan more than Sudan, paralyzing the SPLM/A from negotiating on their behalf (Rolandsen 2011).

The Joint Borders Commission *Agreement on Security Arrangements between The Republic of the Sudan and The Republic of South Sudan* (2012) established SDBZ (SDBZ) of 14 miles around the border. However, the Satellite Sentinel Project (SSP) reported June 18, 2013 both Sudan and South Sudan had violated this agreement by stationing troops within the SDBZ as confirmed by DigitalGlobe satellite imagery acquired May and June 2013 (Satellite Sentinel Project 2013). It should be noted that the Agreement states 14-mile buffer while the SSP report states 12.5 mile buffer around the border.

### **2.3 History**

Prior to the Egyptian invasion in the 1820s, the two kingdoms, Sennar and Darfur had established concentrated circles of power around each central authority. Each conferred land grants to tribal leaders and thereby establishing the tribal ‘dar’ system in the North. Pastoralist evaded authority by marginalizing themselves to the in-between lands. The Rizeigat and Misseriya Baggara Arabs fled to southern areas south of the Bahr al-Arab/Kiir River. The majority of the Misseriya left Darfur for the area known as Southern Kordofan (Schomerus et al. 2009; Johnson 2010).

1821-1885 saw the Turco-Egyptian regime where the sultans retained some control over their lands. During this time, boundaries were flexible, if at all existent. The Turkiyya were overthrown by the Mahdiyya in 1885 and reverted back to the old Sudanic pattern of a central state. This Mahdist state lost control of the southern areas, including the Nuba Mountains and Ethiopian foothills and never completely dominated Darfur (Johnson 2010).

Anglo-Egyptian control began in 1899 and lasted through 1956. The first boundaries were drawn on maps before the government knew the geography of the land. Minor adjustments were made over time to certain areas as needed for administrative conveniences. It was considered best practice to not divide people of the same tribe while purposefully grouping rival tribes together to facilitate resolutions of disputes (Johnson 2010). From the 1920s on, rural administration throughout Sudan followed the principle of indirect rule, or Native Administration, whereby local government was based on customary law applied by customary, or tribal, leaders (Johnson 2010).

This Native Administration led to the Southern Policy for Sudan's non-Muslim, non-Arabic-speaking people in the southern province. The Closed District Ordinance of 1922 which intended to curb illegal economic activities by persons coming from outside of the restricted areas (Ethiopian poachers and White Nile slave-traders), as well as stop the spread of Islam into what was considered pagan areas. The Southern Policy, incorporating the existing Closed District Ordinance and the principles inherent to Native Administration, was made formal in 1930. It explicitly promoted the development of administration based on non-Muslim, non-Arab customs, and left open the possibility of separating the southern provinces from Sudan. The Southern Policy was formally rescinded in 1946 as Sudan was prepping for Independence. Both the Northern Sudanese Nationalist and Egypt opposed any separation of the southern provinces



from Sudan. The Southern Policy created the idea of a distinct territorial base for non-Muslim, non-Arab, African, southern Sudan (Johnson 2010).

Native Administration defined dominant and secondary land rights for tribes. Sometimes, land rights were shared by different groups, depending on the season. The Native Administration regulated overlapping use of land and monitored movement across the land through tribal meetings. In the north, the Condominium government gave the regulation of land use rights to each tribal authority. Because not all tribal areas were contiguous, the 1925 Land Registration and Settlement Act gave all non-tribal land to the government. The north was more inclined to accept fixed boundaries while the south retained some fluidity through Native Administration (Johnson 2010).

After independence, Sudan's land policy remained the same until the 1970s where mechanized farming enabled the development of Sudan's central clay plains. The government feared the lack of clearly defined property rights would discourage investment in the area so The Unregistered Land Act 1970 transferred ownership of all unregistered and unoccupied land to the central government. This gave the 'power to limit the ability of the nomads and the traditional cultivators throughout the country to enjoy the benefits derived from use and enjoyment of land, water, forest, and other resources of the country' (Johnson 2010).

## **2.4 Border conflict in Sudan**

Historically, pastoral tribal claims have driven conflict across this region. In 1965, the Ngok Dinka and Misseriya clashed over grazing areas (Johnson 2008). This fighting spread to Abyei and in addition to mass murders, the son of Deng Majok, paramount chief of the Ngok, was assassinated (Johnson 2008). Abyei received special status under the 1972 Addis Ababa Agreement that entitled the Ngok to vote in a referendum on whether or not to be incorporated

into the newly formed southern region (Johnson 2008). This occurred at a time when rainfall patterns had changed, the Misseriya post-independence cattle herds had more than doubled, and there was growing agricultural pressure on land to the north under Sudan's bread-basket strategy (Johnson 2008). These factors along with the fact that Abyei was under special status and the Ngok wanted to move the border of the southern region to the north, made the Misseriya nervous so they responded to the perceived threats on their seasonal land with help from the armed militias (Johnson 2008).

South Sudan succeeded from Sudan on July 9, 2011 under the terms of the 2005 CPA. Prior to South Sudan's succession, the region has endured the one of the longest civil war on the African continent, 22 years, before establishing independence. Immediately thereafter, several border conflicts arose, including around the city of Heglig, the Blue Nile region, Kafia Kingi, and the Abyei region remain in dispute. The causes for these clashes vary from region to region. The Abyei conflict stems from the mismanagement of pastoralist grazing patterns (Johnson 2006). The Heglig region experiences disputes over oil fields with both Sudan and South Sudan seizing or halting production from Heglig in a tug-o-war manner, often violent.

Natural resource availability plays an important role for conflict management and border delimitation because extraction and distribution is spatially fixed (Buhaug 2002). The most prevalent and profitable resource along the border is oil. Sudan and South Sudan have a combined five billion barrels of proven oil reserves (KPMG 2012) and exported 389 barrels per day (bpd) in 2010, prior to the South Sudan succession. Sudan supplies China with seven percent of their imported oil (Shinn 2014). South Sudan produces most of the regions oil; however the land-locked country is dependent on Sudan's established pipelines to export oil (U. S. Energy Information Administration 2013).

## **2.5 How GIS has been Used in Past Border Studies**

Martin Pratt of the International Boundary Research Unit (IBRU) states: “Good boundaries require an understanding of and sensitivity to both the physical and human landscape (11).” A GIS organizes spatial data and effective boundary management requires the organization (and ideally the exchange) of a wide range of spatial data (Pratt 2006; Wood 2000). Ultimately boundary dispute resolution almost always involves the analysis and interpretation of complex geographic information (Pratt 2006).

William B. Wood introduced the idea of using GIS as a tool for territorial negotiations (Wood 2000). He proposed that social and physical phenomena such as natural features, events, and human activities can be geo-located and organized spatially then analyzed for patterns. In using GIS for negotiations, Wood cautions: “(GIS) is only useful if implemented in a political atmosphere of good-faith negotiations” (76). Problems arise when quantifying qualitative data as both sides have different strategic goals (Wood 2000). Even so, the advantages prevail in that GIS and remote sensing software as applied to territorial negotiations help visualize the types of resources at stake, populations who might be affected and other considerations (Wood 2000). Additionally GIS excels at ‘what-if’ scenarios in regard to each sides goals (Wood 2000). As it applies to the Sudan – South Sudan border, GIS can analyze spatial data with the goal of finding the border resulting in the least probability for conflict.

Harvey Starr asserts GIS is a tool that permits integration of data about spatial phenomenon (Starr 2002). Starr also used GIS to examine types of borders with enduring rivalries to see if there is a pattern based on border length (Starr 2002). Instead, he expands his earlier opportunity and willingness framework to use a GIS for finding vital border areas. This takes the geographical factor previous related to border conflict, i.e. contiguity, border length,

number of shared borders, to examining the nature of the border. This thesis expands on Starr's opportunity and willingness metrics using GIS in the way Wood proposed, for territory negotiations.

