ECONOMIC VALUE OF SOIL WATER ENHANCEMENT FROM BRUSH REMOVAL ON THE PEDERNALES WATERSHED

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by

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Success in life not only comes from within through tenacity and self motivation but also relies on the unconditional confidence and encouragement received from family and friends, and for this, I am forever grateful. They have given me the greatest gift a person could receive, they believed in me.

CONTENTS

TABLES

FIGURES

CHAPTER I

PROBLEM STATEMENT

General Problem

The interest in brush management on Texas rangelands for the purpose of water conservation and range improvement has increased in recent years due to demand from governmental and municipal agencies. The relationship between rangeland brush infestations and potential water yield continues to be studied and debated by researchers. However, the appropriation of over 37 million taxpayer's dollars for brush control by the Texas Legislature in 1999 and 2002 clearly shows a widely held belief that woody plants "waste" water that is drastically needed by Texans (Hamiltion, 2004). It also demonstrates a belief that billions of gallons of water could potentially be conserved by the effective removal of invasive noxious brush species.

The idea of managing brush on Texas rangelands to increase water availability and herbage production has been around for decades while being heavily influenced in the last twenty years due to significant technological advancements in machinery, chemical compounds, and government intervention. It is imperative to understand that the productivity of land, whether for water conservation or livestock production, benefits society as a whole and should be considered a socio/economic issue. Brush management efforts must be viewed as an integral part of the overall system for wise, efficient use and conservation of grassland (Scifres, 1980).

Documentation by early European settlers described Texas rangelands as grasslands (Smeins, 1997). However it is not clear as to how the land looked historically due to biased opinions and comparisons made by early explorers. A grassland with a few clusters of trees could be described as an open grassland by someone from an eastern forest or as a woodland by a farmer (Smeins, 1997). Due to drastic differences in conflicting reports it is hard to say how and when the rangelands of Texas became encroached with brush species.

It is a common belief that Texas rangelands were changed from "natural" grasslands to a land covered with invasive and dominating species of brush once they were settled by Europeans. Since 1900, the rangelands of Texas have continued to experience many changes. Many of these changes can be attributed to the livestock industry and overgrazing by livestock (Smeins, 1997). Once overgrazing occurs, noxious species which are rejected by most species of animals as usable herbage overtake the land. Over the last 200 years, brush populations have steadily increased with fire suppression and the decline of an agricultural based economy.

Texas rangelands have a much different purpose in today's world than they did a century ago. The main focus in the last century was the production of livestock, mainly sheep and cattle. Many of the once open grasslands covered by massive herds of cattle are now inundated with sprawling suburbs and broken up into small farms as opposed to large ranches. With this evolution the importance of rangelands and their purpose of providing high quality herbage diminished with the once legendary cattle kings.

Throughout the past 100 years there have been several ideas and eras concerning brush control. In the post-World War II period of the 1940s and 1950s, the dominant philosophy was to eradicate brush to produce herbage for, and to make money from, livestock production (Hamilton, 2004). It became apparent in the 1960s and 1970s that the total eradication of brush was an economically and biologically impossible task. In the late 1970s and early 1980s, brush management was transformed from an arduous task of eradication to environmental management and wildlife habitat manipulation (Hamiltion, 2004).

The economics of brush control has been evaluated from the view of society, landowners, and wildlife. It is important to note that all of these interests coincide and must be properly managed to produce an optimal economic solution. In 1964, 88.5 million acres, representing a total of 82% of Texas grasslands, were infested by one or more invasive brush species (USDA, 1988). In 1982, the Natural Resource Conservation Service (NRCS) estimated that 101 million acres of the Texas rangelands were infested with brush, up 12% from the previous study. These numbers would continue to rise over the next twenty years despite various control measures.

The process of clearing brush, regardless of the method used, is costly. Because most landowners do not receive their primary source of income from the land, it is often difficult to convince them to make an initial investment in brush control, especially when returns are uncertain. The management of range resources has developed into two main reasons for brush management: enhanced rangeland suitability and or productivity of wildlife and providing sources of surface and/or ground water recharge (Hamilton, 2004; Smeins, 1997). The need to clear brush to enhance water yields from rangelands was a dominating factor in the state's development of a cost-share program to assist landowners in brush control. In 1985, the 69th Texas Legislature passed Senate Bill 1083 which created the Texas Brush Control Program (TSSWB 2004). This program was designed to increase water availability across the state through various brush control practices on selected watersheds. The Texas State Soil and Water Conservation Board was given authority to delegate certain funds and priorities for cost-sharing brush control projects to local conservation districts.

In 1986, in accordance with Section 203.051, the TSSWCB prepared and adopted the State Brush Control Program. The funds available from this act allowed landowners to set up a cost-share agreement with the government where the State pays up to 80% of the project's cost (TSSWCB 2004). However, the brush control project was limited to certain watersheds (see Figure 1.2) that receive between 16 and 36 inches of rainfall per year (see Figure 1.1). General revenue allocated to the program from 2000-2005 totals $37,048,599. Since 1999, the Brush Control Program has cleared 582,642 acres of the 675,386 acres under contract (TSSWCB, 2004).

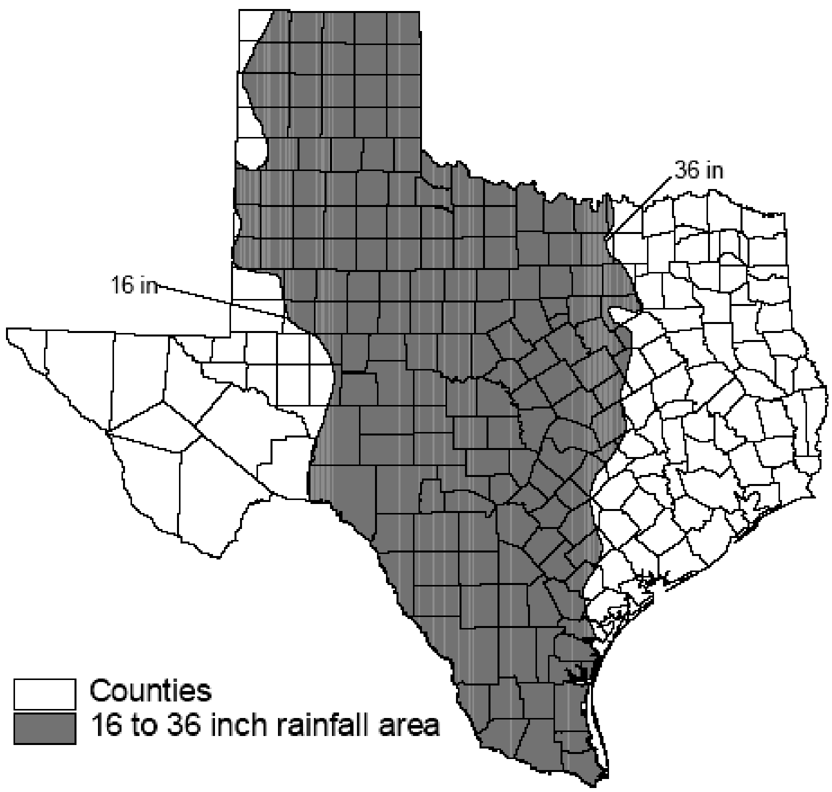

Figure 1.1. General Brush Control Area as Defined by Rainfall.
Source: Texas Soil and Water Conservation Board, 2004

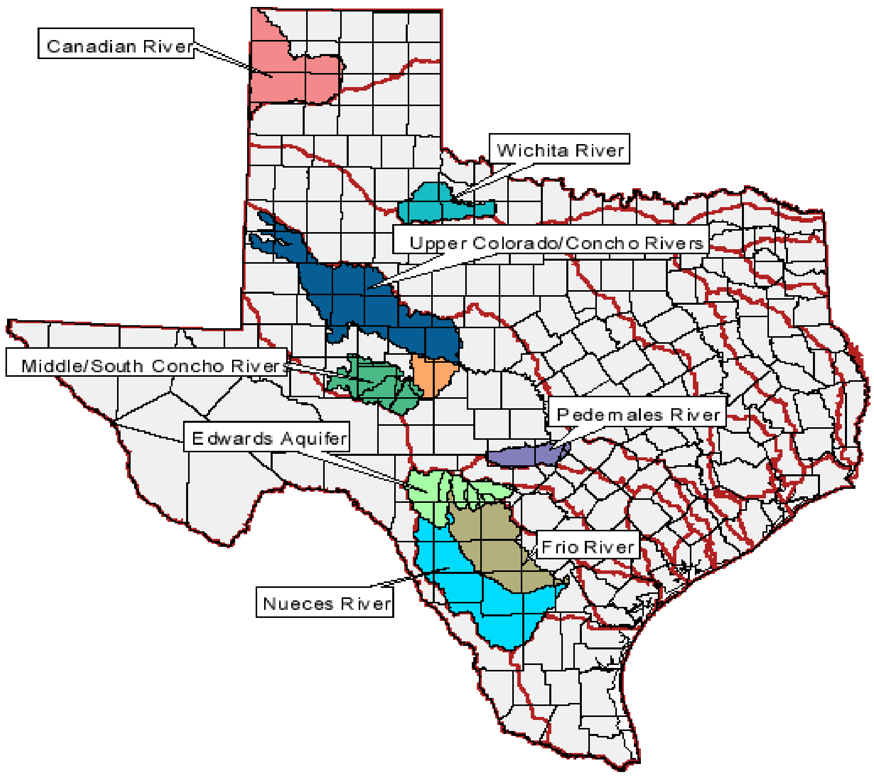

Figure 1.2. Specific Watersheds of Concentrated Effort.
Source: Texas Soil and Water Conservation Board, 2004

One of the major species of brush invading Texas rangeland is Ashe (blueberry) juniper (Juniperus ashei Buchholz). The habitat of this noxious species ranges from southern Missouri, through Arkansas into Oklahoma, across central Texas and into Mexico and Guatemala (Smeins, 2001). Its greatest abundance in Texas is found on the eastern and southern Edwards Plateau located in the heart of the Texas Hill Country. It is a hardy species which typically grows on shallow rocky soils, but has the potential to survive on a variety of soil types. In 1991, the Texas Soil and Water Conservation Board estimated that Ashe juniper infested over 6.7 million acres in Texas alone.

Researchers and society alike have been placing emphasis on our most precious resources for decades with the evidence of continuing population growth and urban sprawl. It is estimated that the population of Texas alone will double in the next 25-50 years. Central cities such as Austin and San Antonio have developed at astounding rates into major metropolitan areas with a high demand for a continuous water supply.

San Antonio is the tenth largest city in the nation and the only major city that obtains all of its water from a single aquifer, the Edwards Aquifer (Texas Water Development Board 1991). Water supplies for these major cities depend heavily on aquifer recharge and runoff from Texas rangelands. Today, the Texas State Soil and Water Conservation Board estimates that Texas alone uses nearly 3.5 trillion gallons of water annually. As the water needs of Texans increase there will be a continued need to evaluate the need for brush control, not only from an ecological standpoint, but also from an economical and financial basis.

Specific Problem

Although the government initiated brush control projects throughout the state, the programs that received the most attention were those nearest to populated cities, areas with moderately high rainfall, and regions with potential to have the highest yield of water from the brush clearing program. In 1999, the legislature designed feasibility studies for eight watersheds across Texas, one of them being the Pedernales Watershed Brush Control Project. The U.S. Geological Survey estimated the boundary of the watershed to encompass approximately 815,000 acres (1,273 square miles) of central Texas. As Figure 1.3 indicates, the watershed is contained primarily in Gillespie and Blanco counties, however; the watershed also includes small portions of Burnet, Hays, Kendall, Kerr, Kimble, and Travis counties (TSSWCB, LCRA, 2004). The watershed flows eastward and empties into Lake Travis, a major source of water for Austin. The Pedernales River is the main waterway in the watershed and is joined by the Colorado River in western Travis County. The river's course is 951 miles long; 391 miles of that is perennial flow (TSSWCB, LCRA, 2004).

In September of 2002, the Pedernales River watershed brush control project was initiated to provide Lake Travis and the Austin municipal district with a more reliable supply of water. The project estimated that 62,000 acres of brush could be cleared to produce an estimated 317,000 acre-feet of water annually (TSSWCB, LCRA, 2004). Additional funding will be required to clear the additional 140,000 acres in the watershed. As of 2004, 55,696 acres of brush had been cleared within this watershed.

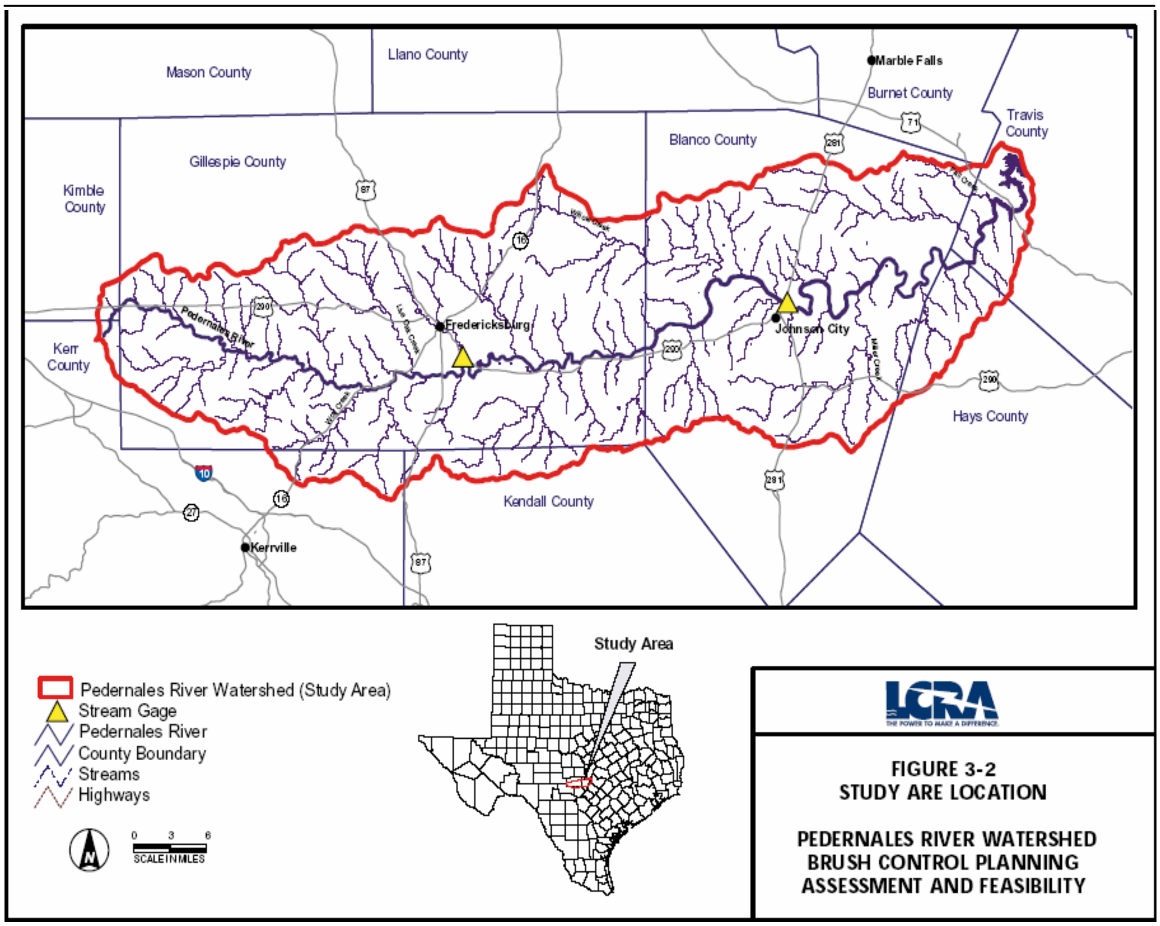

Figure 1.3 Pedernales Watershed.
Source. Lower Colorado River Authority.

Although several studies have been conducted to estimate the amount of surface water yield and the associated cost and returns that could result from removing brush, there has not been a study specifically looking at soil water content after the removal of Ashe juniper. Bach and Conner (2000) analyzed the cost of an additional acre-foot of surface water associated with the cost-share program for various species of brush on the Pedernales Watershed. They concluded that the average cost of an additional acre-foot of water was $16.41 over the entire basin, with a range of $5.92 to $6,139.23 per acre-foot.

Within mechanical brush control there are a variety of styles, equipment, and procedures, and as a result, each project has different aesthetic characteristics when completed. In many cases the differences in characteristics are based upon the landowner's expectations, the contractor's ability, and the type of equipment being used. These three factors coincide to give each project a unique aesthetic appearance. In many cases, one of the main objectives of the landowners' aside from removing the brush is to maintain a pleasing appearance to the land and to make the land more accessible. However, these wants are limited by the operator's ability and the terrain of the land.

In most cases, when heavy bulldozers or hydraulic excavators are used, the turf is greatly disturbed upon the removal of brush. When Ashe juniper is removed by means of a bulldozer there is generally a pit left behind where the trees' root system once was. Depending on the size of the tree and the soil type, these holes can vary in size. These pits can act as reservoirs during times of rain and, thus, can potentially increase on-site water retention and result in greater herbage production. However, the downside to the pitted terrain is lack of accessibility and displeasing aesthetic appearance. In contrast, either by the operator's ability or as a result of the landowner's instruction, these pits are covered to give the land a smooth surface to enhance one's ability to traverse the treated area.