## **2.6 GIS and Sudan – South Sudan**

The situation with Sudan and South Sudan's border disputes is very complex. This thesis has demonstrated many ways borders can entice and enable conflict if factors that increase the probability of conflict are not considered. These factors can be represented in a GIS to assist negotiators in determining a border that will reduce conflict. There has been little research in developing even the simplest method for using GIS in negotiations. The goal of this paper is to show the utility of GIS in border negotiations to provide a better, less conflicted outcome for a border region using the research of Starr and Thomas' opportunity and willingness framework. Since the utility of GIS in border negotiations has not been studied in-depth; its place in the process has yet to be established. For this study, GIS is used in the middle of the process to identify areas that may be prone to conflict based on a previous border conflict study, Starr and Thomas (2005). Ideally, GIS would be used throughout the process beginning with a complete and spatially accurate dataset of the border region that is agreed upon by both countries and by the negotiators.

### CHAPTER THREE: DATA AND METHODS

This thesis examines the Sudan – South Sudan border as a way to demonstrate the utility of GIS in border negotiations. Both opportunity and willingness variables were analyzed with the shared goal of reducing conflict. The methodology follows four steps: (1) Determine border area by creating a 100 kilometer buffer around the current border between Sudan and South Sudan; (2) Create an opportunity index by analyzing locations of roads, railroads, and waterways in relation to each other, indicating where high, medium and low opportunity for interaction exists; (3) Create a willingness index by analyzing key towns, air fields, mineral deposits and power plants in relation to each other, indicating where high, medium, and low willingness exists; (4) Locate where high, medium, and low combined opportunity and willingness exist in the border area with the expectation of locating medium levels of combined opportunity and willingness.

This analysis adopts methods from both Starr and Thomas' (2002) *Opportunity, Willingness and Geographic Information Systems (GIS): Re-conceptualizing Borders in International Relations* (2002) and Starr's (2005) *Nature of Border and International Conflict: Revisiting Hypotheses on Territory*. Starr and Thomas (2005) concluded that conflict most likely occurs at medium levels of opportunity and willingness. I apply this knowledge specifically to the Sudan – South Sudan border region by using an adaptation of Starr's (2002) method of quantifying opportunity and willingness in GIS. However, this thesis differs from Starr (2002) in one central way. Rather than looking at a multitude of past conflict areas to determine the opportunity and willingness levels of the border regions that are most prone to conflict, this thesis adapts the opportunity and willingness framework to one specific case study in an effort to present a border less prone to conflict. A new border would need to avoid areas of medium opportunity and willingness in order to reduce conflict in the border region. Again, it is not the

intention of this thesis to prove or disprove Starr and Thomas (2005), but rather explore the utility of GIS.

### **3.1 Study Area**

This case study examines the newly established border region between Sudan and South Sudan. A 100 kilometer buffer around the current border will be the study area as shown in the Study Area Reference Map in Chapter 1 (Figure 1).

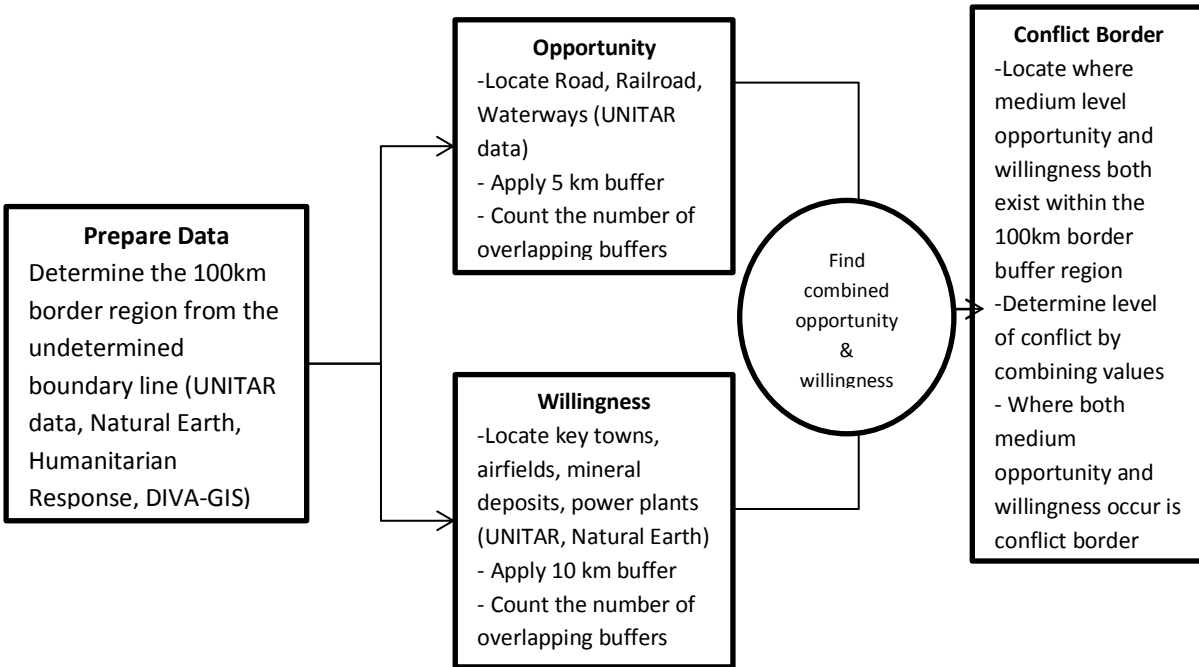
### **3.2 Data**

The best factors for the value of land in Sudan and South Sudan's border area are oilfields, oil wells, pastoral land, and cultural identity. This data was not available and therefore the analysis had to rely on proxy data as indicators of willingness, or value. After this thesis was near completion, a static map of oil fields was obtained through the United States Agency for International Development (USAID) showing the location of oilfields and concession holders as of 2001 (United States Agency for International Development 2001).

Pastoral land and cultural identity data are difficult to acquire but this data is very important to the people living in the border region. It requires a robust data collection process in order to be accurate for border placement. Even then, the tribal nature of this region includes longstanding alliances between these tribes that may be difficult to discern spatially and seasonally in a GIS.

### **3.3 Method**

As shown in Figure 3, this case study analysis first determined the opportunity of interaction, and then determined the willingness of interaction in the current border region (Figure 3). Next, this study determines where both opportunity and willingness exist to determine areas of conflicted



**Figure 3 Methodology Flowchart**

border area (Starr 2002). Knowing the conflicted border area assists in the determination of border location. To achieve the conflicted border measurement, I follow Starr's methodology put forth in his 2002 study. Starr looked at ways to explain the probability of border conflict based on the nature of past border conflicts using opportunity and willingness as their metrics. I take their findings and apply them to the future border decision using opportunity and willingness as the metric for this study. For example, if we know that areas of medium opportunity and willingness result in a more conflicted border, we can attempt to avoid placing a border through an area with medium opportunity and willingness as a means to reduce conflict. This will be achieved using Esri ArcGIS 10.2 software, data from the United Nations Institute for Training and Research (UNITAR), Humanitarian Response, and DIVA-GIS.

### ***3.3.1 Opportunity for Interaction***

Starr (2002) determined opportunity can be measured by the existence of roads, railroads and steepness of terrain. This border region is relatively flat and will replace the steepness of terrain variable with a waterways variable as a mode or barrier to transportation. An opportunity or ease of interaction index was created as shown in Table 1.

Roads (RD) and railroads (RR) were located in the 100 kilometer buffer zone using spatial data from UNITAR. Both roads and railroads are relevant because they are two of several factors that facilitate opportunity for interaction between neighboring countries (Starr 2005).

Waterways (WW) are relevant to the Sudan – South Sudan border region in that next to the few roads and railroads, water is how the population travels. The western side of the border region has the Bahr el-Arab, or Kiir River, that acts as the border between Sudan and South Sudan. The White Nile on the eastern side of the border region runs from the south to the north, and for a short distance, acts as the border between Sudan and South Sudan. The existence of a waterway increases the accessibility and vitality of the area. Waterways are substituted for steepness of terrain due to the flatness of the entire border region between Sudan and South Sudan.

Table 1 shows the index created using the roads, railroads and waterways (Table 1). Five kilometer buffers were created around each road, railroad and waterway. The polygon created by the buffer serves as the area of influence the road and railroad possess. The presence of buffered road, railroad or waterway polygon indicates a low opportunity for interaction and a value of one is assigned to that polygon. The intersection of two buffer polygons indicates medium levels of opportunity and a value of two is assigned to that polygon. The intersection of three or more



buffer polygons indicates high levels of opportunity and a value of three is assigned to that polygon.

**Table 1 Opportunity for Interaction Index**

<b>OPPORTUNITY FOR INTERACTION INDEX</b>			
<b>ROAD (RD) RAILROAD (RR) WATERWAY (WW)</b>			
<b>FEATURES</b>	<b>OPPORTUNITY</b>	<b>CONFLICT LEVEL</b>	<b>VALUE</b>
<b>RD + RR + WW*</b>	High	Low	3
<b>RD + RR</b>	Medium	High	2
<b>RD + WW</b>	Medium	High	2
<b>RR + WW</b>	Medium	High	2
<b>RD</b>	Low	Low	1
<b>RR</b>	Low	Low	1
<b>WW</b>	Low	Low	1
<b>RD = Road data; RR = Railroad data; WW = Waterway data</b>			
<b>*OR ANY COMBINATION OF THE THREE FEATURES</b>			

### *3.3.2 Willingness of Interaction or Salience*

The willingness of interaction across borders is rooted in the value, or importance of the land or resources along the border. Starr determines value by examining key cities, state capital location, airfields, and cultural landmarks in relation to each other and in relation to the border (Starr 2002). Due to data constraints and the underdeveloped nature of the study area, this study examines key cities, airfields, mineral deposits and power plants as factors for willingness.

Key city locations were used to determine population distribution. Neither Sudan nor South Sudan conducted a census since the 2011 succession of South Sudan; therefore, the most recent 2008 census was without spatial reference data and was smaller than the state level. Settlement distribution data found at the United Nations Institute for Training and Research (UNITAR) factors into determining the value of the land at the border. Starr states that International Relations theory needs to capture the central elements of the state: territory,

population, and government in order to determine the value of land (Starr 2002). The settlement distribution for Sudan and South Sudan will satisfy territory and population.

Airfields are a key factor to transportation within and between Sudan and South Sudan and thus any airfield found within the border buffer zone add value to the area and thus increase willingness of the border area. There are 179 airfields that exist within the border buffer zone, 15 in Sudan and 164 in South Sudan.

Mineral deposits also add value to an area as a natural resource. The border region contains six existing mining operations, three in Sudan and three in South Sudan. These operations mine bauxite, copper, manganese, oil, and asbestos. The economic value of each of these mines varies but this study will just look at the presence or absence of the mine. The presence of a mine increases the value of the border area.

Power plants contribute to the value of an area. However, there are only two within the 100 kilometer buffer zone: one in Sudan and one in South Sudan. Power plants touch on all the key aspects of transportation, communication, energy production, industrial, agricultural and security infrastructures that make land valuable, increasing the vitality of the border area (Starr 2002).

A ten kilometer buffer was created around each key town, air field, mineral deposit and power plant. The numbers of other features in that buffer were counted to determine the value of the area. A count polygon tool was used in ArcGIS to count the number of overlapping features in the buffer polygon. The process is shown in Figure 4. The buffered areas with two or more intersecting buffers were dissolved into one polygon representing the value of the polygon with the number of features found within ten kilometer of each other. As shown in Table 2, areas with six or more features within a ten kilometer distance of each other will receive a high level of

willingness value. Areas with three to five features within a ten kilometer distance of each other will receive a medium value. Areas with one to two features within a ten kilometer distance of each other will receive a low value (Table 2). A high level of territorial value or saliency indicates a high willingness for interaction. Starr and Thomas (2005) state that conflict is most likely to occur at medium levels of willingness, where motivation exists, but the area is not so valuable that mutual cooperation has taken place between the states (Starr and Thomas 2005).

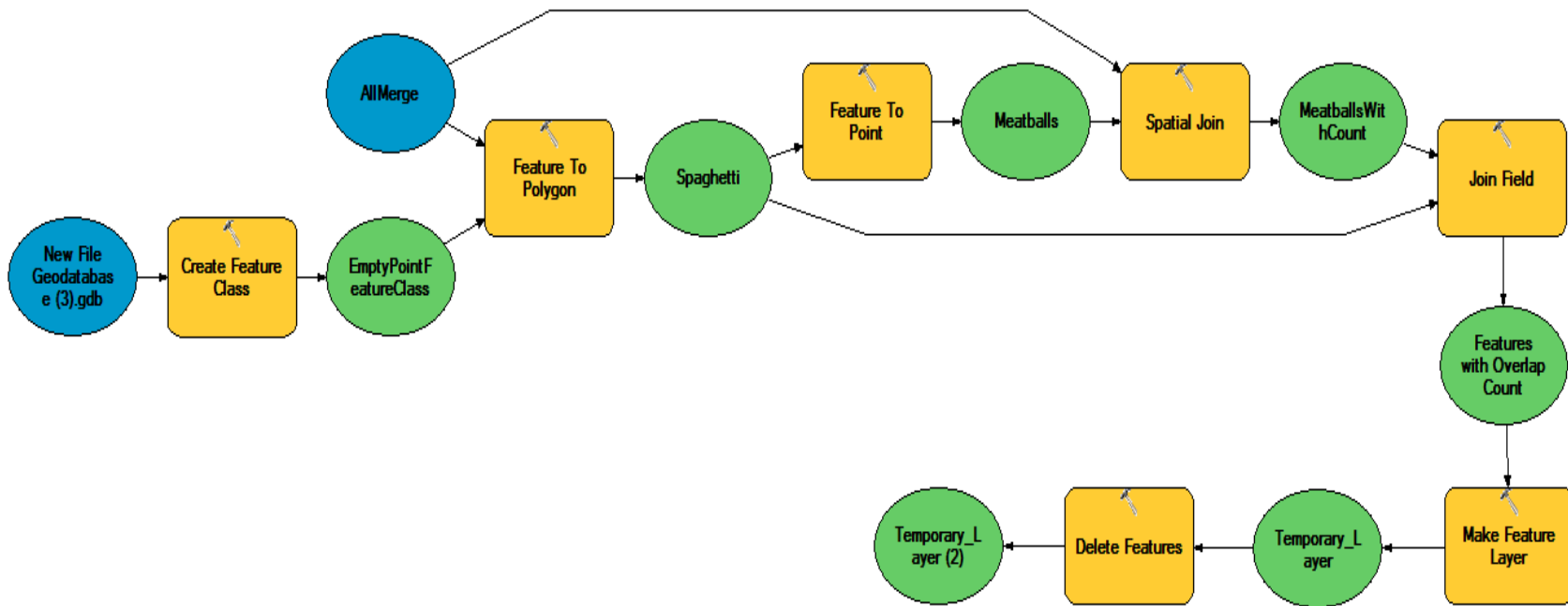


Figure 4 Count Polygon Model (Esri ArcGIS 10.2)

**Table 2 Willingness for Interaction Index**

WILLINGNESS FOR INTERACTION INDEX			
NUMBER OF FEATURES IN BUFFER	VALUE	WILLINGNESS	CONFLICT LEVEL
4+ Features	3	High	Low
3 Features	2	Medium	High
2 Features	1	Low	High
0 Features	0	Low	Low

**3.3.3 The Conflict Border**

The conflict border is the areas where both medium levels of opportunity and willingness exist in the same space. For this study, the space will be represented by polygons. The conflict area is where a border negotiator would want to avoid placing a border. Starr and Thomas (2005) determined conflict is less likely where the highest and lowest levels of opportunity and willingness occur, and the most likelihood of conflict occurs in the middle where states have both opportunity and willingness, but not so much that they have become interdependent (Starr and Thomas 2005). This is shown in Table 3 (Table 3). According to Starr and Thomas conflict occurs where the border region has infrastructure in place to mobilize militarily and the area is salient, but not so salient that there is a mutual cooperation between states.