It is these differences following mechanical grubbing of Ashe juniper that will be analyzed in this particular study. A comparison will be made between three treatments, one area will be left rough and pitted, one will be deliberately smoothed, and another will be left non-treated entirely. Additional comparisons will be made as to how each treatment interacts with the overall hydrology of the land and herbage production.

The purpose of this study is to analyze the amount of soil water content and herbage production following Ashe juniper removal and determine the economic costs and potential returns to the landowner as a result of the project. The results of this study will aid the underlying problem of how to conserve water more effectively and economically. With these data, researchers can accurately depict the gains returned to the landowner after the projects have been completed. Aside from the landowner, some estimates can be made to determine the various aspects of water conservation and how brush clearing in general will affect society as a whole, both from the stand point of a water supply and water availability. Additionally, determinations can be made about the effectiveness of government intervention and the cost-share program as a whole.

Objectives

General Objective

The overall objective of this project is to determine the expected level of benefits and costs to the landowner in terms of enhanced productivity of the land and additional water gained from clearing Ashe Juniper in the Pedernales Watershed under a governmental cost-share program.

Specific Objectives

The specific objectives are to:

1. Determine the soil water content (%) as a result of mechanical brush control under three scenarios.
2. Estimate the potential economic returns to the landowner in terms of enhanced productivity as a result of removing Ashe juniper.

CHAPTER II

LITERATURE REVIEW

This section presents information regarding past research on brush control specifically related to the control of Ashe juniper. The research is broken down into categories based on certain aspects of brush control. First, the methods and effectiveness of juniper control will be reviewed. Second, the economic and financial aspects of brush control. Third, potential water gains from removing invasive brush species will be presented.

Methods and Effectiveness

The control of most brush species breaks down into four main categories; mechanical, chemical, prescribed burning, and biological. Throughout the past 60 years there have been drastic improvements in the ability of heavy equipment to effectively clear brush. Most of these advancements came in the form of faster, more powerful, and more energy efficient hydraulic equipment. However, as the demand for specific equipment for brush control became more evident, many companies modified existing equipment to suit the needs of contractors and landowners. Recent engineering innovations, such as front-end loaders with smaller track cleats or rubber tires aided with hydrostatic steering (each track driven by a separate hydraulic circuit), have provided high maneuverability while minimizing surface damage (Ueckert, 2001).

The simplest method is selective brush control with either a hand axe or chain saw (Scifres, 1980). The first and most widely accepted method of removing juniper is by mechanical means. However, bulldozers and/or tractors can be equipped with a variety of special equipment such as root-plows, grubbers, shears, and shredders (Scifres, 1980).

Chaining, tree dozing or grubbing, bulldozing, and root plowing have been the traditional methods used for controlling juniper (Scifres, 1980). Most of the equipment being used to clear juniper follows a process of uprooting the tree by a method of grubbing. Grubbing and piling brush is often done with a bulldozer. This can also be achieved by a variety of equipment ranging from a light weight farm tractor to extremely heavy duty bulldozers and excavators weighing in excess of 30 tons.

More recently there have been advancements in small equipment used to shear Ashe juniper at ground level. Since Ashe juniper does not resprout from the basal crown, shearing is highly effective. A skid-steer loader accomplishes this by using hydraulic shears. The low cost of operation and high maneuverability of the skid-steer renders this method popular with contractors (Wiedemann, 2004). This process is sometimes preferred over traditional equipment in that it does not destroy the turf to the degree of other common methods.

In October of 1993, a stand of large juniper was cleared by chaining in south central Oklahoma. Wiedemann (2001) indicated that the process was done by pulling a 180 foot 2 1/16 inch chain weighing about 4000 lbs between two D8 crawler tractors. The stand of juniper consisted of mature trees with 90% of the trees being 12-25 ft tall. The results showed that after 17 months the percent mortality was 98% using prescribed burning as a follow-up treatment (Wiedemann, 2001).

In the North Concho River Watershed Project, Walker (2004) did an analysis of the overall effectiveness of different treatment options for brush control. In this study, which included 26 different treatments, Walker found that mechanical methods were most effective with 93% of the treatments being considered a success. However, individual treatments varied with density, population, and equipment used (see Table 2.1).

Economic and Financial Considerations

At the base of the current Texas Brush Control Program is the North Concho River Watershed Initiative. This was the first and most dramatic effort by the State to reduce invasive brush in Texas. This project was appropriated in 1999 and was given a two-year program budget of $7 million dollars. The main reason for this program was the drastic need for water by citizens of San Angelo from a former and nearly non-existent water source outside the city, the O.C. Fisher Reservoir. This lake was reaching drastically low levels and was, until recently, only at 6% capacity (TSSWCB, 2004)

The North-Concho watershed consists of 950,000 acres with an estimated potential water gain of up to 26,700 acre-feet per year from the project (TSSWCB, 2004). This project has continued to be analyzed and, as a result, several additional watershed brush control projects across the state have been initiated.

There are many economical and financial considerations with regard to brush control. These considerations and responsibilities are not only placed on the landowner, but also on the public sector and government. Kennedy (1970) indicated that if control cost for brush exceeded $10 per acre for a high level of infestation (removing 50% to 75% canopy) that it would not be economically feasible without assistance from non-ranch sources. Without private, public, and governmental entities working together it will not be possible to initiate brush control programs in an economical manner.

Table 2.1 Percent Success of Areas Surveyed for Different Brush Control Practices in the North Concho Brush Control Program.

Method	Number Surveyed	Percent Success
	Mechanical	
Dozer	5	80%
Excavator	6	100%
Skid-Steer	1	100%
Track Loader	1	100%
Hand Grub	1	100%
Sub-total Mechanical	14	93%
	Chemical	
Mesquite IPT	5	60%
Juniper IPT	1	0%
Sub-total Chemical	6	50%
	Mechanical & Chemical	
Shear & Spray	7	36%

Source: Walker, 2004

It is important to understand that brush control of any type is costly and costs increase with the density of the brush infestation. Before the initiation of government-funded brush removal programs landowners may have been deterred by the high cost of brush control. However, with recent evolutions in cost-share programs, landowners can expect up to 80% of the cost for certain brush control projects to be covered by the government.

The most specific and comprehensive study thus far on the Pedernales Watershed Brush Control Program was done by Bach and Conner (2000) using the Soil and Water Assessment Tool (SWAT). This study covered several important aspects of brush control in the Pedernales Watershed including cost-share, landowner returns, and cost of potential water gained. As Table 2.2 indicates, State cost-share values in the Pedernales watershed can be as low as $49/acre or as high as $128.56/acre depending on the type and location of the brush control project (Bach and Conner, 2000). This study also estimated that the total control cost in the Pedernales Watershed ranged from $70.42/acre for moderate mesquite densities treated with herbicide to $160.42/acre for treatment of dense juniper stands by mechanical methods.

One of the landowner's main sources of investment recovery for brush control is the increased herbage production on the land allowing ranchers to increase the number of livestock/acre, thus increasing per acre income. Bach and Conner (2002) estimated that the returns through enhanced livestock production could range from $21.22/acre to $40.61/acre, depending on the original brush density of the project.

Table 2.2. Landowner / State Cost-Shares of Brush Control for the Pedernales River Watershed Project

Brush Category	Control Practice	Cost ($/Acre)	Share ($/Acre)	Landowner Percent	State Share ($/Acre)	State Percent
Heavy Cedar	Doze or Shear	120.42		0.26	88.56	0.74
	Doze - Heavy	160.42	31.86	0.2	128.56	0.8
Heavy Mesquite	Chemical	100.32		0.4	59.71	0.6
	Rootplow	128.91		0.32	88.3	0.68
	Doze & Plow[1]	158.91	40.61	0.26	118.3	0.74
Heavy Mixed Brush	Chemical	100.32		0.33	67.01	0.67
	Rootplow	128.9		0.26	95.6	0.74
	Doze & Plow[1]	158.91	33.31	0.21	125.6	0.79
Moderate Cedar	Doze or Shear	80.42	25.74	0.32	54.68	0.68
Moderate Mesquite	Chemical	70.42	21.22	0.3	49.2	0.7
Moderate Mixed Brush	Chemical	70.42	21.22	0.3	49.2	0.7
Averages:		16.22	32.15	0.29	84.07	0.71

Source: Bach and Conner "Pedernales River Watershed-Economic Analysis" 2000

[1]Average is calculated as simple average, not relative average. The averages are based on the Heavy Mesquite Chemical comprising 50% of the cost for Heavy Mesquite control and Heavy Mesquite Mechanical comprising the other 50% of the cost for Heavy Mesquite. Also, it is assumed that Mechanical and Chemical comprise 50% each of cost for Moderate Mesquite control. Actual averages may change depending on relative amounts of each Type- Density Category of brush in each control category.

As shown in Table 2.3, this study also estimated through cost-share analysis that the cost of added water ranged from $5.92 to $6,139.33 per acre-foot depending on the sub-basin with an average of $16.41 per acre-foot of water gained. The total cost of the Pedernales Watershed project is currently at $17,096,351.

Reinecke, Conner, and Thurow (2001) conducted a study on the Edwards Plateau regarding the economics of Ashe juniper control under six different management scenarios. The percent canopy cover on the six different sites ranged from 3% to 75%. The economic evaluation was based upon grazing lease revenues and costs for the management practices. Stocking rates estimated lease revenues and were derived from estimates on herbage production based on the different densities of brush. Cost associated with continual management of the area was included along with lease revenues of $8.33 per animal unit month (AUM). Their results indicate that for juniper canopy covers ranging from 3% to 75%, annual net cash flows using rotational grazing could reach $23.51 and $56.13 per acre, respectively. These results indicated that once a site reaches a situation where mechanical means are necessary to reduce the brush dominance (stands with>75% canopy cover) cash flows are dramatically decreased, but the additional grazing lease revenues resulting from the implantation will equal, or in many cases exceed, the initial cost.

Table 2.3 Estimated Cost of Added Water from Brush Control by Sub-Basin (Acre-Foot) for the Pedernales River Watershed Project

Sub-basin	Total State Cost	Avg. Annual Water Increase	10 Year Added Water	State Cost for Added Water
No.	(Dollars)	(Acre-Feet)	(Acre-Feet)	(Dollars Per Acre-foot)
1	938,379.39	10,771.59	84,039.97	11.17
2	1,076,826.70	11,754.85	91,711.35	11.74
3	862,557.20	3,600.07	28,087.72	30.71
4	579,534.36	3,693.20	28,814.38	20.11
5	1,063,687.50	8,020.86	62,578.79	17
6	416,425.30	6,378.46	49,764.73	8.37
7	1,503,135.60	6,575.01	51,298.20	29.3
8	231,102.24	438.94	3,424.63	67.48
9	172,041.49	2,976.66	23,223.91	7.41
10	731,119.03	10,740.37	83,796.40	8.72
11	55,839.22	252.78	1,972.21	28.31
12	923,234.38	10,248.74	79,960.65	11.55
13	124,894.59	140.66	1,097.39	113.81
14	495,537.10	3,437.90	26,822.51	18.47
15	450,494.89	1,480.69	11,552.35	39
16	595,143.09	688.84	5,374.35	110.74
17	0	0	0	0
18	78,285.36	1,694.60	13,221.30	5.92
19	22,506.29	166.41	1,298.36	17.33
20	409,738.01	8,000.00	62,416.03	6.56
21	0	0	0	0
22	534,242.78	10,097.56	78,781.14	6.78
23	398,726.56	2,107.99	16,446.50	24.24
24	451,531.88	4,696.92	36,645.35	12.32
25	353,602.60	2,466.43	19,243.12	18.38
26	310,622.73	6.49	50.6	6,139.23
27	341,117.23	4,150.06	32,378.76	10.54
28	27,700.89	5.7	44.5	622.45
29	488,733.87	3,293.75	25,697.85	19.02
30	274,075.84	1,461.41	11,401.92	24.04
31	304,869.05	996.19	7,772.28	39.23
32	269,065.96	4,651.95	36,294.50	7.41
33	102,060.22	921.88	7,192.49	14.19
34	1,689,484.70	7,505.34	58,556.69	28.85
35	820,034.68	75.6	589.87	1,390.20
Totals:	$17,096,351.00	----------	$1,041,550.82	Average: $16.41

Source: Bach and Conner 2000 “Pedernales River Watershed-Economic Analysis”

Rowan and Conner (1994) studied the feasibility of controlling Ashe juniper stands in the Texas Edwards Plateau. The study analyzed four different control scenarios, each at different levels of canopy cover and tree ages with different treatment methods. The first scenario considered a 4.3% canopy cover of small juniper trees treated using prescribed burning, and a 7.7% canopy cover that was treated with chaining and prescribed fire. The second scenario examined mechanical control of a stand with 16.5% canopy cover followed up by a prescribed burn. The third scenario included a stand with 32.2% canopy cover cleared by dozing or hand-cutting and followed by a prescribed burn one year later. The fourth scenario evaluated the control of a stand with 100% canopy cover using three different control methods: (1) dozing the first year and prescribed burning the second year, (2) dozing the first year and prescribed burning the second year, followed by a prescribed burn in the seventh year, and (3) hand-cutting the first year and prescribed burning the second year. The study estimated the internal rates of return over a 12-year planning horizon. In summary, they concluded that for treatment of juniper stands, which have canopy cover of 16% to 32%, to be economically feasible, costs must be reduced or revenues must be increased. Also, they concluded that if the canopy cover and tree size is such that it can be controlled initially by prescribed burning, then this is the most economical and efficient way of controlling small juniper trees.

Potential Water Gained and Associated Economics

Brush and vegetative management for water yield enhancement has received scientific and policy consideration for a number of years (Griffin and McCarl, 1989). Within the various aspects of brush control the most debatable and studied portion is that which pertains to the potential water gained from clearing invasive brush species. Since land productivity is considered a benefit to the landowner, the social and economic values of increasing the potential water yields from rangelands is of interest, not only to ranchers, but also municipal and state government agencies. Numerous studies have been conducted by governmental agencies to identify future situations which can be acted upon to satisfy society's continual need for a dependable water source. Agencies such as the Texas Agricultural Experiment Station and the Natural Resource Conservation Service continually monitor and study the concept of how to effectively meet the water needs on Texas rangelands through various means of brush control including mechanical, chemical, and biological methods.

Bednarz et al. (2000) conducted a feasibility study on water yield for brush control and estimated that water yield gains on rangelands could range from 13,000 gallons per treated acre in the Canadian watershed to 172,000 gallons per treated acre in the Medina watershed. These values depend heavily on the annual rainfall which was estimated to be slightly over 17 inches per year in the Canadian Watershed and over 33 inches per year in the Medina watershed.

Rosenthal (2000) conducted research on the hydrologic simulation on the Pedernales Watershed taking into consideration weather patterns from 1960-1998 and using temperature data along with the Soil and Water Assessment Tool (SWAT). SWAT was developed to predict the impact of climate and management (e.g. vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large non-gauged basins (Bednarz et al. 2000). To satisfy the objective, the model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) functions within continuous time capable of simulating long periods for computing the effects of management changes. SWAT allows a basin to be divided into hundreds or thousands of grid cells or sub-watersheds.

Rosenthal's (2000) study took into consideration climate, topography, and soil type in the analysis. Results indicated that annual increases in water varied among sub basins and ranged from 739 gallons to 611,720 gallons per acre of brush removed. The variations in result are influenced by brush type, density, soil type, and average annual rainfall per sub basin. Results for the entire watershed indicate that average annual water yield can be increased by 36% or approximately 89,348 acre-feet with control of brush. This translates to an additional 57,050 acre-feet into Lake Travis, a major water source for Austin.

Bach and Conner (2001) reported that the cost of added water for eight watersheds across Texas ranged from $16.41 to $204.05 per acre-foot. Conner (2000) conducted a study on the Wichita watershed with results indicating that a total of 1.186 million acre-feet of water could potentially be gained from brush control over a ten year planning horizon. The Texas Soil and Water Conservation Board (TSSWCB, 2004) estimated that if the targeted 140,000 acres of brush was removed from the Pedernales

Watershed that the potential gain in additional water could be 715,000 acre-feet over the life of the project.

Thurow and Hester (2001) reported in an article pertaining to hydrology of rangelands after juniper removal that an increase in juniper cover on rangelands reduces the amount of precipitation that reaches the soil surface. "Ashe juniper has a much denser canopy and, thus, has more surface area on which precipitation can adhere and then be lost to the atmosphere via evaporation" (Thurow and Hester, 2001). In summary, the presence of juniper alters the amount and distribution of water reaching the soil.

In 1988, the Texas Agricultural Experiment station in Sonora set up a project to determine the degree to which brush cover influenced water yield. This was achieved by setting up seven moderately grazed 10-acre watersheds on similar soils with slopes ranging from 3% to 10%. In 1991, after the watersheds had been observed and calibrated, all woody vegetation was cut with an axe and hauled off of the sites. Runoff was monitored until late 1993. Using weighing lysimeters to track soil water content the soil along with transpiration and stomatal conductance of dominant vegetation types and rainfall simulators, preliminary results indicate that substantial amounts of water could be gained from transforming pasture vegetation from brush to grass dominance (Thurow and Hester, 2001).

Dugas et al. (1998) conducted a study on the Seco Creek Watershed located west of San Antonio in Uvalde County. The study was conducted from 1991 through 1995 on two similar, adjacent, and non-replicated areas with slopes less than 10%. This study evaluated the increase in water yield from a spring located below the study areas. In February of 1991 a flow meter was attached to a stream below 7.9 acres of a dense juniper stand. In mid 1992, 85% of the juniper was removed by hand cutting up slope from the spring. Weekly rainfall and spring flow data were recorded along with monthly reports of vegetation analysis and water quality. After 78 months, Dugas et al. concluded that the water quality was not affected and met all drinking standards. The increase flow of 0.67 gallons per minute from the spring could provide an additional 352,152 gallons following juniper control per year which could average 44,576 gallons per acre per year of potential water savings. Hence, this application could be applied to the 45 square miles of juniper infested watershed that covered much of the Edwards Aquifer recharge zone.

Summary of Literature

The material presented in this section presents views on the subject as a whole and the various aspects which are entwined in this highly debated issue.

It may be difficult to fully summarize the vast body of knowledge, prior research, opinion, and potential ideas that revolve around brush control. However, most of the prior knowledge is based upon the conceptualization that brush control will benefit landowners and society even though there may be non-defined discrepancies as to the empirical effects that will be produced. It is crucial, at least for this project, to keep in mind that prior data and research fails to give an exact value that links the benefits from brush control to its potential beneficiaries. In the literature review, there are many important theories, data analysis, and conclusions that will influence the procedures and ideas that underlie this study.

This study will contribute to the prior knowledge in a fashion that has previously not been explored to a great extent. Also, results from this project should produce information that will enable scientists, researchers, and policy makers to determine the cost/benefit of governmental subsidized brush control.

CHAPTER III

CONCEPTUAL FRAMEWORK

The economic evaluation of Ashe juniper control should be considered as an investment in the long-term productivity of rangeland. Costs of brush control are incurred at the time of initial control and periodically thereafter for follow-up treatments while the benefits of the improvements are not realized until several years have passed. In this analysis, three brush control treatments will be evaluated: the first is a treatment where all juniper was removed leaving the ground surface in a smooth state; the second entails clearing all juniper, but leaving the pits resulting from the removal of the trees, and the third treatment option is where no juniper is removed. Although there are various species of brush to be removed with the juniper, the Ashe juniper is dominant and considered to be the main species of focus.

This section describes the economic theory that can be used to analyze the relationships between the removal of Ashe juniper and soil water content. As a result, predictions can be made that involve the potential productivity of the land with respect to herbage production, water yield, and the overall cost/benefit of a cost-share program.

Biological Relationships

Ashe Juniper Response

There are several biological response functions involved in Ashe juniper control. These biological relationships include response functions between grass and canopy cover, grass and livestock production, and canopy cover and water yield. Rowan and

Conner (1994) hypothesized an exponential relationship between the level of juniper canopy cover and time as indicated in Figure 3.1. The growth rate (or infestation rate) shown in this graph is based on five data points taken over a forty-three year period. The first four are from the Texas A&M University Research Station at Sonora and were measured with a Geographic Information System while the fifth point is estimated from transect measurements. As shown in Figure 3.1, the growth of canopy cover in the early years (1950-1990) is minimal followed by a rapid increase in growth once the canopy cover reaches approximately 25% during the later stages of tree development. With these five points the curve shown in Figure 3.1 was estimated.

Grass Response

Rollins (1983) indicated that Ashe juniper canopy cover and grass production had an inverse relationship. The relationship's negative slope is explained by the competition between Ashe juniper and herbage for water, nutrients, and light. As juniper canopy cover increases there is a resulting negative effect on grass production as shown in Figure 3.2. The relationship between grass production and Ashe juniper canopy cover can be expressed as:

$$G=g\,(CC), \tag{3.1}$$

where G is grass production, CC is percent canopy cover, and $\partial G/\partial CC < 0$. Under the assumption that brush control takes place on a ranching operation, grass would have been produced with or without juniper control.

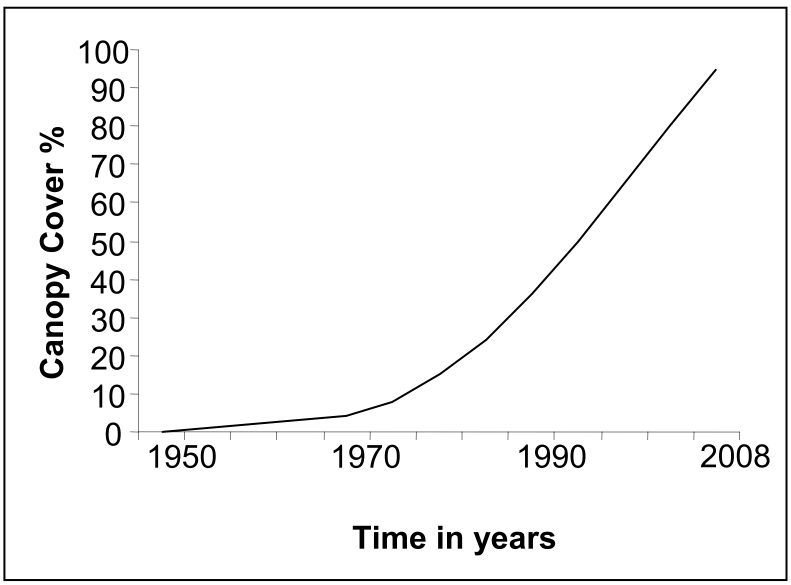

Figure 3.1 Juniper Cover Through Time.

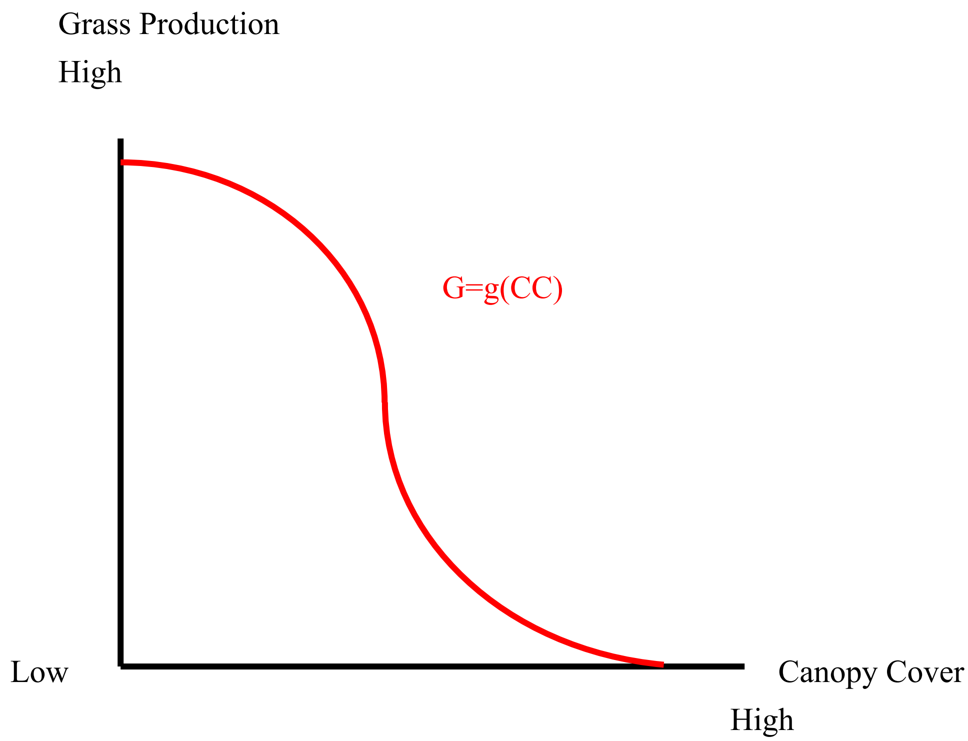

Figure 3.2 Hypothesized Relationship Between Ashe Juniper Canopy Cover and Herbage Production.

where AG is the added grass produced, G_w is grass production with the control of Ashe juniper, and $G_{w/o}$ is the grass production without the control of Ashe juniper. The assumption is made that if no treatment is implemented, grass production will decline over time as canopy cover continues to increase and any added grass production will result mainly from the implementation of a brush control treatment practice.

The decreased amount of herbage per unit increase in canopy cover is assumed to vary as Ashe juniper canopy cover increases. As canopy cover increases, herbage production decreases at an increasing rate and then decreases at a decreasing rate. Initially, the canopy cover of Ashe juniper does not have a substantial affect on grass production when the juniper is in an infantile stage. However, grass production will decrease as the juniper matures and the canopy becomes more closed. Eventually, canopy cover will increase to the point at which grass production becomes minimal or in some cases non existent.

Livestock Response

The clearing of Ashe juniper increases the productivity of the land by increasing the total available pounds of herbage per acre and by increasing the efficiency of variable inputs. Through greater herbage production greater returns can be realized through higher stocking rates and/or weight gains per animal unit. Holding herbage availability constant, Figure 3.3 shows the relationship between livestock production and variable inputs. This relationship was developed by Gerbolini, 1996.

The function CP_w indicates the level of cattle production at each level of variable input as the control of juniper is introduced. $CP_{w/o}$ shows the level of cattle production at each level of variable input without the introduction of juniper control. The marginal productivity of livestock decreases at the higher of levels of variable inputs and at maximum livestock production, vi max, the marginal productivity of the variable inputs becomes zero. This marginal productivity is responsible for the shape of the curves CP_w and $CP_{w/o}$. The figure also shows that marginal productivity for land with juniper control is higher at every level of variable input. At vi*, cattle production is higher on land with treatments resulting in a higher efficiency from the use of variable inputs. Figure 3.3 indicates a static view of the difference in cattle production before and immediately after the treatment is complete. Since it is assumed that juniper will reinvade the rangeland if follow up treatments are not introduced, then the CP_w curve will move toward the $CP_{w/o}$ curve over time.

Revenue and Cost Relationships

The economic response of brush control treatments is directly related to the manner in which herbage production occurs through time after the treatment is completed. Cash inflows or revenue depend on herbage production while cash outflows for treatment cost depend on the treatment schedule. Similar cash flows will be dictated through herbage production and inflows from livestock sales. Revenues from mechanical treatment will vary over time depending on the herbage output. Although the costs and returns for a brush control project are dynamic through time, it is important to fully understand a static model as well.

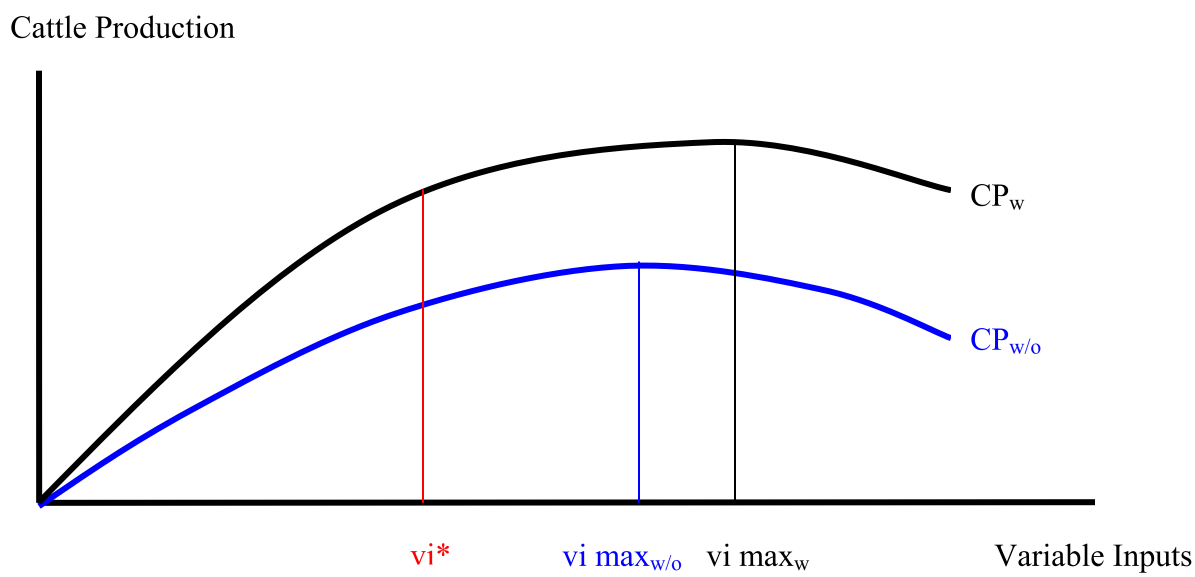

Figure 3.3 Cattle Production With and Without Ashe Juniper Control.
Gerbolini 1996.

Gerbolini (1996) developed a static perspective which can be seen through the costs and returns of brush control in relation to cattle production as indicated in Figure 3.4. In this scenario, the producer will attempt to produce at C* where profits are maximized. These profit maximizations can be seen for cattle production with brush control C^*_w and production of cattle without brush control treatment $C^*_{w/o.}$ The point of profit maximization occurs where the slope of the total cost curves (marginal cost) and the total revenue curve (marginal revenue) are equal. Figure 3.4 indicates where the profit maximization for cattle production will occur for two options, with and without control ($C^*_{w,}$ $C^*_{w/o}$).

The depiction of the cost benefit diagram also indicates that there is only one Total Revenue line (TR). This is developed under the assumption that the price received (per lb) for cattle is the same regardless of the juniper control. The upward rotation and shift of the total cost curve with treatment, TC_w, is a result of the increased total fixed cost, TFC, due to the treatment expense. In this case, even though cash outflows may occur at specific times, it is considered to be amortized through time.

Even though the variable costs per acre have increased, each added variable input will produce more cattle units than before the treatment was applied. Since it is hypothesized that canopy cover of Ashe juniper will increase over time thus reducing livestock productivity, it is expected that TC_w will shift leftward and approach $TC_{w/o}$, thus causing the cattle production per acre, $C^*_{w,}$ to gradually decrease each year following treatment.

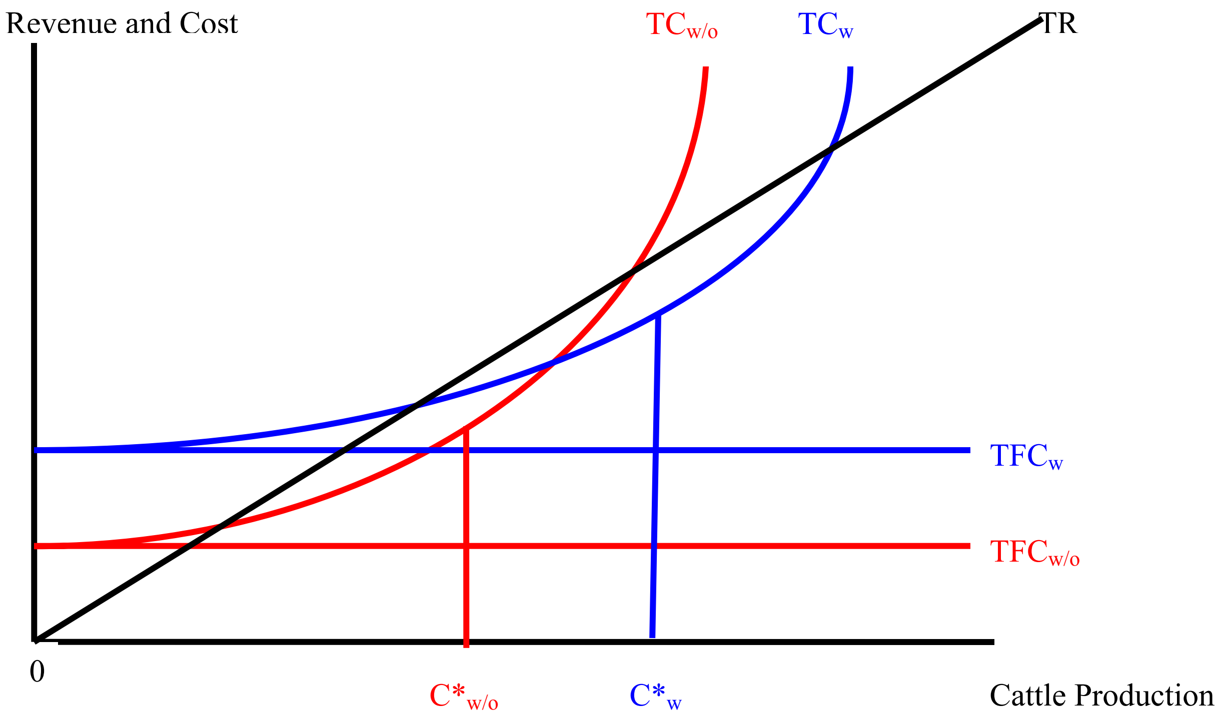

Figure 3.4. Total Cost and Revenues as a Function of Cattle Production. Gerbolini 1996.

In this process, two assumptions must be made, (1) the stream of cash flows produced by the project can be estimated without error, and (2) the opportunity cost of the funds provided to the firm is known. Under assumption (1), herbage production and cattle prices (per cwt) are known with certainty.