**Table 3 Conflict Index**

CONFLICT INDEX			
Conflict Value	Opportunity & Willingness Level	Conflict Likelihood	Meaning
6-7	High	Low	Easy Interaction - Salient
2-5	Medium	High	Medium Interaction- Medium Saliency
0-1	Low	Low	Difficult Interaction – Low Saliency

This study presents a way to determine a border using GIS. A border index showing high, medium and low conflict areas was created using a four point scale, and then combining the

areas value to find areas of conflict border. For example, if an area possesses both a high opportunity for interaction, value four, at a location that also has a high willingness for interaction, value three, then the values for each will be combined resulting in a value of 7 as shown in Table 1. This thesis assumes border negotiation teams have the shared desire to reduce conflict.

### ***3.3.4 Counting the Features Method versus Other Methods***

The overlapping polygons created by the five and ten kilometer buffers were counted to determine the level of opportunity and willingness in the conflict border data. The number of overlapping polygons indicates areas where opportunity, willingness or both are strong. For example, if there is a road polygon (five kilometer buffer) that overlaps the railroad polygon (five kilometer buffer), and also an airfield buffer (ten kilometer buffer), then it is counted as three polygons and determined to have a level of medium opportunity and willingness. This thesis assumes the militaries of Sudan and South Sudan have the capability to transport troops and equipment within those distances, even at the most labor – intensive level of picking up the gear and walking it some distance.

There are several ways to approach the problem of quantifying the opportunity and willingness of a region. The length of each road, river, and railroad could have been taken into consideration especially since the length of the journey matter when considering cost. This thesis did not take this into consideration because it is not known if the length of roads, railroads, and waterways within a border region contribute to the probability of conflict along a border. Additionally, this is somewhat built into the willingness portion of the framework. If the area within a border region has value to one side, then the cost to get a military operation to the location has been considered.

A network analysis could have been performed for the opportunity portion of the analysis. This would require more detailed road, waterway and railroad data than was available. For example, the state of the road and waterways, i.e. dirt road, seasonal, width, would have to be known in order to evaluate feasible routes between Sudan and South Sudan to determine opportunity.

The counting overlapping features method used in this thesis also experienced limitations. This method assumes that more of the features concentrated in one location means better opportunity and willingness and thus more conflict until the area reaches the level of mutual cooperation. This may not be the case for the people of each country or the people living in the border region. For example, perhaps to an outsider, a power plant next to a road, a key city, and an airfield would be a very important place with easy access. However, to the person living in the border region, a single waterway could be the most important aspect to their livelihood. The waterway would receive a low score on opportunity and willingness while the power plant area receives a high opportunity and willingness score.

Also this method does not take into consideration the condition of each factor. The fact that a road exists at a location does not mean the road is fit for large military trucks, for example. The existence of an airfield does not truly indicate the value of the area if that airfield is merely a small strip of dirt used for small aircraft. The data available for this thesis could not discern the condition of the factor, only the existence.

Lastly, the five and ten kilometer buffers are inherently abrupt. For example, 9.9 kilometers from an airfield, the land is valuable but at 10.1 kilometers, the area possesses zero value. This is probably not true in real life negotiations. I chose the buffers because eventually

there has to be cut off to the value of land and for the purpose of Sudan and South Sudan, the five and ten kilometers are appropriate.

### ***3.3.5 Weights***

The factors for this thesis did not have weights applied to them. Early on, weights were a consideration when evaluating the factors of opportunity and willingness. Later, it was determined that not enough information was available to accurately decide which factors were more important to the people living in Sudan – South Sudan border region. This information could only be assumed and thus were not included in the analysis. Furthermore, because the data available was not the optimal data but rather proxy data, the weights would not be as helpful as weighting the best data, such as oil field data and seasonal pastoral land claims.



## CHAPTER FOUR: RESULTS

The final result shows 76 areas where both medium levels of opportunity and willingness overlap, mostly occurring in South Sudan. According to Starr and Thomas conflict occurs where the border region has infrastructure in place to mobilize militarily and the area is salient, but not so salient that there is a mutual cooperation between states. The areas of medium opportunity and willingness would be areas negotiators would want to avoid to deter conflict.

### 4.1 Opportunity Results

The goal of the opportunity process was to find areas prone to conflict by locating medium levels of opportunity. The result counts are shown below in Table 4. A series of four maps were created to locate areas of high, medium opportunity in the border area.

Figure 5 refers to the data used in determining opportunity levels – roads, railroads, and waterways as reference (Figure 5). This map shows the visual distribution of the opportunity data throughout the border region. While there is only one railroad that actually crosses the border, there are many rivers and roads. The roads are mostly dirt roads, not paved and some of the waterways can be seasonal. Figure 6 shows the results of the five kilometer buffer around each road, railroad and waterway (Figure 6). This map shows the visual distribution of opportunity factors.

Figure 7 shows where three or more features intersect within a five kilometer buffer making a high level of opportunity (Figure 7). There are six polygons with three variables existing within five kilometers of each other. By determining high level opportunity, medium level opportunity can be found. Figure 8 shows medium levels of opportunity or where two factors exist within five kilometers of each other. There were 237 polygons with medium level opportunity (Figure 8). The opportunity for interaction between Sudan and South Sudan at these

locations is at the medium level and prone to experience conflict. Surprisingly, there are few places where the medium level opportunity actually crosses the current border, the major exception being where the Kiir River serves as the border.

**Table 4 Opportunity for Interaction Result Count**

<b>OPPORTUNITY FOR INTERACTION RESULT COUNT</b>			
<b>ROAD (RD) RAILROAD (RR) WATERWAY (WW)</b>			
<b>VARIABLES</b>	<b>COUNT</b>	<b>OPPORTUNITY</b>	<b>CONFLICT</b>
<b>RD + RR + WW*</b>	6	High	Low
<b>RD + RR</b>	24	Medium	High
<b>RD + WW</b>	150	Medium	High
<b>RR + WW</b>	63	Medium	High
<b>RD or RR or WW</b>	-	Low	Low
<b>RD = Road data; RR = Railroad data; WW = Waterway data</b>			