Investment Profitability

The investment profitability of Ashe juniper control can be evaluated using the net present value budgeting technique. The net present value of the project is the discounted cash flows at the firm's or ranch's discount rate. The feasibility of Ashe juniper control is evaluated by:

$$NPV = \sum_{t=0}^{n} \frac{\mathrm{AR}_t}{(1+i)^t} - \sum_{t=o}^{n} \frac{AC_t}{(1+i)^t} \qquad (3.3)$$

where NPV is the net present value of the treatment, *t* is the year following mechanical brush removal, AR is the added revenue from the treatment, AC is the added cost of the treatment, *n* is the treatment life, and *i* is the discount rate. For the removal of Ashe juniper to be feasible, the NPV must be greater than or equal to zero. The opportunity cost is the value of the best alternatives forgone. The discount rate is the firms opportunity cost of the capital investment. The discount rate for a firm should cover risk and inflation and generate earnings at least as high as the opportunity cost of the best alternative.

Water Yield

For the purposes of this project, it is assumed that if you reduce the percentage canopy cover of Ashe juniper that water yield will increase. This basic relationship is indicated in Figure 3.5, showing the potential of water that could be gained if juniper is removed. However, the exact values of the potential water gained from bush removal indicate contradicting views from previous literature on the exact quantity of water that could be gained. During the course of this project, analysis and specific testing will be conducted to allow for some predictions to be made as to the exact amount of water that could be gained. Also the water gained will have an associated cost, most of which will be incurred by the State's investment in the cost-share program while a smaller percentage incurred by the landowner. It is imperative to remember that without cost-share programs many of the brush control projects would never be initiated. However, with the cost-share programs contributing a substantial portion of the funds required for brush clearing, there are benefits and costs associated not only with the landowner, but also with the State. These financial considerations are expressed as Present Values in relation to the percentage of canopy cover cleared and the condition the land is in after brush removal (i.e. pitted or smooth). It is hypothesized that these two treatment conditions will affect how much and what type of water yield can potentially be gained. The Total Benefit (TB) is the total water gained from the two treatment options. Figure 3.6 depicts the hypothesized water gains for pitted land with various percentages of canopy cover removed. The total benefit of water (TB_W) is hypothesized

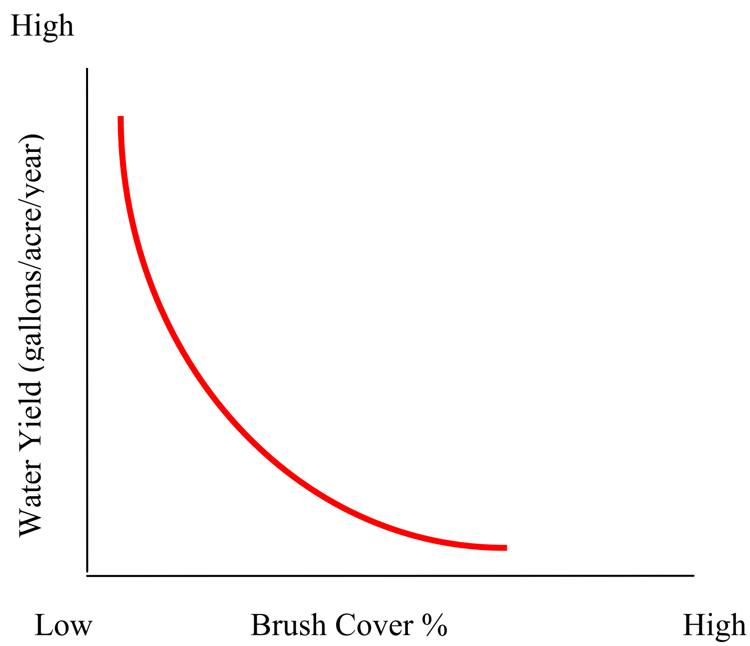

Figure 3.5. Potential Water Yield from Brush Removal

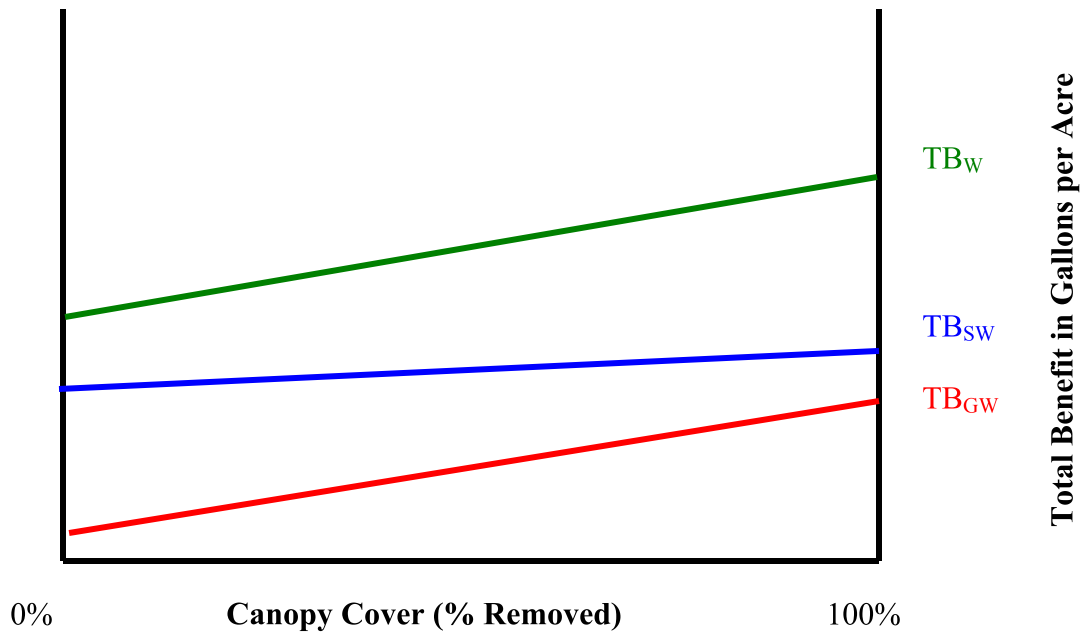

Figure 3.6. Total Benefit of Water from Pitted Land after Ashe Juniper Removal.

to increase as the percent of brush removal increases. However, this illustration indicates that if the land is left rough that there will be a greater gain in Ground Water (TB_{GW}) than in Surface Water (TB_{SW}). This does not imply that there will be no gain in surface water, only that the potential gain of ground water or soil water content should be higher under this condition.

Figure 3.7 illustrates the hypothesized water gains if the land is left smooth. The gain in surface water (TB_{SW}) is hypothesized to have a greater net increase than ground water (TB_{GW}) due to the increased potential for surface runoff and erosion if the land is smoothed. It is also important to understand that the total benefit in water yield (TB_{W}) might be the same under the pitted and smooth scenarios with direction or allocation of water differing.

Figure 3.8 shows the benefit to the State (TB_{S}) and the landowner (TB_{L}) as a result of juniper being removed and the soil left pitted. This indicates that the total benefit to the landowner would be higher in the sense that more water is retained on site which would directly affect the rancher through an increase in herbage production.

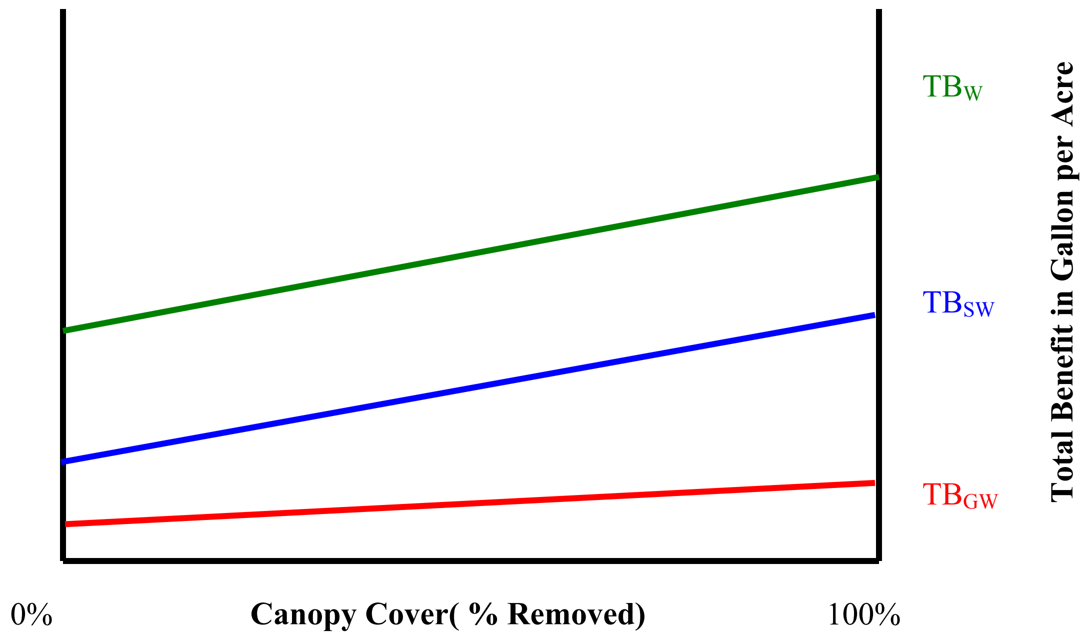

Figure 3.7. Total Benefit of Water from Smooth Land after Ashe Juniper Removal.

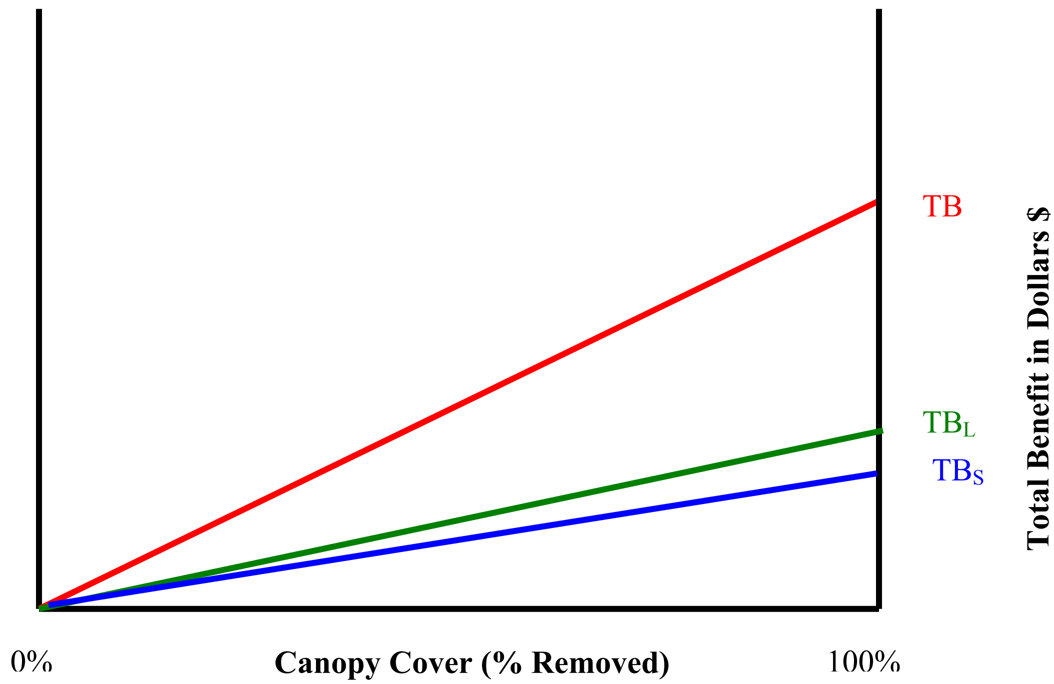

Figure 3.8. Total Benefit for Ashe Juniper Removal on Pitted Site.

As depicted in Figure 3.9, the opposite will occur if the land is smoothed after the removal of brush. This graph shows that the State (TB_S) will benefit more than the landowner (TB_L) due to the increased ability of the land to produce runoff. These two benefit graphs are based on the assumption that both entities will benefit with one receiving greater results from certain clearing practices.

The total cost curves shown in Figure 3.10 are based on the concept of brush control cost-share initiated by the State. The State could cover up to 80% of the project cost making their cost (TC_S) greater than the landowners total cost (TC_L). These costs will increase for each level of canopy cover with a maximum cost incurred at 100% canopy cover.

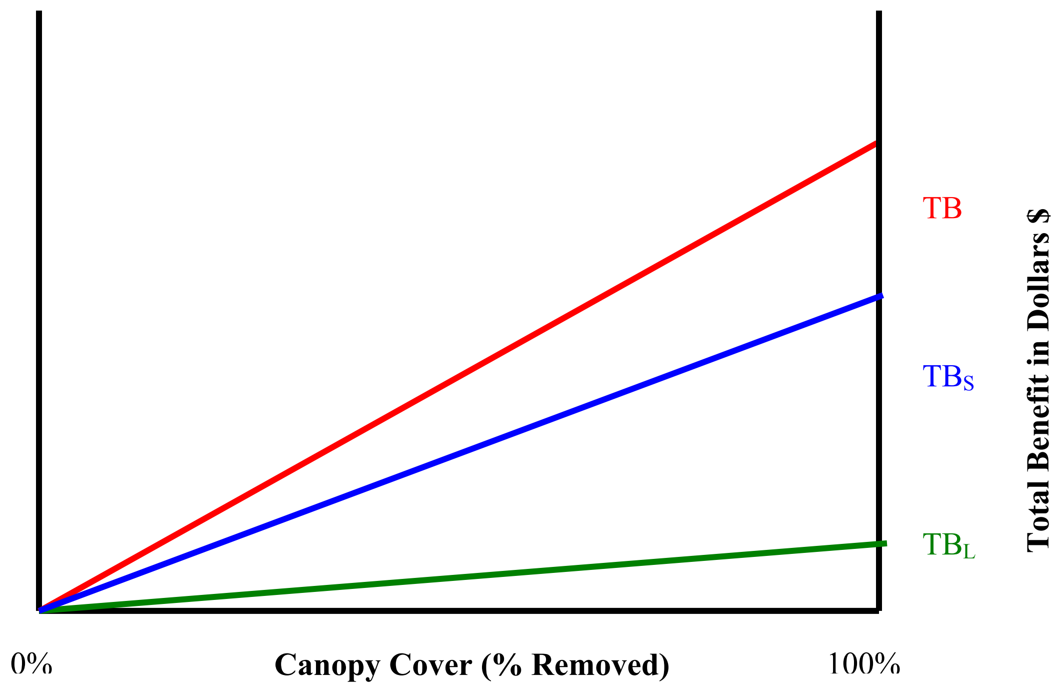

Figure 3.9. Total Benefit for Ashe Juniper Removal on Smooth Site.

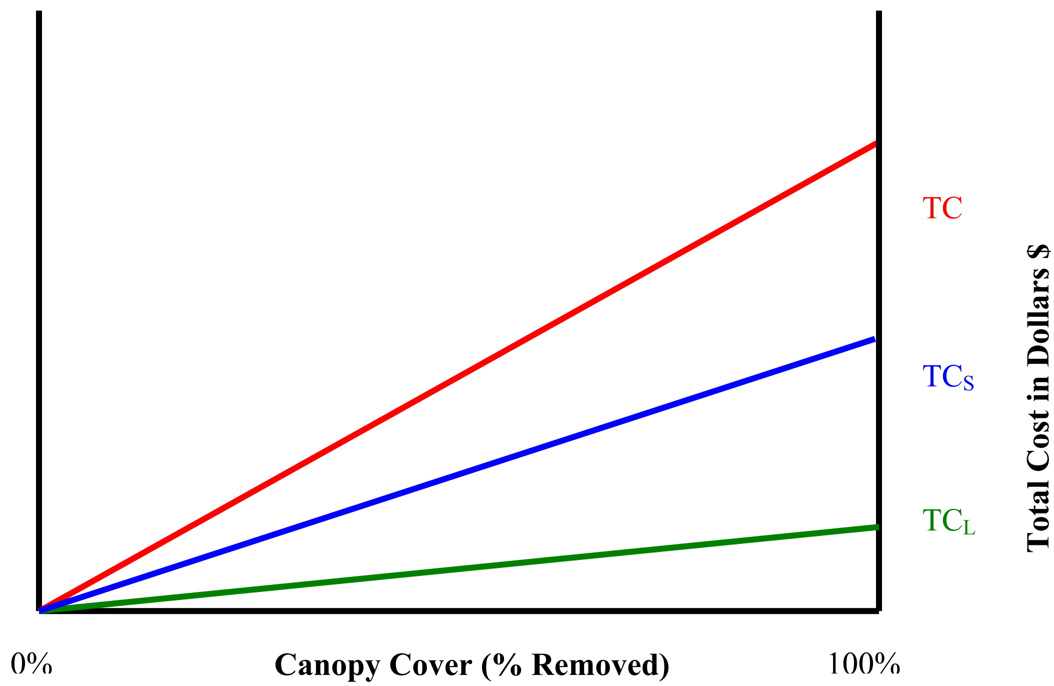

Figure 3.10 Total Cost of Juniper Removal with Government Cost-share.

CHAPTER IV

METHODS AND PROCEDURES

General Approach

In this study there were three different treatment options evaluated for the purpose of soil water enhancement, herbage production, and cost benefit analysis. The first two treatments include the removal of Ashe juniper, each leaving the topsoil in different states, one having a smooth surface and the other being pitted with tree removal. The third treatment was left in a natural state and was not treated. The main focus of the project is to determine the costs and benefits of brush removal associated with the government cost-share program through potential soil water enhancement. The main data for the project will be primary data collected through soil samples and herbage samples throughout a one-year collection period.