# Opportunity Reference Map

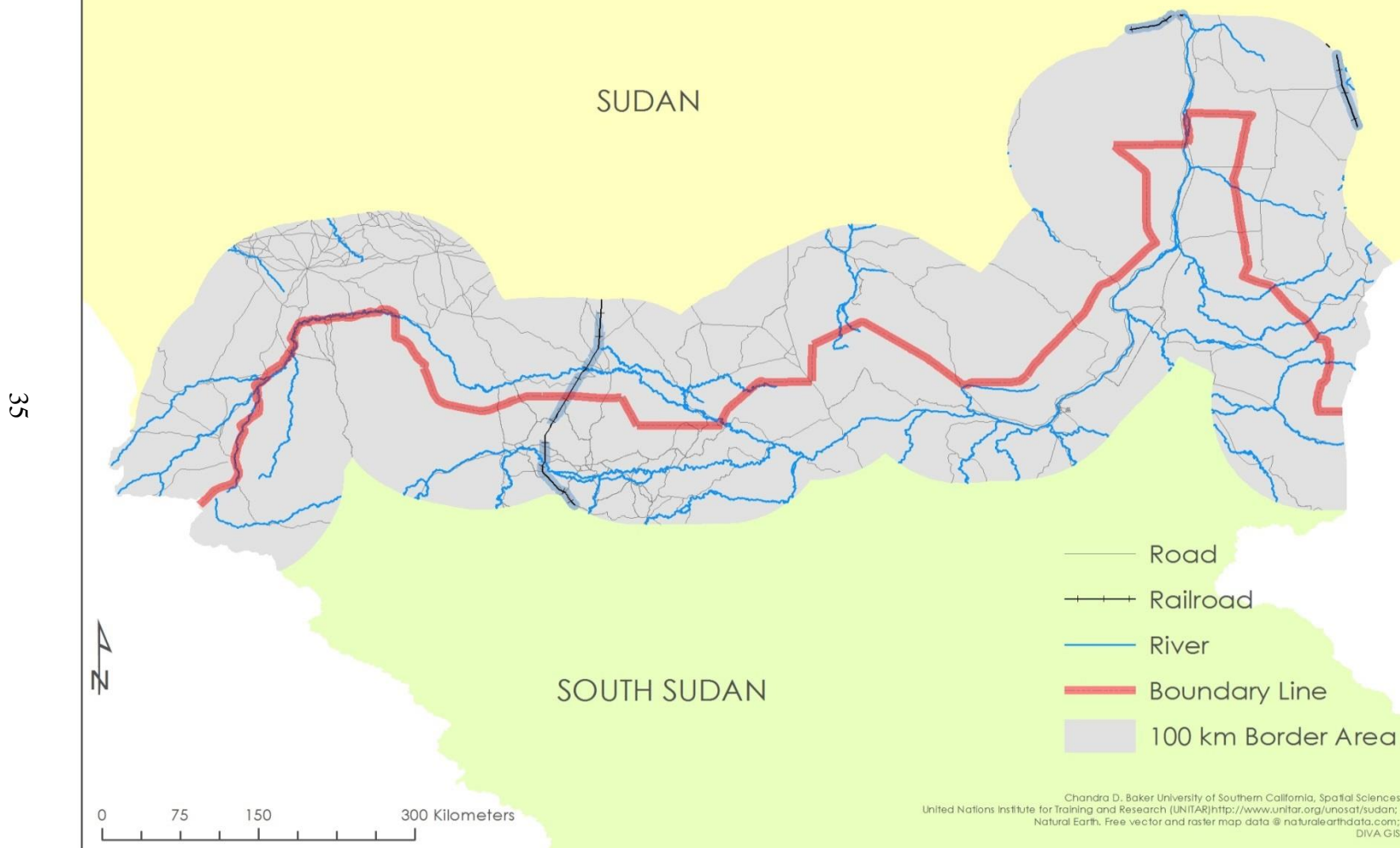


Figure 5 Opportunity Reference Map

# Opportunity 5 km Buffer Map

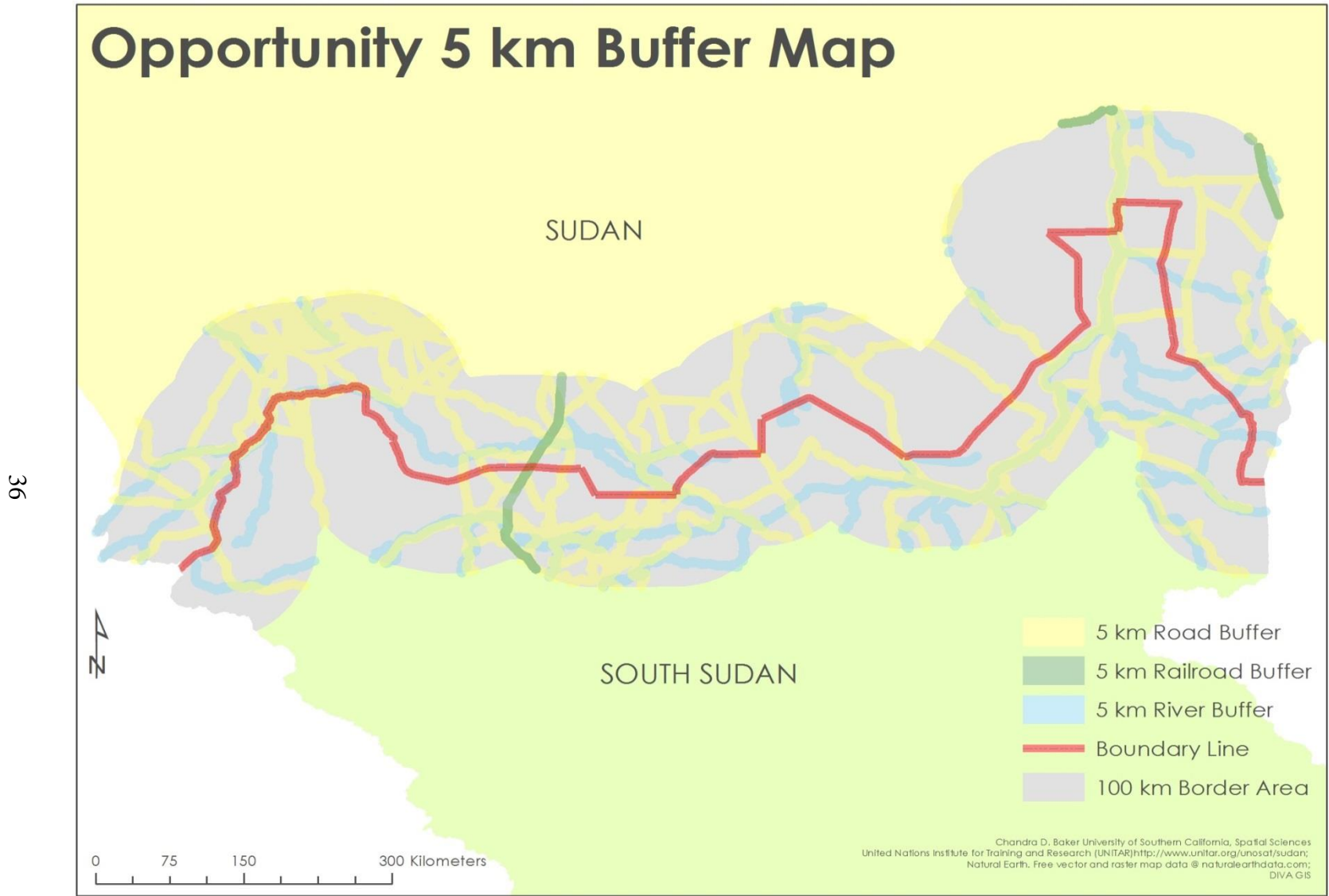


Figure 6 Opportunity 5 km Reference Map



**Figure 7 High Opportunity Areas**

# Medium Opportunity Areas



Figure 8 Medium Opportunity Areas

## 4.2 Willingness Results

Areas of high, medium and low willingness were determined by using airfield, mineral, power plants, and key cities as indicators of value. According to Starr and Thomas, the areas that are most valuable (salient) have a greater tendency for mutual cooperation and thus less prone to conflict. Areas with low value do not motivate conflict (Starr and Thomas 2005). This study focuses on medium level conflict where opportunity and motivation exist. There are 639 overlapping polygons total, of that, 398 of the polygons have 1 or 2 features in the ten kilometer area and thus low willingness, 234 polygons have 3, 4 or 5 features overlapping and thus medium level willingness, and 7 of the 639 polygons have 6-7 features overlapping and thus high willingness. Table 5 reveals the willingness result counts (Table 5).

**Table 5 Willingness for Interaction Results**

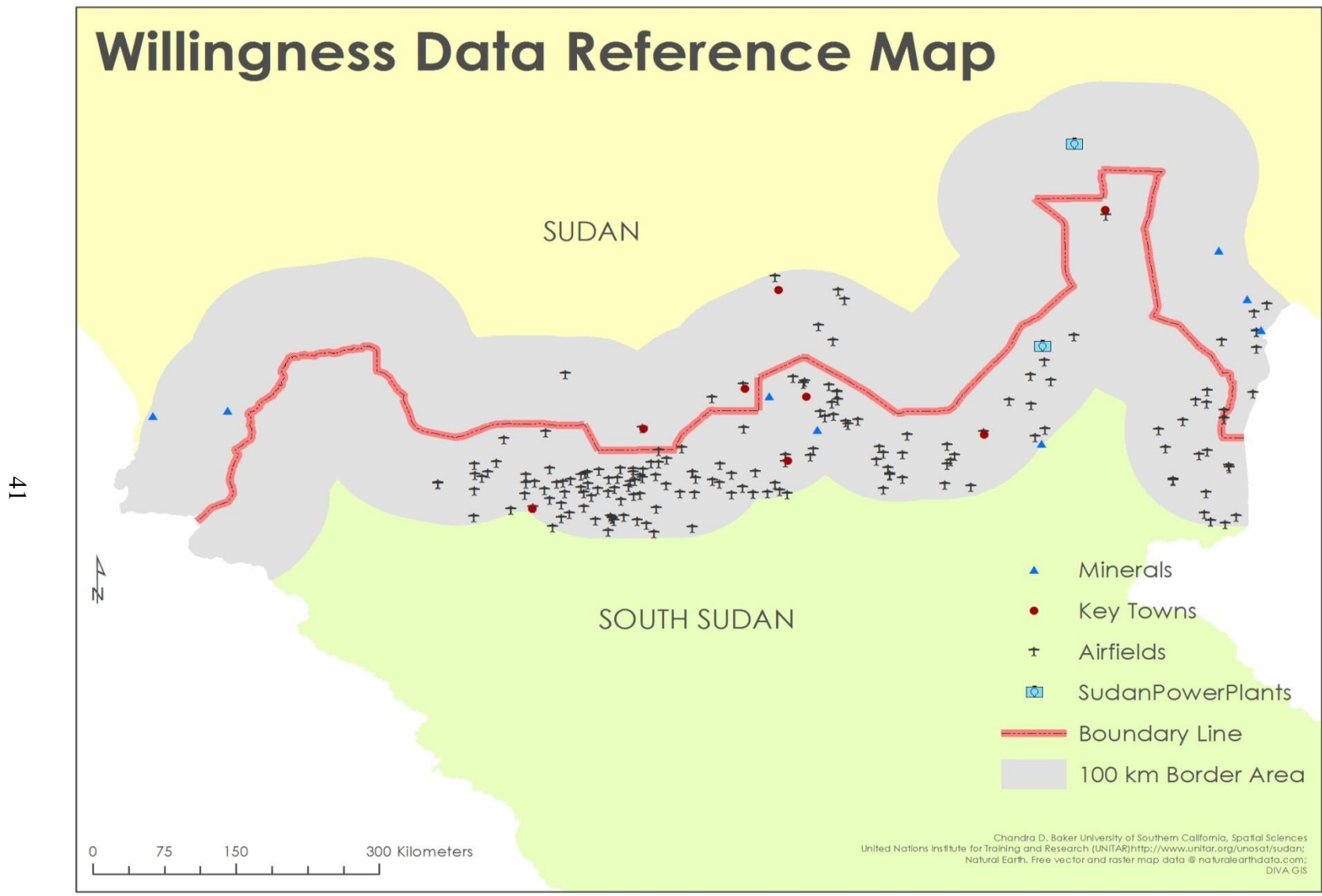
WILLINGNESS FOR INTERACTION RESULTS			
NUMBER OF FEATURES IN 10 KM BUFFER	COUNT	WILLINGNESS	CONFLICT LEVEL
6-7 Features	7	High	Low
3-5 Features	234	Medium	High
1-2 Features	398	Low	Low

Three maps were created to show the visual distribution of data and locate areas of high, medium, and low willingness in the border area. Figure 9 refers to the data used in determining willingness levels – airfields, minerals, power plants, and key cities as reference (Figure 9). This shows a majority of airfields located in South Sudan and only two power plants. Figure 10 reveals the spatial distribution of willingness features along the border area after the ten kilometer buffer and the count polygon analysis was applied. The resulting data are broken down

into the index categories of high, medium, and low (Figure 10). A high level polygon is where 6-7 buffered features overlap. A medium level polygon is where 3-5 buffered features overlap. A low level polygon is where 1-2 buffered features overlap. Figure 11 shows the only areas of medium level willingness (3-5 overlapping factors) and thus the areas that contribute to the willingness to resort to conflict due to the presence of valuable land or infrastructure (Figure 11). These polygons are concentrated in Southern Sudan and in the center of the border region, particularly the Abyei region. None of the polygons are on the border.