Study Area

The particular area being studied, as indicated by the arrow in Figure 4.1, is a 111.29 hectare-property located East of Fredericksburg Texas in Gillespie County. This location lies within the Pedernales Watershed which is centered on the Pedernales River, a major tributary in the Hill Country and an important source of water for Austin and surrounding communities. The property has a variety of soil types, but for the purposes of consistency an area was chosen containing Brackett soils (BrC) which is typical of the Hill Country and is the dominant soil type for Ashe juniper infestations.

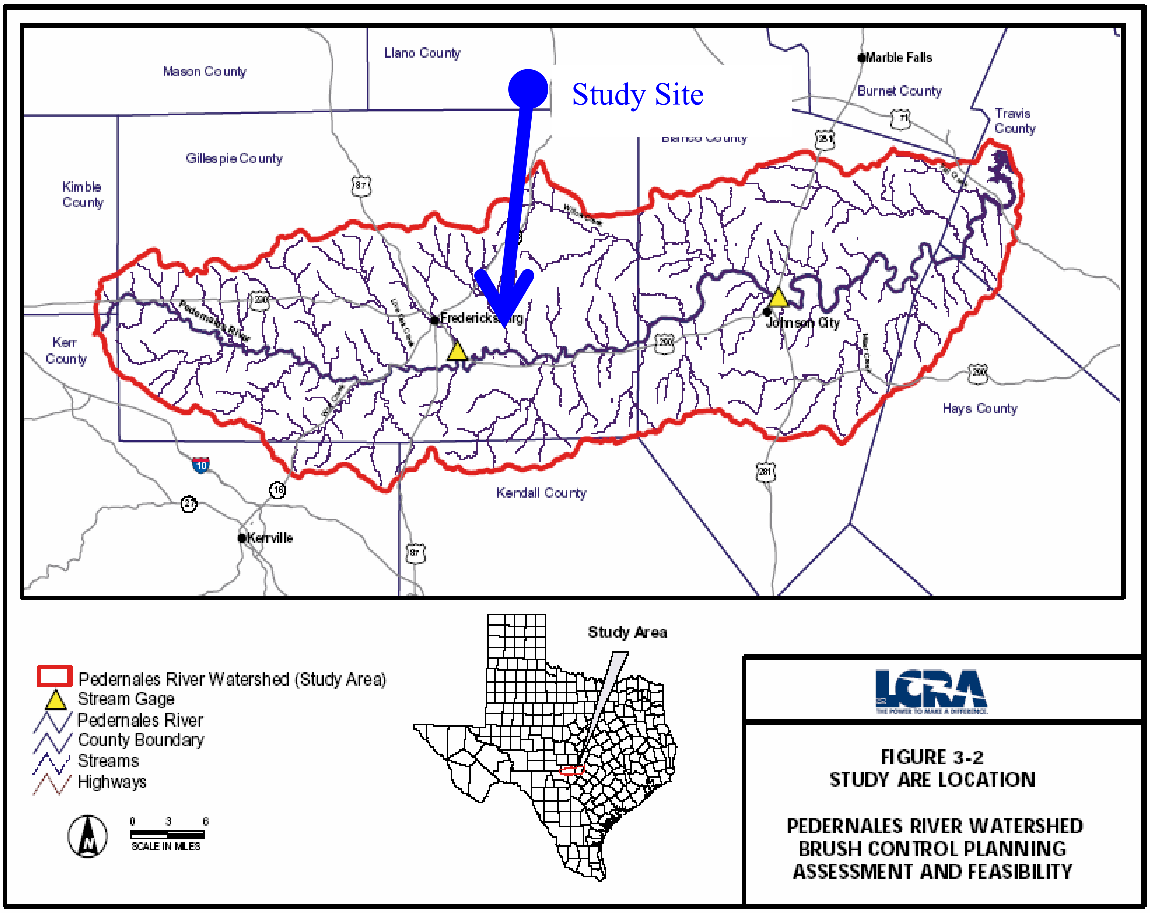

Figure 4.1 Location of Study Site Within the Pedernales Watershed.
Source. Lower Colorado River Authority.

In 2004, the Ashe juniper was removed from the site by mechanical means using a large crawler bulldozer. Three tracts were staked off each of which has the same soil type. Each of these tracts is .405 ha in size and represents one of the following three treatments being analyzed. Pictures documenting each treatment can be seen in Appendix G.

Smooth Treatment

The Ashe juniper was removed using a large crawler tractor or bulldozer which weighs approximately 45,000 lbs. This tractor equipped with a large eleven foot wide blade which was used to uproot the trees. As the trees were uprooted, they were stacked into large piles and burned. Any remaining holes created by the uprooting of the trees were then covered and the ground surface smoothed. This was done by skimming the blade across the ground, gathering loose soil and debris pushed into the pits. The end result left the ground surface smooth which increases the traversability and visual appearance.

Pitted Treatment

This treatment follows the same initial processes as the smooth treatment with the exception of filling in the pits or holes that were created during the clearing process. In this treatment, the Juniper was stacked and burned in a similar manner, but the ground surface was left in a pitted and rough condition which is hypothesized to increase soil water content due to decreased surface runoff.

Non-treated

On the non-treated site there was no attempt to remove any of the juniper from the site. The area was left in a natural condition which contains a large amount of mature Ashe juniper, similar to what the other sites had prior to being treated.

Data Collection

Soil water content was measured on sites that had been smoothed, sites where the tree pits had been left, and sites where no brush control practice had been performed. Soil samples were taken at each site on a monthly basis, averaging approximately thirty to forty samples per month. The sampling technique entailed taking samples at six inch increments to a maximum depth of twenty-four inches using a 2 ¼ inch diameter soil augur. These samples were a distribution of each six-inch interval meaning the sample taken consisted of soil from all portions of the six-inch increment. The samples were then put into an 8 oz collection can and an initial weight was obtained using an Ohaus scale. They were then dried at a temperature of 100° C for forty-eight hours in a Thelco oven and a dry-weight was obtained using an Ohaus scale to determine soil water content. Soil water content (%) was calculated using the following formula:

$$\%Water = \frac{Fieldweight(grams) - OvenDryweight(grams)}{OvenDryweight(grams) - tare} * 100 \qquad (4.1)$$

where *tare* is the weight the sample can used for the individual sample, *fieldweight* is the initial weight of soil sample including the sample can, and *ovendryweight* is the weight of the soil sample and can after the drying is complete.

Rainfall was measured on each treatment plot with accuracy capable of 0.01 inches. Gauges were set in areas that would best represent the treatment plot. To account for interception loss on the non-treated site, the rain gauge was placed underneath the canopy of the juniper stand.

Herbage production was measured at the end or peak of the growing season in the second week of September, 2005. Herbage estimates were obtained by using a transect method and clipping total herbage at ground level. Herbage production was estimated by three transects on each plot with four .25m^2 quadrats per treatment. Herbage production was categorized by grass, weeds, shrubs, down litter, and standing litter, and was then placed in paper bags which were dried for 168 hrs at 60°C. Once dried, the herbage was weighed in grams and then converted to a kilograms per hectare basis. The formula by which the grams of herbage were converted to kilograms per hectare is as follows:

$$HP = [\text{Herbage (grams)} - \text{tare}]*40, \qquad (4.2)$$

where HP is herbage production in kilograms per hectare and tare is the value obtained from averaging the weight in grams of ten randomly selected paper collection bags.

Investment Profitability and Economic Analysis

An economic analysis of the feasibility of brush control was completed using the cost of control and the estimated increased herbage availability. Investment returns were analyzed from the standpoint of landowner with respect to potential return on investment with and without a cost-share program.

The investment profitability of Ashe juniper control was evaluated using the net present value budgeting technique. The net present value of the project is the discounted cash flows at the firm's or ranch's discount rate. The feasibility of Ashe juniper control was evaluated by:

$$NPV = \sum_{t=0}^{n} \frac{\mathrm{AR}_t}{(1+i)^t} - \sum_{t=o}^{n} \frac{AC_t}{(1+i)^t}, \qquad (4.3)$$

where NPV is the net present value of the treatment, *t* is the year following mechanical brush removal, AR is the added revenue from the treatment, AC is the added cost of the treatment, *n* is the treatment life, and *i* is the discount rate. For the removal of Ashe juniper to be feasible, the NPV must be greater than or equal to zero.

The opportunity cost is the value of the best alternatives forgone. The discount rate is the firm's opportunity cost of the capital investment. The discount rate for a firm should cover risk and inflation and generate earnings at least as high as the opportunity cost of the best alternative. Since the expected price of livestock and costs of control through time were considered constant and were estimated at current values, the discount rate was adjusted for the effects of inflation. The real discount rate (i) of 7.29% was calculated by using the following equation:

$$i = \frac{1+\beta}{1+\delta} - 1 \ , \qquad (4.4)$$

where i is the real discount rate used, β is the nominal discount rate, and δ is the yearly expected inflation rate. β was calculated using values received from statistical releases received form the Federal Reserve Bank of Dallas on the average interest rates for intermediate term agricultural loans. The average expected increase in inflation per year of 1.99%, was calculated by taking the average of the percent increase in the producer price index from 1995 to 2005 (Federal Reserve Bank in Dallas, 2006).

In order to depict the profitability of the potential increased herbage from the treated sites, the herbage production had to be converted to livestock production which is directly marketable. Ethridge et al., (1984) developed the following equation to convert herbage to livestock production as:

$$ALP_t = K * AFP_t \ , \tag{4.5}$$

where ALP_t is the additional livestock production in kg/ha in year *t*, and K is amount of livestock produced per kilogram of herbage measured in kilograms. Ethridge et al. estimated that it would take 11,862.5 kg, considering trampling and vigor maintenance, of herbage to annually sustain one animal unit and thus a K of 0.020054 was estimated, the assumption of grazing 40% of standing herbage. Kennedy (1970) defined an animal unit within a cow-calf operation as a cow consisting of 453.6 kg, calf at 181.4 kg, 5% of a 725.8 kg bull, and 14% of a 294.8 kg replacement heifer. Additionally, the assumption was made that the marketable weight of heifers and steers was 244.76 kg and 262.49 kg, respectively, along with an 82.27 weaning percentage and a 14% heifer replacement. It was also assumed that the operation would market 237.89 kg per marketable animal unit (MAU). See Appendix F for calculations and references on MAU.

The price of livestock was calculated on the contributions made by heifer claves, steer calves, and cows based on the percent weight each contributed to a marketable animal unit. Price of livestock was calculated as follows:

$$\begin{aligned} PL = &((WH)(\%H)/MAU * PH)) + ((WS)(\%S)/MAU * PS)) + \\ &((WC)(\%C)/MAU * PC)), \end{aligned} \tag{4.6}$$

where PL is the weighted price of livestock in \$/kg, WH is the weight in kg of a heifer at weaning, %H is the percent of a heifer sold per animal unit, WS is the weight in kg of a steer at weaning, %S is the percent of a steer sold per animal unit, WC is the weight in kg of a cull cow, %C is the percent of a cull cow sold per animal unit. PH, PS, and PC are the prices of heifers, steers, and cull cows respectively. Heifer, steer, and cull cow prices where obtained for Oklahoma City (USDA, Livestock Prices).

The associated added variable cost for producing one kilogram of marketable calf was estimated by dividing the summation of the variable input costs given in Table 4.1 by the MAU as defined previously and in Appendix F. Brush retreatment costs were estimated at $8.73/hectare based upon data from Caudle (1995) from estimations on burning in the High Plains of Texas.

The variable values used in NPV analyses for both treatment types, Table 4.2, include; the calculated discount rate (%), initial canopy cover (%), juniper growth (%), re-infestation of juniper (%), price of livestock ($/kg), and initial treatment and retreatment costs ($/ha).

Table 4.1. Associated Added Costs for a Cow-calf Marketable Animal Unit.

Item	$/AU
Barn	0.04
Fence	2.91
Interest - Earned	-0.63
Interest - OC Borrowed	5.5
Other direct Cost	$30.00
Pickup Truck 3/4 Ton	$28.55
Salt and mineral	$5.40
Shed	$0.02
Sprayer	$0.07
Supplemental feed	$61.25
Trailer	$0.48
Vet medicine cow-calf	$14.32
Water	$0.18
Working Pens	$0.04
Bull expense	$0.04
Death loss	$10.72
Hay	$40.00
Livestock labor	$40.32
miscellaneous expense	$12.00
Sales commission	$8.29
Depreciation, taxes, insurance	$36.29
Total	$295.79

Source: Extension Agricultural Economics, Texas A&M University System, Crop and Livestock Budgets, District Seven, 2005.

Table 4.2. Variable Values used in NPV Analyses.

	Smooth Treatment						Pitted Treatment					
	Cost Share			Full Cost			Cost Share			Full Cost		
Variables			Avg.			Avg.			Avg.			Avg.
$TC_{Treatment}$ in $/ha	138.38	172.97	164.57	345.94	432.43	411.46	138.38	172.97	164.57	345.94	432.43	411.46
$CC_{t=0}$ in %	425	68.75	62.3	42.5	68.75	62.3	425	68.75	62.3	42.5	68.75	62.3
r of re.inf.%	2	2	2	2	2	2	2	2	2	2	2	2
r in %	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
PL in $/kg	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59
i in %	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29
$TC_{Re\text{-}treatment}$ in $/ha	8.73	8.73	8.73	8.73	8.73	8.73	8.73	8.73	8.73	8.73	8.73	8.73

[1]$TC_{treatment}$ is the total initial cost of treatment, $CC_{t=0}$ is the intial canopy cover, r of re.inf. the rate of infestation post treatment, r is the rate of juniper growth, PL is the price of livestock, i is the discount rate, and $TC_{retreatment}$ is the cost of retreatment.

[2]AVG. Is the weighted average of variables encompassing the entire treated area.

CHAPTER V

RESULTS

The results of this thesis are presented in four sections. The first section presents the results on water yield through soil water enhancement by the removal of Ashe juniper. The second section includes results dealing with herbage production. The third section presents the potential economic benefits received by the landowner as a result of the cost-share program through a net present value analysis. The final section provides a generalized evaluation of the results.

Water Yield and Hydrologic Implications

This section illustrates the variations and potential impacts of juniper removal on water yield and the hydrologic balance. As previously indicated in the methods and procedures section, soil samples were collected on a monthly basis and the soil water content (%) was determined using equation 4.1. Throughout the one-year time horizon, there were fluctuations in rainfall which may be difficult to interpret by most practical range and/or environmental methods. However, in certain cases, trends can be seen that may relate to the hypothesis of increasing deep percolation and runoff from precipitation events after juniper has been removed.

Rainfall

Rainfall in 2005 measured at the study site was below the long-term average for Gillespie County of 30.3 inches resulting in lower than average soil water contents. Total rainfall for each treatment site on a monthly basis is depicted in Figure 5.1. During the year 2005, rainfall in January, March and July was above average. In the month of April, no precipitation was recorded and unusually low amounts occurred in the months of September through November. It is imperative to point out that only one year of precipitation was measured during this study.

Figure 5.2 depicts the cumulative rainfall for 2005 as measured at the study sites compared to the normal rainfall for Gillespie County. This graph clearly illustrates that 2005 was a below-average year for precipitation. The 2005 cumulative rainfall as measured at the treated sites was 17.5 inches, which was 13.0 inches or 42% below the long-term average. The measured rainfall on the non-treated site was approximately 1.15 inches below that on the treated sites. Given the close proximity of the treated and non-treated sites, the lower rainfall totals for the non-treated site may be attributed to interception loss from the heavy juniper canopy cover on the non-treated site.

Soil Water Content

The following section presents the various aspects, implications, and results obtained from the monthly soil moisture content samples. The soil structure was similar across treatments with variation occurring in the soil profile depth. Due to the shallow nature of the soils, measurements were not collected below a depth of 24 inches. Many of the measurements collected were shallower, resulting in inconsistent depths for the random monthly samples. These variations in sample depth continued throughout the year. Missing data points for soil water content by depth, were filled by taking the average of all samples collected within a particular treatment and depth.

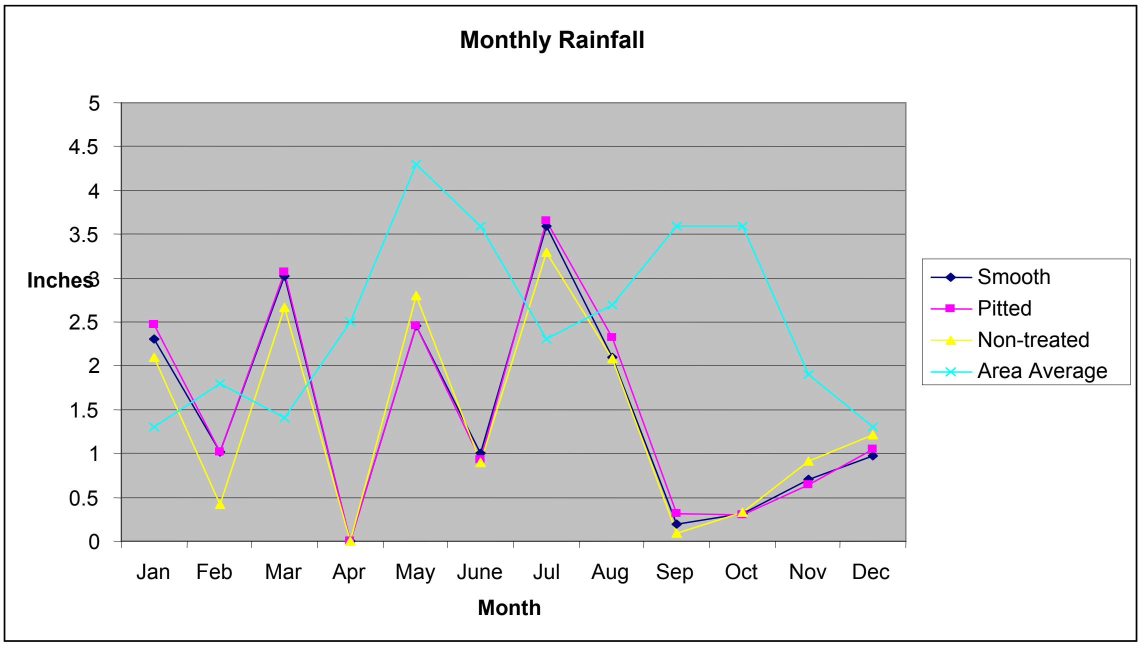

Figure 5.1. Monthly Rainfall Totals on the Study Plots and Area Average.