# Willingness Data Reference Map



41

Figure 9 Willingness Data Reference Map

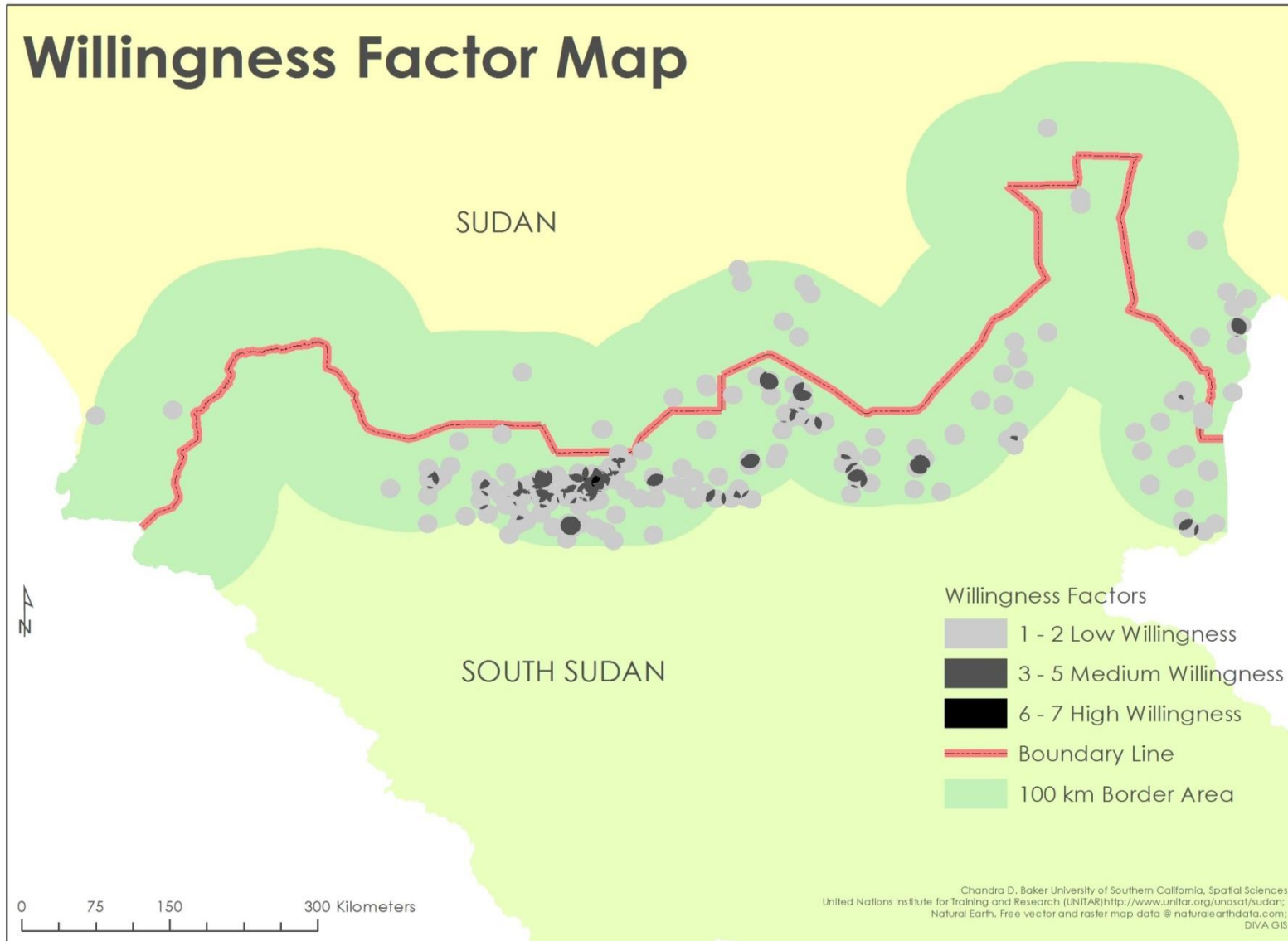
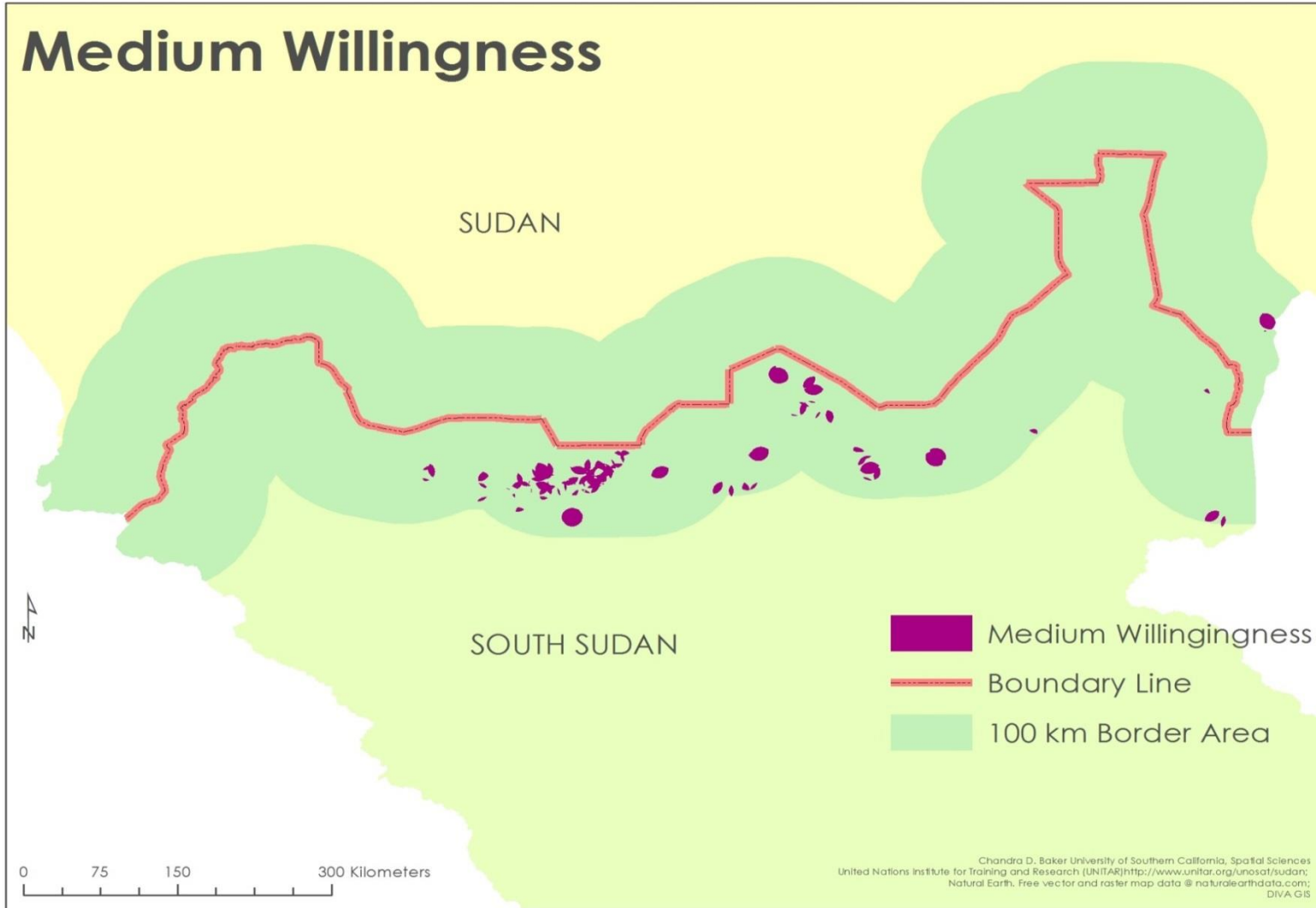