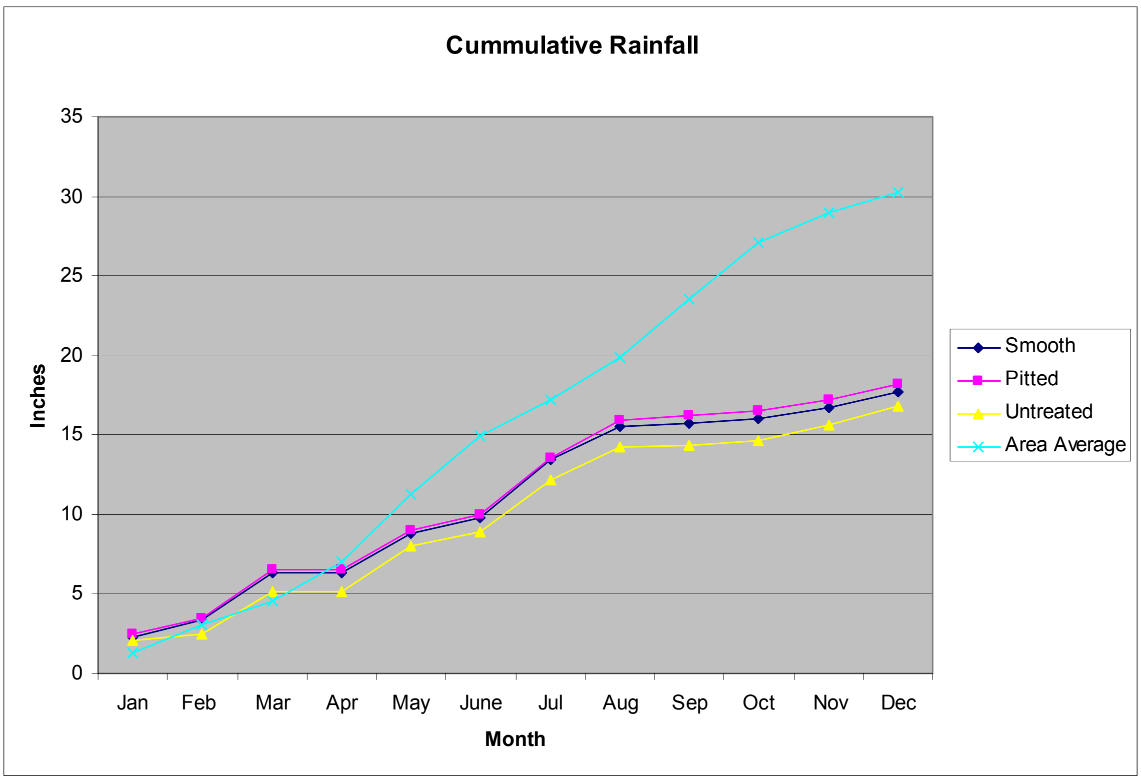

Figure 5.2. Cumulative Rainfall Across Treatment Plots and Area Average.

Soil cores were weighed and oven-dried to derive the volumetric water content using equation 4.1. Soil water content in percentages or volumetric measurements from equation 4.1 was converted to acre-inches and gallons. Figure 5.3 illustrates the average soil water content in acre-inches for all treatments compared with monthly rainfall totals. It is difficult to make concrete assessments of soil water content on this basis due to the lag effects that occur throughout the process of soil water storage from period to period in the soil profile. Figure 5.3 shows a general decline in soil water across treatments, with soil water on the non-treated area generally less than the two treated plots. However, the lag affects of establishing herbage or pasture plants on the treated sites may have caused the higher initial soil water contents.

When soil water content is compared with rainfall, there appears to be trends in precipitation received and water content in the soil profile; however, this interpretation can be skewed due to the lag in soil water storage. As Figure 5.3 illustrates, the only soil water content measurements that relatively and logically follow the precipitation received were inside the pits. These values may be a direct result of increased infiltration of received rainfall inside the pits due to the pits catching rainfall and reducing runoff.

Figure 5.4 gives the yearly average soil water content across treatments. The annual average soil water content for the smooth and pitted treatments was similar at 22.76% and 22.83%, respectively. The highest water content was found inside the pits at 26.59% which was 6.96% higher than the non-treated site at 19.98%.The pitted treatment allowed rainfall to be captured and retained on-site because of the increased surface area within the pits which will decrease overland flow and runoff, and the physical characteristics of the pits as catchments. As a result, more water will be stored or held in

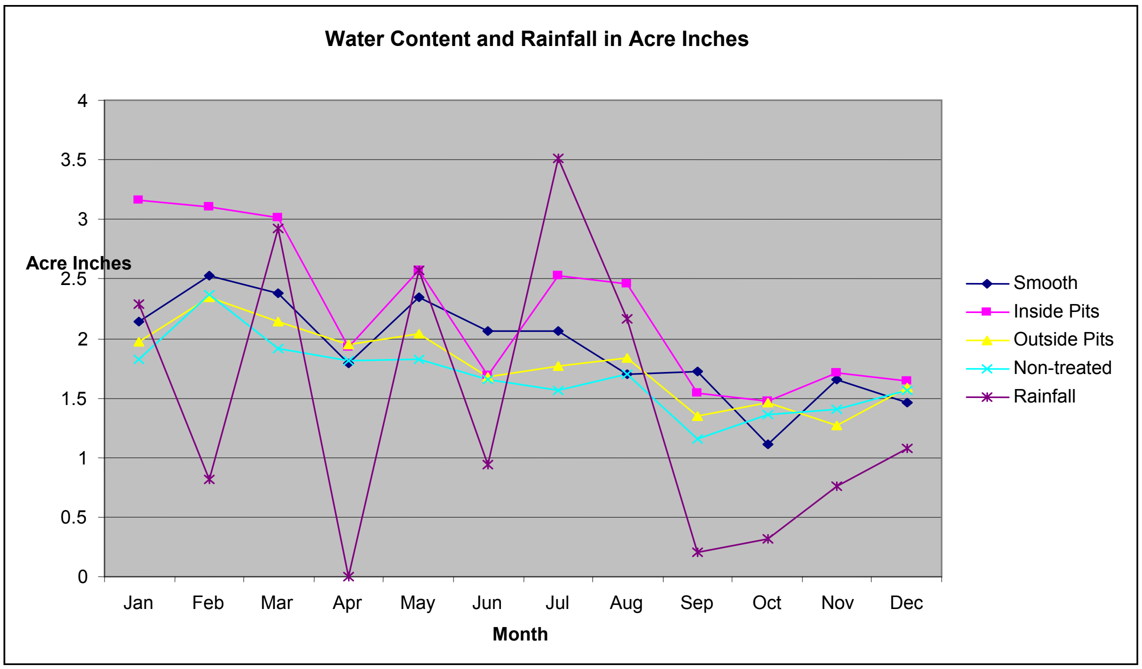

Figure 5.3. Average Acre Inches of Water/six inch Increments by Treatment and Monthly Rainfall.

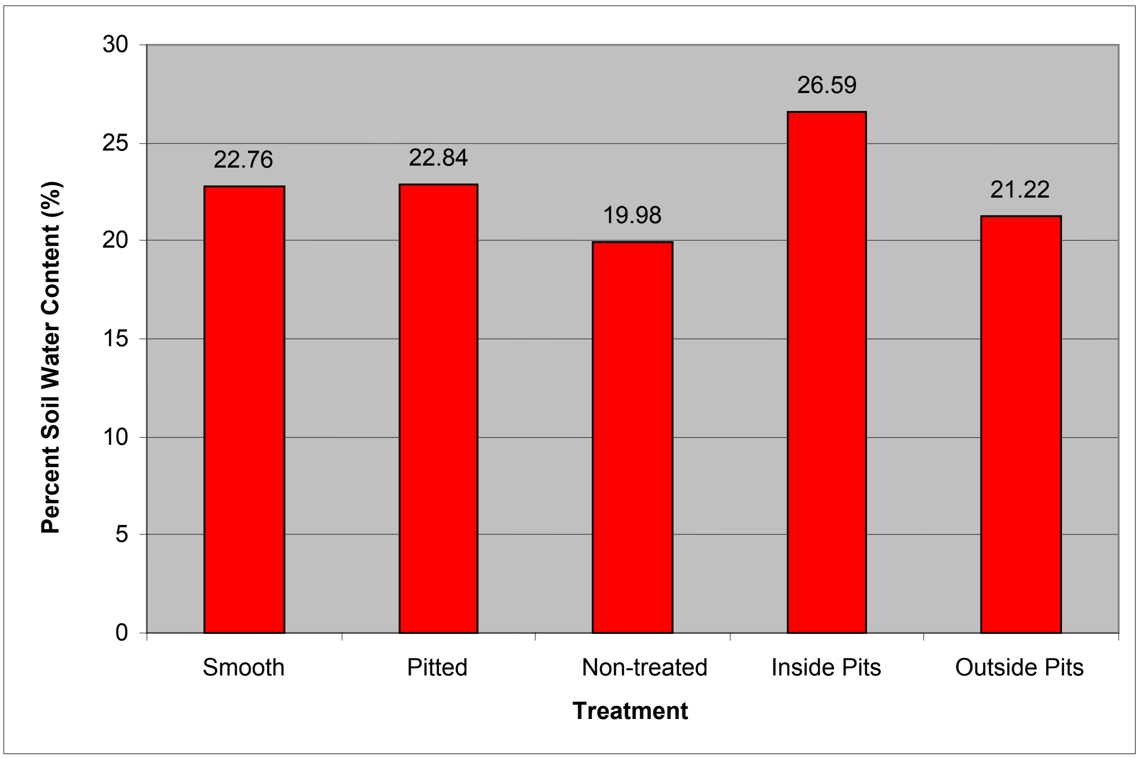

Figure 5.4. Average Percent Soil Water Content (%) Across Treatments.

the pits where it can either contribute to deep percolation or evapotranspiration. Figure 5.4 also illustrates that the non-treated area had a lower overall soil water content. This affect could be attributed to the very large amount of down litter under the dense juniper canopy which totaled 18,311 kg/ha compared with an average of 5,020 kg/ha on the treated sites. Litter absorbed the water before it entered the soil profile and allowed for increased evaporation.

Figure 5.5 illustrates the differences in soil water content in terms of gallons of water per acre. It shows that there could be a potential gain of 6,424 gallons per year per acre if juniper was removed when compared with the average gallons per acre of the treated sites. This value results in slightly less than ¼ of an inch of precipitation gained per year per acre on the treated sites.

There are three main possibilities or channels for precipitation to take once it has reached the soil surface. First, the precipitation can be absorbed into the soil profile which could potentially lead to deep percolation and potential aquifer recharge. Second the water can be absorbed by the vegetation either through interception losses or by absorption via root uptake and thus be transpired back into the atmosphere. Finally, the water can run off. Any runoff amount would depend on weather or storm conditions, slope, ground landscape, surface roughness, and vegetative status and growth patterns. As a result of collecting soil water content and precipitation, a value for evaporation and transpiration, more commonly known as evapotranspiration (ET), was calculated under the assumption that runoff and deep percolation were the same across treatments and had a value of zero.

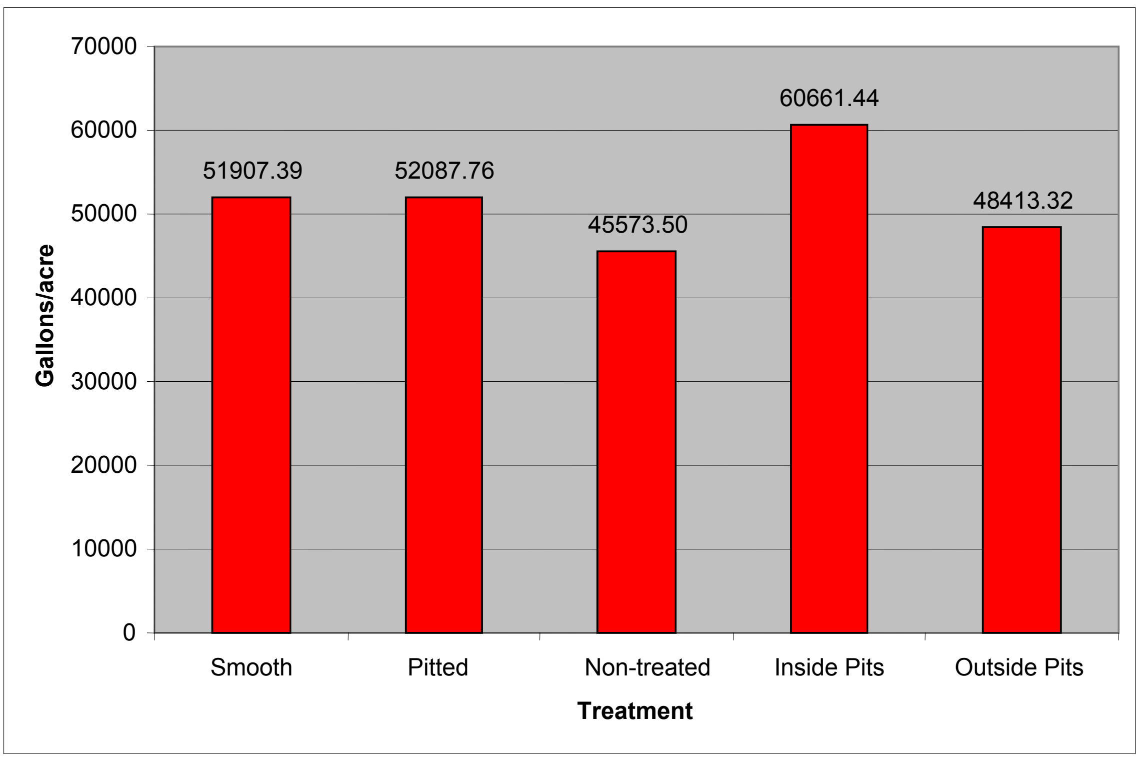

Figure 5.5. Average Gallons of Water per Acre in Soil Profile Across Collection Points.

Equation 5.1 was used to calculate the relative relationship between treatments in overall evapotranspiration, potential runoff, and deep percolation. The following equation was used to calculate relative ET:

$$ET = \Delta S + P - RODP, \tag{5.1}$$

where ET is potential evapotranspiration, ΔS is the change in storage or soil water content, P is precipitation received, and RODP is the value associated with runoff and deep percolation which for this case is assumed to be zero. To reach comparable values of ET it was assumed that runoff and deep percolation were zero due the lack of data available to make accurate estimates of these values. The values for ΔS were calculated using average soil water content for each treatment: smooth, pitted, and non-treated to a maximum depth of 18 inches.

Of the three ET values calculated, the lowest value of 17.60 inches of potential evapotranspiration per year was calculated on the non-treated site, which was somewhat unexpected. In comparison, the smooth site resulted in an ET value of 18.99 inches per year while the pitted or rough site resulted in an ET value of 19.10. The lower value calculated on the non-treated site could be the result of several ecological characteristics such as shading effects and the reduction of wind currents. If the brush canopy shades the ground, this could potentially reduce radiant energy hitting the ground thus reducing the overall evaporation of water from the soil surface. Additionally, it could be hypothesized that since the juniper stand was very dense, wind currents within the stand were reduced thus allowing for more water to accumulate in the soil profile.

Herbage Relationship

The most noticeable gains from juniper control was the significant increase in potential herbage on the treated sites compared to the non-treated site. The process of converting a non profitable biomass such as juniper into a more useable rangeland resource is the only reason a landowner has for justifying his or her cost in juniper removal. The landowner may justify the investment in brush control based on potential gains from increased amounts of usable biomass which can then be converted to livestock gains and thus profit.

Herbage samples where collected in late September which was assumed to be the end of the growing season. The two treated sites had approximately one and one half growing seasons following treatment while the non-treated site had no time restriction in its production. The collected herbage samples were grouped into three main categories: grass, forbs, and shrubs. Figure 5.6 illustrates the total amount of grass production in kilograms per hectare from the various collection points. It is clear that the amount of potential herbage (usable grass) production increased with juniper removal. The weighted average grass production on the pitted site was 1,316.84 kg/ha compared with 1,513.09 kg/ha and 46.66kg/ha on the smooth and non-treated sites, respectively. The production on the pitted site was calculated on an assumed ratio of 70% of the area between the pits and 30% of the area in the pits. However, the area outside the pits had a higher level of grass production compared to the smooth area. The results indicate that there is a 2,822% increase in grass production if the pits are left following juniper control and a 3,143% increase if the land is smoothed following treatment.

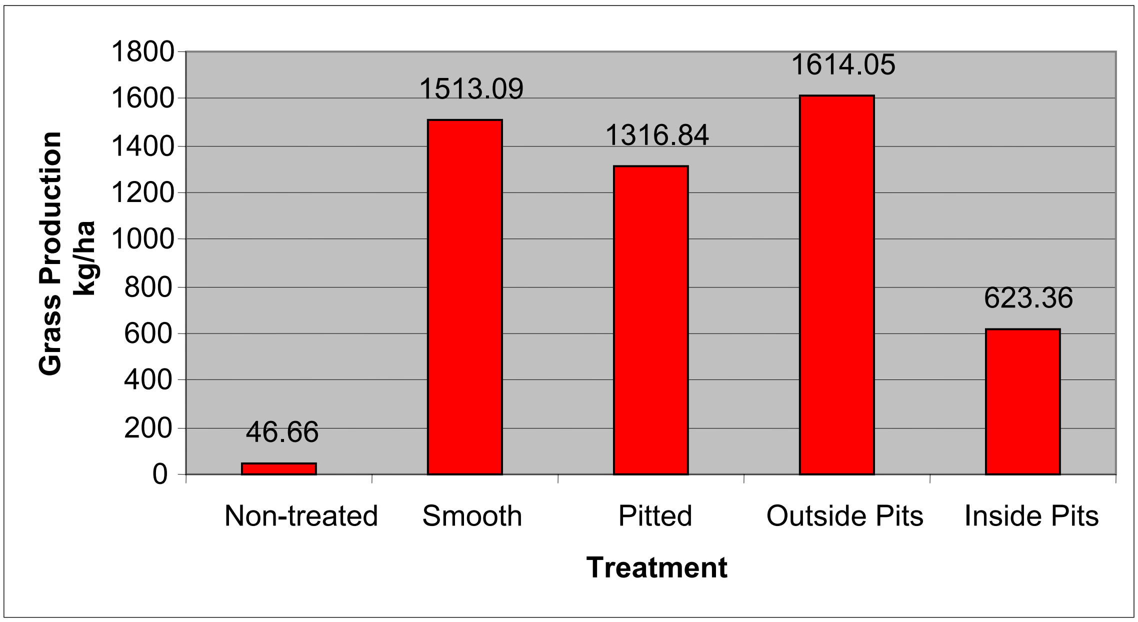

Figure 5.6. Grass Production Across Treatments and Collection Points.

As Figure 5.7 indicates, there was also an increase in encroachment of forb species following juniper control. Forbs (often weedy species) tended to mainly develop on the bare exposed soil that is in the bottom of the pits where sediment collects along with other organic debris. As shown in Figure 5.7, 1,197.23 kg/ha of forbs were produced inside the pits. The pitted site had 688.78 kg/ha of forb production compared to 382.04 kg/ha and 11.53 kg/ha on the smooth and non-treated sites, respectively. Forb encroachment would be expected on the treated sites due to the disturbance of the surface soil by the mechanical brush control process. The long-term balance of forbs and grass production will depend on grass species, grazing practices and environmental factors.

Figure 5.8 presents the total herbage production for each treatment which includes both grass and forb production. The pitted site had the highest total herbage production at 2,005.68 kg/ha compared to 1,895.13 kg/ha and 58.16 kg/ha for the smooth and non-treated sites, respectively. Figure 5.8 rather dramatically illustrates the effect of juniper control on herbage production. The level of total herbage production on the non-treated site was extremely low and was also virtually unusable due to the dense stand of juniper which made access by livestock difficult.

As Figure 5.9 shows, the amount of young shrubs, mostly juniper, sprouting on the treated sites is substantial. Average shrub production on the treated sites was 267.35 kg/ha compared to 37.47 kg/ha on the non-treated site. The presence of seedling shrubs reiterates the need for the landowner to continue retreating of these sites periodically to maintain productivity and prevent a re-infestation of noxious brush species. The most common method of retreatment used is burning although other methods such as spraying or hand cutting would also be sufficient to maintain productivity.

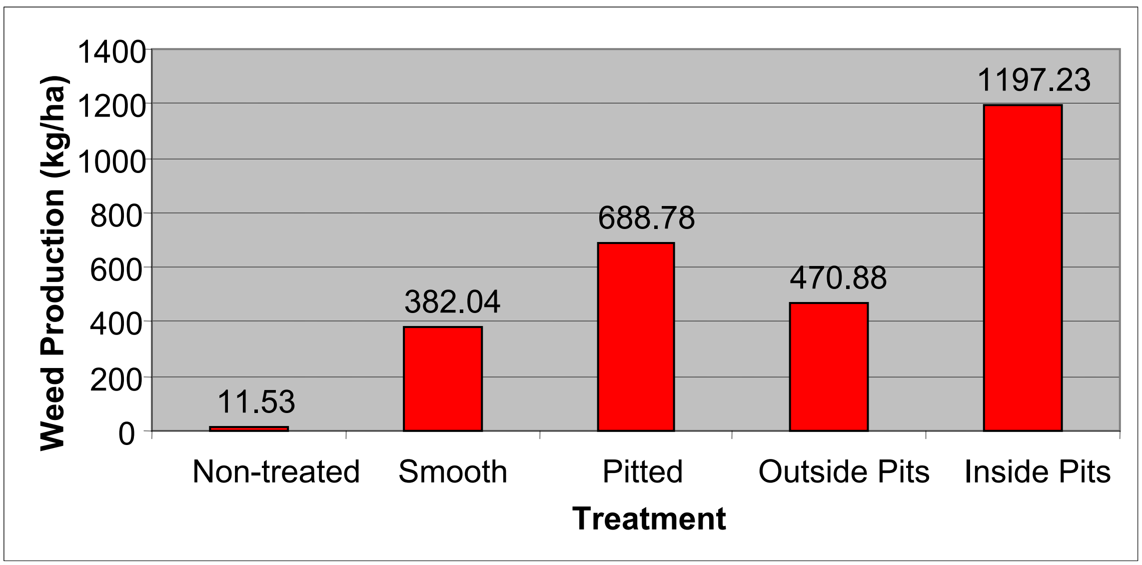

Figure 5.7. Forb Production across Treatments and Collection Points.

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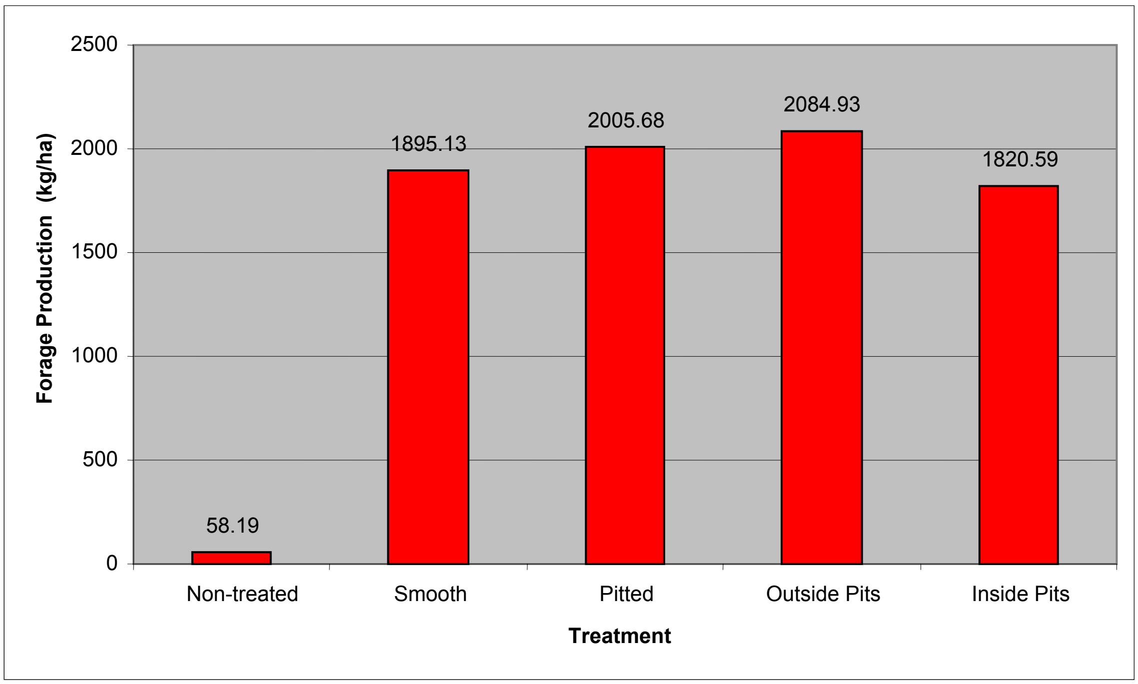

Figure 5.8. Total Herbage Production by Treatment.

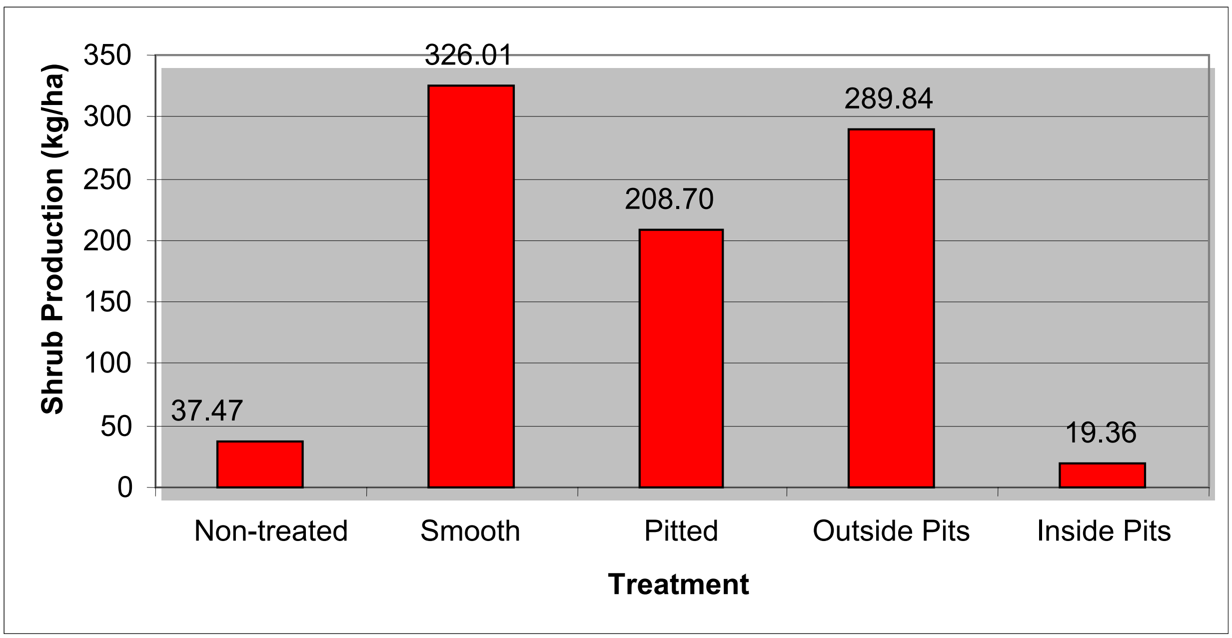

Figure 5.9. Shrub Production Across Treatments and Collection points.

To determine potential herbage production from juniper removal, production functions relative to juniper canopy cover were modified to reflect the level of herbage production measured on the study sites. The herbage production functions were taken from Gerbolini (1996) and Sorrelle (2000). Gerbolini estimated a natural logarithmic function using data collected on a clay loam range site near Justiceburg, Texas. The site in Gerbolini's study was similar to the study site in Gillespie County, although the study sites are located in different geographic regions.

The herbage response production function was used to estimate potential herbage production under better than average range conditions based on percent canopy cover of juniper. The estimated function (Gerbolini, 1996 and Johnson et.al 1999) was adjusted to reflect the level of herbage production on each treated site. This was accomplished by adjusting the intercept and slope of the function. The resulting equation for the smooth treatment is as follows:

$$FP_t = e^{(7.547042-.000495* CC2)}, \qquad (5.4)$$

where FP_t is herbage production in kg/ha at time t, CC2 is canopy cover squared, and e is Euler's coefficient. With a zero percent canopy cover herbage production is $e^{7.547042}$ or 1,895.13 kg/ha. The equation describing herbage production on the pitted site is as follows:

$$FP_t = e^{(7.603738-.000495* CC2)}, \qquad (5.5)$$

where all variables are as previously described. The herbage production on the pitted site with zero percent canopy cover is $e^{7.603738}$ or 2,005.63 kg/ha. The estimated herbage production using the adjusted equations at a 70% canopy, which is representative of the non-treated site, was 167.57 kg/ha and 173.00 kg/ha for the smooth and pitted sites, respectively. These estimates compare to the measured herbage on the non-treated site of 58.16 kg/ha.

The adjusted production functions for the smooth and pitted treatments are shown in Figure 5.10. The differences in herbage production capability results in a 110.50 kg/ha increase on the pitted treatment. This difference could be attributed to the increased roughness of the site which potentially decreased overland flow thus allowing for greater infiltration. Additionally the pitted treatment will have a greater surface area allowing for more herbage to be produced.

However, the adjusted herbage production functions for the treated areas were based on measured grass and forb production collected after only 1½ growing seasons; therefore, there is a possibility that the level of herbage production could increase as the range site becomes more established following treatment. Additionally, 2005 was a below average year with regard to precipitation, which might have reduced the amount of herbage production on the study sites. The Gillespie County Soil Survey states that herbage production on the range sites represented in the study can vary from 1,685 kg/ha in a dry year to in excess of 3,931 kg/ha in a wet year. The herbage data gathered from the study sites was within this range; however, below the average which appears to be consistent with precipitation received in 2005.

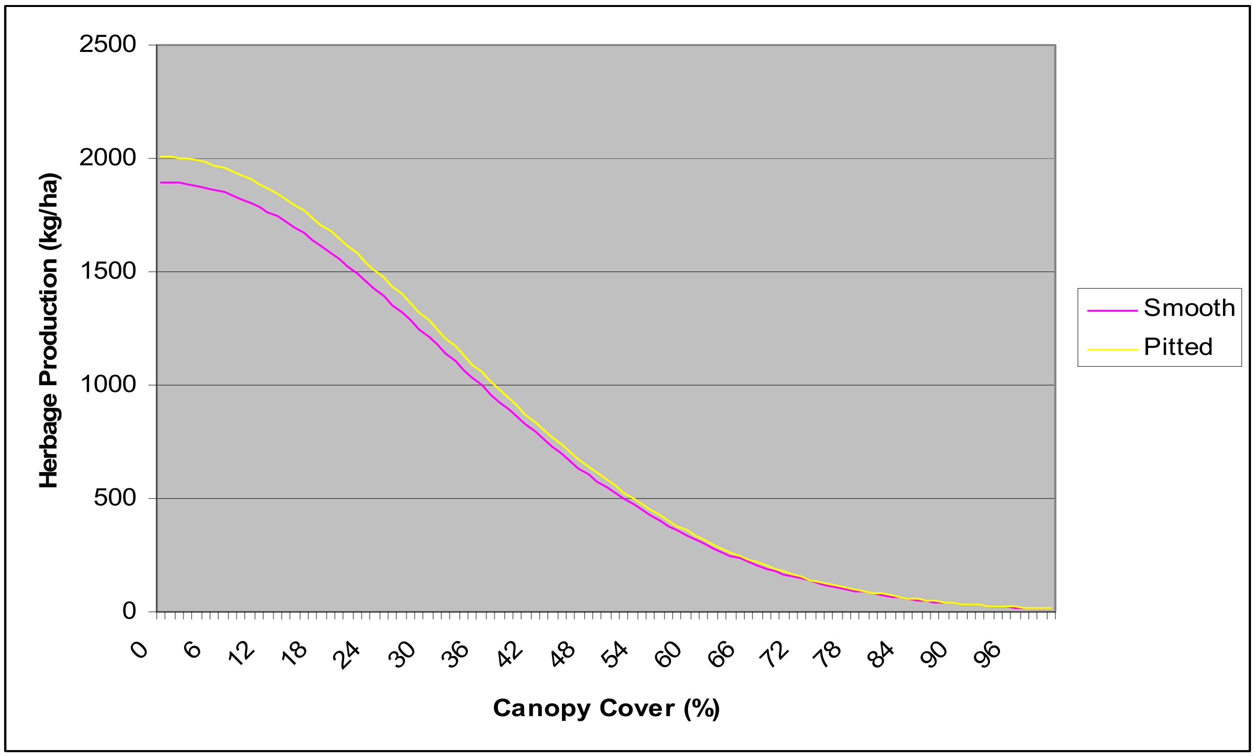

Figure 5.10. Herbage Production on Smooth and Pitted Treatments as a Function of Juniper Canopy Cover.