Figure 10 Willingness Factor Map



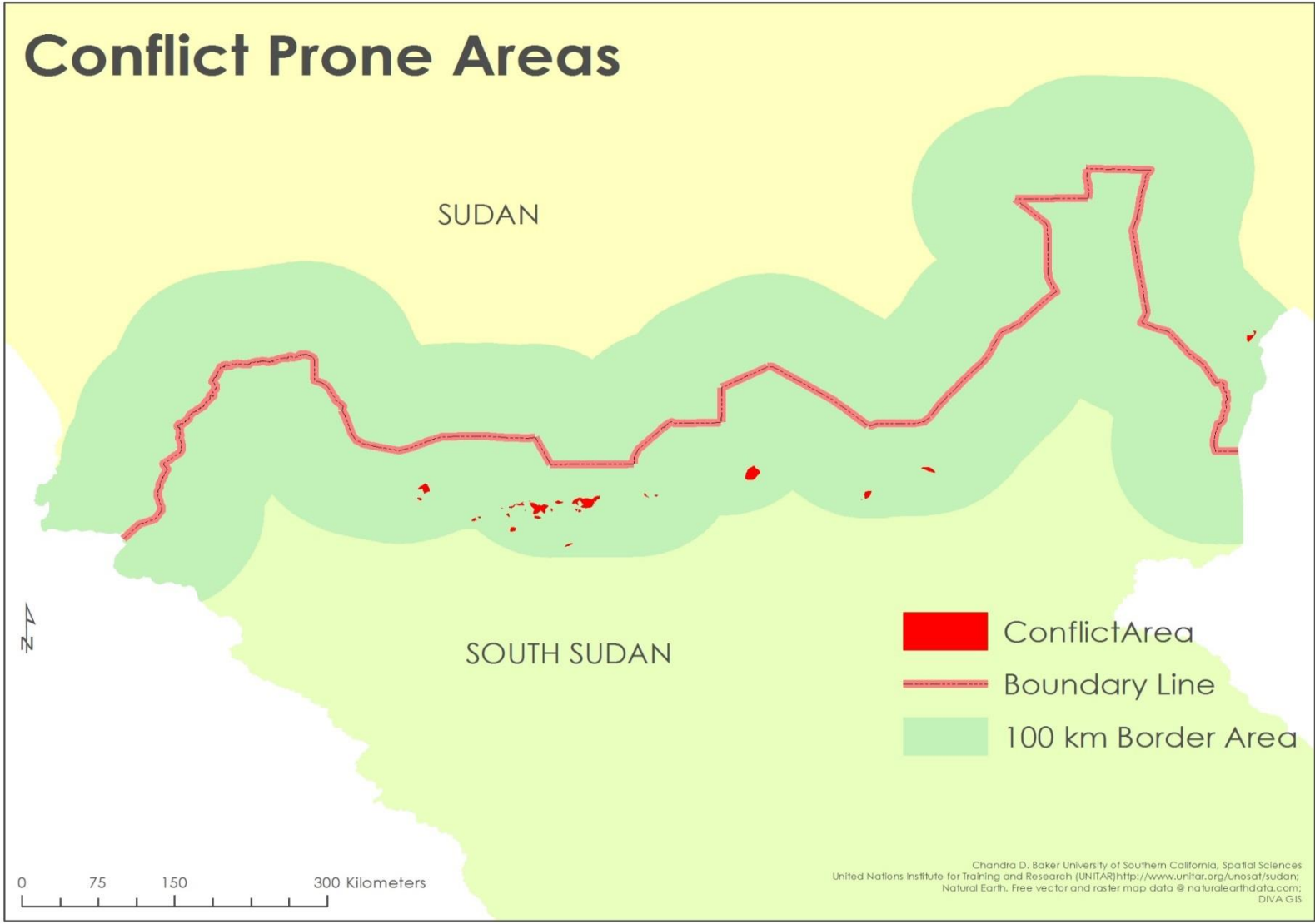
**Figure 11 Medium Willingness Areas**

### 4.3 Conflict Results

The result of combining the individual medium level opportunity and willingness analyses is shown in Table 6, The Conflict Index and Figure 12, the Conflict Prone Areas Map (Table 6) (Figure 12). These are the areas along the border that resulted in medium opportunity and medium willingness in the same overlapping location. Conflict is not likely unless the requirements of both opportunity and willingness are satisfied. Figure 12 shows where negotiators would want to avoid placing a border because the presences of both opportunity and willingness exist at a level prone to conflict (Figure 12). The Conflict Index shows the number of overlapping polygons in the high and medium ranges. There is no value for the low opportunity and willingness overlap.

**Table 6 Conflict Index**

<b>CONFLICT INDEX</b>				
<b>Conflict Value</b>	<b>Count</b>	<b>Opportunity &amp; Willingness Level</b>	<b>Conflict Likelihood</b>	<b>Meaning</b>
<b>6-7</b>	0	High	Low	Easy Interaction - Salient
<b>2-5</b>	76	Medium	High	Medium Interaction- Medium Saliency
<b>0-1</b>	-	Low	Low	Difficult Interaction – Low Saliency



**Figure 12 Conflict Prone Areas**

## **CHAPTER FIVE: DISCUSSION**

This thesis demonstrated one way that GIS can be used to determine areas to place or avoid placing a border by examining data along the conflicted Sudan and South Sudan border. The analysis is based on Harvey Starr's Opportunity and Willingness Index (Starr 2002) and Starr and Thomas' findings that conflict is most likely to occur at medium levels of opportunity and willingness (Starr and Thomas 2002).

### **5.1 Key Observations**

This thesis demonstrated that GIS is useful in identifying areas of medium opportunity and willingness which have proved to be prone to conflict. Such areas could not be easily identified without the aid of GIS. This thesis demonstrated how Starr and Thomas's opportunity and willingness model could be adapted from a worldwide study of general border conflicts to a specific border conflict. By isolating areas of medium willingness and medium opportunity, conflict prone areas in the border region were identified. Such data could empower negotiators to consider key overlaps of opportunity and willingness factors. The goal of this thesis was not to determine the final border, but rather to show how GIS can be utilized in border placement.

Data findings in this thesis have shown that areas of medium level opportunity and willingness are located south of the current border in Sudan. This result suggests three likely outcomes. First, the result may indicate that the current border location has already been mitigated for the opportunity and willingness factors, advertently or inadvertently. Perhaps, if the current border bisected the medium level of opportunity and willingness regions to the south, there would be more conflict in the area. Second, the result could be a factor of the border area's remote nature and lack of development and thus lack of data. Third, it may be that it is not enough to simply avoid placing a border through an area of medium opportunity and willingness

but rather make it might be necessary to make sure that those areas do not exist in the border region in order to reduce conflict.

The implication of this study's findings are that the opportunity and willingness metric is limited in its ability to establish a conflict-free border. The metric may be able to mitigate some drivers of conflict but every border and the factors considered are different. Had the opportunity and willingness metric been able to fully mitigate conflict in border areas, we would not see border conflict in the Sudan – South Sudan border region, because the current border does not bisect the areas of medium opportunity and willingness.

Additionally, since the start of this thesis, civil war has broken out in South Sudan. This has made distinguishing internal conflict in South Sudan from international conflict over the border between Sudan and South Sudan difficult. It is difficult to determine if the conflict in the border region is a result of the CPA not including an agreed upon border or civil war internal to South Sudan or both.

It is difficult to use GIS to model cooperation between two states. This analysis is spatial in nature and does not account for non-spatial cooperation between the states such as free markets and treaties that facilitate cooperation between states but are not spatial in nature (Starr 2005).

## **5.2 Recommendations for Future Research**

Moving forward, this analysis should be tested on several conflicted border regions. The general framework for utilizing GIS as a way to determine a border has been constructed through this thesis and would translate into any region using the relevant factors to that location. It would be interesting to see Starr and Thomas's opportunity and willingness concept adapted to other conflict regions and other type of border dispute such as Kosovo and The Republic of Serbia

which is another example of a territory that succeeded from a nation to establish its own nation, much like Sudan and South Sudan. Another example of a border dispute where the opportunity and willingness framework can be applied is the Kashmir region in India. Here, three nations, Pakistan, India, and China are fighting over a territory while some of the people in that territory seek a sovereign government.

Available data changes from location to location and the available data for Sudan and South Sudan border is sparse and lacking in reliability. It would be valuable to revisit this region after entities such as Open Street Map – Sudan and South Sudan is complete and more reliable data is available (© OpenStreetMap, 2015). In addition, the factors chosen for this thesis were chosen based on availability rather than regional factors that contribute to the perceived value of land in the border region. This is especially true for the willingness analysis. The value of land in the border area exists in oilfields, oil wells, pastoral land, and cultural identity. This data was not available and therefore had to rely on proxy data for this analysis. It would be interesting to see how the Conflict Prone Areas would change when using data more reflective of the ground situation in Sudan and South Sudan. Additionally, factoring in non-assumed weights to the analysis would allow for a more in-depth reflection of the border situation. This would also be a tool for the negotiator to evaluate the effects of changing a particular border scenario.

There are many ways to quantify opportunity and willingness. Further research is needed to explore these methods such as taking into consideration the length of factors like roads, railroads, and waterways or using a network analysis to determine routes for the ease of interaction. This would allow the analysis to better demonstrate the opportunity for interaction possessed by each country; however, more data regarding the condition of each factor would be needed.



Within the literature on opportunity and willingness, scholars continue to disagree on the best way to conceptualize borders. This thesis can be analyzed further by comparing the conflicting literature from Deutsch and Vasquez to Starr and Thomas using a case study such as Sudan and South Sudan. According to Starr and Thomas, conflict occurs where the border region has infrastructure in place to mobilize militarily and the area is salient, but not so salient that mutual cooperation between states has occurred as shown in Figure 1 (Starr and Thomas 2005). Deutsch (1970) claimed that easier border crossings (high opportunity) and an increased saliency (high willingness) of the border region equate to a border which is *less* likely to experience conflict (Starr and Thomas 2005). Deutsch based this claim on the idea that interdependence and integration can be facilitated through highly permeable and salient borders thus making conflict less likely (Starr and Thomas 2005). On the contrary, Vasquez (1993) claimed that easier border crossings (high opportunity) and an increased saliency of the border region (high willingness) are associated with a border which is *more* likely to experience conflict (Starr and Thomas 2005). Vasquez based this claim on the idea that border regions with significant access between populations paired with high value of the border region land and resources result in a greater likelihood of conflict.

In all, further research is needed to examine where GIS can be ideally integrated into the process of border negotiations. The future of GIS research and its role in border negotiations is limited only by the data available to that region. As countries understand the importance of spatial data collection and dissemination, research can expand into creating more robust models and interactive maps for on-demand negotiation changes.

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