Economic Evaluation

The Gillespie County Natural Resource Conservation Service (NRCS) calculated cost-share payment amounts based on transects used to estimated canopy cover for the property on which the study sites are located. The government cost-shared 66.77 ha of the 111.29 ha in the property. A cost-share amount was derived for two areas of the property. The first area (moderate infestation) encompassed approximately 16.19 ha with an average canopy cover of 42.5% which was derived from two transects measuring 40% and 45%. The second area (heavy infestation) was 50.58 ha with an average canopy cover estimated to be 68.75% resulting from four transects which measured 80%, 70%, 65%, and 60%. The NRCS estimate of treatment costs were based on the canopy cover measurements that are categorized as light, moderate, or heavy infestation. Moderate juniper infestation is considered to be between 30% and 50% canopy cover and heavy juniper infestation is greater than 50% canopy cover.

The estimated cost of treatment for the moderately infested area was estimated at $345.94/ha of which 60% was cost-shared by the government. The treatment cost for the heavily infested area was estimated at $432.43/ha of which 60% would be cost-shared. The landowner paid $172.97/ha on the heavily infested area for a total investment cost of $8,748.82 and $138.55/ha on moderately infested at a cost of $2,243.12. The total investment cost for the producer was $10,991.94. The weighted cost was $164.62/ha over the 66.77 ha treated area.

For the purposes of this study the main emphasis on economic returns will be based on the area which had the heaviest juniper infestation. However, additional analyses were conducted for comparison purposes on both areas (moderate and heavy infestations) to evaluate the differences in treatment cost, herbage outputs, and treatment applications. Net present value (NPV) calculations were based on different scenarios of the landowner's cost-share and also if the landowner incurred the entire treatment cost with no cost-share.

<u>Net Present Value</u>

All NPV calculations were derived using a spreadsheet model that estimates net returns over a time horizon based on potential herbage production using the herbage response function relative to canopy cover, livestock costs, returns based on a cow/calf production unit, initial brush removal costs, rate of brush re-infestation, periodic retreatment costs using prescribed burning, and land deferment before and after retreatment. The rates for canopy cover growth were assumed to be 1.5% per year if the juniper stand was not treated. Upon treatment, the re-infestation rate of juniper was assumed to occur at a rate of 2% per year.

A 15-year time horizon was chosen for both treatments allowing for three retreatment cycles. Throughout the 15-year time horizon the initial canopy cover has the potential to increase by 22.5%. This can be seen in Appendices D and E under canopy cover at time t (CCt), which is the percent canopy cover prior to treatment. An optimal schedule for retreatment was developed by Gerbolini (1996), which applied prescribed burning to the treated areas. These controlled burns were conducted three years following the initial treatment and every six years after the first retreatment.

Pitted Treatment

On the pitted treatment with herbage production estimated at 2,005 kg/ha the landowner will not gain returns great enough over a 15 year time horizon to justify the initial expense and retreatment cost. If the landowner was to pay the full estimated treatment cost of $432.43/ha on the heavily infested juniper area (68.75% canopy cover) while applying the pitted treatment, the NPV would be -$336.92/ha. With a cost-share of 60% the landowner would invest $172.97/ha; however, even with a 60% reduction in the cost of treatment the NPV continues to be negative at -$77.29/ha. If the pitted treatment and it's potential herbage productivity was applied to the moderately infested juniper area (42.5% canopy cover), the NPV for a cost-share of 60% or $138.38/ha would be -$73.77/ha or -$281.33/ha if the full cost was incurred by the landlord. If the pitted treatment was applied to the total treated area, the landowner would have invested a weighted average of $164.57/ha based on a 60% cost-share. The resulting NPV would be -$73.49/ha. These results indicate that even with a cost-share the investment would not meet the required rate of return of 7.29%.

The NPVs for the pitted treatment show strong evidence that at the cost-share percentages paid on this project, landowners cannot expect to receive the required rate of return of 7.29% even with the potential increased herbage production resulting from the application of the pitted treatment. The calculated IRR of the investment under the cost-share was -1.86%, which would indicate that the project did not cash flow. A sensitivity analysis indicated that it would take a cost-share percentage of 78% to give the landowner a zero NPV for the investment which would represent a 7.29% return on investment.

Smooth Treatment

As with the pitted treatment, various combinations of initial investment costs and canopy cover were analyzed under the smooth treatment option. Though the cost of brush removal was assumed to be the same for both treatments, the cost for the smooth treatment may actually be slightly higher due to additional machine hours required for the smoothing process. All NPVs calculated on the smooth treatment were less desirable or more negative than the pitted treatment due to the lower level of herbage production indicated for the smooth treatment. If the full cost of brush removal was incurred by the landowner to clear the heaviest infestation of juniper, the NPV would be -$342.82/ha. With a 60% cost-share the amount paid by the landowner was $172.97/ha resulting in a NPV of -$83.37/ha. If the smooth treatment was applied to the moderately dense area, the full cost of treatment was $345.94/ha and the resulting NPV was -$285.78/ha. With a 60% cost-share, the investment costs dropped to $138.38/ha with a resulting NPV of -$78.21/ha. Across the cleared area for the project using the smooth treatment, the landowner would have a weighted average NPV of -$79.21/ha. The calculated IRR of the investment under the cost-share was -2.71%, which would indicate that the project did not cash flow. Sensitivity analysis indicate that government cost-share percentages would need to be 79.5% to give the landowner a NPV of zero representing the required rate of return of 7.29%.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND LIMITATIONS

Summary

The infestation of Ashe juniper is a severe problem in many areas of Texas having detrimental affects on land productivity and the overall ecology of the native rangelands. Recently, efforts have been made to rehabilitate these rangelands through brush control practices which evolved from the increasing demands for municipal water supplies by major cities across Texas. Early research estimations indicated that water yields for various Texas watersheds could dramatically be increased if invasive noxious species of brush were removed. As a result, in 1999 the Texas legislature appropriated over $37 million dollars for a program to cost-share brush control projects in certain watersheds. This program provided an incentive for landowners to clear brush from their property at substantially lower cost. With the implementation of the cost-share program, landowners across the state began clearing thousands of acres of invasive brush species. The objectives of these projects were to improve the offsite water yield and improve or maintain the overall range conditions to allow for better grazing capability, improved wildlife habitat, and increasing the aesthetic value of the property.

Over the past decade, there have been great advancements in the development of equipment used to mechanically control brush. As a result, the type of equipment used and the operator's effectiveness was hypothesized to affect the potential results on the land from water storage and herbage production standpoints. Since the implementation of the cost-share program numerous studies have evaluated the effectiveness of brush control from range, water, and economic standpoints with some conflicting results.

However, few studies have researched how the final state of the turf or top-soil profile affects onsite water yield and herbage production after Ashe juniper has been removed. In 2004, a 23 ton bulldozer was used to mechanically clear Ashe juniper on a Gillespie County farm in Central Texas which is in the Pedernales River Watershed. Following the clearing process two treated plots and one non-treated plot, each 2.47 ha in size, were studied over the course of 2005 to determine differences in soil water infiltration and herbage production. One of the treated sites was left "rough" or pitted, a result of uprooting the trees, while the other treated site was smoothed, covering the pits, to give the tract a desirable finish and appearance.

The objective of the study was to compare the pitted and smooth sites with an non-treated site to determine the benefits and costs to the landowner in terms of range productivity and additional water gained from clearing Ashe juniper under the Pedernales River Watershed cost-share program. Specifically, water infiltration into the soil profile was measured on each of the treated sites and the non-treated site; and estimated economic returns to the landowner were evaluated based on increased herbage production as a result of brush removal.

Soil water samples were collected monthly along with rainfall measurements to determine differences in potential soil water infiltration across treatments. This infiltration could possibly lead to deep percolation and aquifer recharge which was one of the goals established by the state for the cost-share program. Herbage samples were taken at the end of the growing season to evaluate the impacts of brush removal on herbage production. A net present value analysis was used to evaluate the returns to the landowner from the investment in brush control.

Three soil water content measurements per month were collected on each of the three study plots. On the pitted site, measurements were collected both inside and outside of the pits. The measurements were then analyzed over the course of the year in correlation with rainfall events. Additionally, herbage samples were collected which were used to determine returns to the landowner via livestock production. The economic or net present value analysis was conducted on the basis of several factors including initial juniper canopy cover percentage, brush removal cost, potential livestock production, and cost of range maintenance.

Soil water content was slightly higher on the treated sites; however, this advantage may decline as the re-establishment of herbage species continues to occur following brush removal. Fluctuations in the soil water content observed could have also been attributed to the 2005 precipitation being nearly 50% less than normal. Overall, the results of the soil water infiltration did not indicate drastic improvements in soil water on the treated sites compared to the non-treated site.

The most significant result determined from the study was the large positive gain in herbage production following brush removal. Herbage production on the treated sites averaged 1,950.40 kg/ha compared to 58.16 kg/ha on the non-treated site, representing a 3,353% increase in herbage production. This provided strong evidence that range productivity can be improved through the control of Ashe juniper. However, the net present value analysis indicated that the brush control program was not a profitable investment even under cost-share payments of 60%. Different scenarios were run based on initial investment cost, potential herbage production based on type of treatment, and pretreatment canopy cover. All scenarios returned negative net present values ranging from -$73.49/ha to -$342.83/ha. A sensitivity analysis of the cost-share percentage indicated that the cost-share would have to exceed 78% in order for the landowner to realize the required 7.29% return on investment.

Conclusions

The most important factor that must be considered before investing in a cost-share brush control program is the land use goals in both the short run and long run. These goals will vary greatly between landowners. Making a decision to invest in brush control based solely on economic return may not apply to all landowners or ranching operations. Many landowners engage in rangeland improvement activities due to their personal interests, desires, and beliefs. To coincide with project goals, analyses in this study were tied directly to the economic value of brush control with no consideration of a landowner's personal goals.

Unless current cost-share percentages are increased, it will be very difficult for landowners to receive returns high enough to justify their investment based on the added returns through livestock production. However, taxpayers also want sufficient returns for their investment as well through increased water yield. Any substantial gains in water yield from brush removal were not indicated in the data. This study did not indicate that the government was receiving significant increases in on-site water yield through soil water infiltration analysis. Furthermore the benefit to cost ratio for the government's investment in brush control is low as indicated by the lack of significant increase in water yield. This could indicate that the State brush control program should be revised or modified on a policy or objective basis to better allocate funds for brush control. While there was some increase in soil water levels following brush control, there was no strong evidence that deep percolation was occurring. In fact, the calculated evapotranspiration levels for the treated and non-treated sites indicated that the treated sites had higher levels which would indicate that precipitation was primarily being used to grow herbage.

The analysis of the data collected in this study indicates that the major benefit from the removal of brush was to produce an economically valuable biomass verses brush which is has no or little economic value. Therefore, it appears from the analysis that the benefits of brush removal, if any, are accruing to the landowner. The landowner could receive other benefits that were not addressed directly in this study such as improved aesthetic value, improved wildlife habitat, and possible increased land values.

Limitations and Recommendations

The most restrictive limitation in this study was the short duration of time for which the data was collected. The one year time frame presented a small portion of understanding on how the removal of juniper affects land productivity and water yield. In addition, the data was collected in year where precipitation events were below the expected area average. The combination of the previously listed limitations influenced the results presented in this study.

Additionally, methods by which soil water content was collected could be modified to allow a better understanding of deep percolation if samples could be taken at depths greater than 24 inches in order to estimate possible aquifer recharge capabilities. In order to fully understand the potential water yields and water balance, runoff measurements from each site would have expanded the data to allow a more specific calculation of evapotranspiration for each treatment. Specific evapotranspiration rates would have allowed a more accurate determination of water use efficiency of juniper versus native rangelands. As previously mentioned there are several additional types of data that could have been collected over a longer period of time to fully understand the effectiveness of juniper control. This information could be applied to expand our understanding of how altering the landscape affects herbage production and the environments water balance.

It is inevitable and well documented by scientist and researchers that the demand for water is going to continue to escalate. There may be potential ways to increase the water yield while restoring our rangelands through brush control. Land productivity and water yield are crucial to the well being and survival of every aspect of life. Without future research to better understand how we can manage our natural resources, our most prized and needed resources may not be available to future generations.

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APPENDIX A

SOIL WATER DATA

This appendix provides all of the monthly data taken on soil water content. Each month consist of the original sample weight in grams or field weight, the oven-dried weight in grams, and percent soil water resulting from the difference in weights. The weights are broken into tiers or depths at which soil water samples were taken. Each tier consists of one six inch soil sample. These tiers are labeled on the basis of inches; 6”, 12”, 18”, and 24”.

On the smooth treatment and the non-treated sites, three samples per month were collected to a maximum depth of four tiers or 24”. On the pitted site three samples were also collected, but measurements were collected both inside and outside of each pit. IP1 refers to the measurement inside the first sample pit. OP refers the sample that was taken outside of the sample pit. OP1 is the first six inch measurement outside of pit 1. At each site, the samples were collected as deep as the soil profile would allow, however changes throughout the plots in soil depth caused lags in the collection of data indicated by blank values.

Table A.1. Soil moisture data for the month of January.

Sample	January Sample				January Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	191.64	198.74	174.82		166.56	164.14	148.80		19.60	27.58	23.71	
2	218.76	194.60			187.50	154.66			21.00	34.51		
3	209.63	176.83			179.90	141.62			21.03	34.33		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	160.48				129.63				34.02			
OP1	170.14	186.36			148.38	151.82			19.86	30.46		
IP2	175.36				137.73				38.10			
OP2	183.20	162.02			152.33	132.33			27.15	31.49		
IP3	159.89				124.81				40.80			
OP3	169.21	183.80	163.73		148.75	152.84	132.68		18.59	27.17	33.12	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	165.40	189.70	184.75	186.63	142.63	164.66	160.37	160.30	21.95	19.90	20.09	21.63
2	195.40	214.02	197.65	178.60	161.17	181.77	167.11	152.36	27.94	22.52	23.69	23.10
3	154.87	182.65	191.23	175.47	136.33	159.75	164.08	149.96	19.03	18.82	21.54	22.89

Table A.2. Soil moisture data for the month of February.

Sample	February Sample				February Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	244.26	191.63			198.12	154.4			28.92246	32.17249		
2	196.42	163.36			163.36	133.09			26.51375	32.14399		
3	206.98	194.15			167.71	158.32			30.4065	30.04108		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	226.08				174.54				38.00885			
OP1	245.9	228.19			201.5	181.71			27.29284	32.44224		
IP2	235.2				182.17				37.02954			
OP2	186.85	197.18			149.88	156.04			33.22549	34.87032		
IP3	217.81				170.49				35.94106			
OP3	219.65	214.14			175.48	169.22			32.29746	34.47164		
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	221.996	220.5	172.74	171.27	181.51	182.53	143.89	143.02	28.38533	26.42678	27.50238	27.05161
2	172.34	231.66	156.06	170.88	143.03	190.73	132.61	142.77	28.0774	26.90108	24.83321	27.02365
3	200.17	221.98	187.14		156.03	181.78	156.44		37.69106	27.973	25.92686	

Table A.3. Soil moisture data for the month of March.

Sample	March Sample				March Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	161.13	201.4			137.42	164.78			23.99069	29.04044		
2	181.23	167.72			153.04	135.63			24.64807	33.18168		
3	215.38	212.88	167.18		186.4	172.35	136.47		19.60227	30.4051	31.2761	
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	169.85	172.34			134.64	141.26			36.79206	30.28354		
OP1	141.53	203.33	195.53		116.02	170.05	164.7		33.04404	25.28683	24.47797	
IP2	110.9	209.34			85.88	168.93			53.32481	31.08462		
OP2	176.69	177.45			149.11	143.67			24.95928	31.98561		
IP3	163.54				132.6				32.99563			
OP3	188.92	224.27	209.04		160.96	193.34	176.97		22.87304	20.02849	23.2324	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	177.36	218.52	207.89	202.93	155.18	186.84	177.18	170.35	19.07137	21.40685	22.22303	24.72678
2	186.85	206.06	182.45	177.82	161.06	176.42	157.31	150	21.06682	21.50319	21.103	25.00674
3	169.21	187.01	167.39	193.12	139.23	158.24	141.62	161.79	29.88735	23.94108	24.87692	25.41575

Table A.4. Soil moisture data for the month of April.

Sample	April Sample				April Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	193.39				165.44				22.0339			
2	219.07	215.8			189.14	196.25			19.89101	12.42611		
3	207.43	193.65	219.83		177.73	157.52	181.66		21.34081	30.49717	26.62157	
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	154.33				140.89				13.18293			
OP1	188.28	172.65			164.54	149.88			18.88323	20.43252		
IP2	182.58	188	177.57		156.48	158.69	153.01		22.20899	24.47395	21.41425	
OP2	192.91	191.04	199.04		170.49	159.05	169.28		17.0003	26.4402	22.7697	
IP3	191.22				156.91				29.05657			
OP3	192.54	179.09	197.8		164.73	149.93	165.09		22.06968	26.26554	25.92739	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	161.14	195.35	196.4		144.52	169.15	165.79		15.73268	20.10744	24.14038	
2	177.34	190.9	189.85	184.18	156.41	165.34	163.96	156.28	17.77193	20.16409	20.58356	23.73862
3	175.26	173.99	206.83		147.76	146.69	172.92		25.26645	25.13349	25.139	

Table A.5. Soil moisture data for the month of May.

Sample	May Sample				May Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	198.88	199.12			173.52	164			18.79493	28.02426		
2	195.54	174.28	168.47		164.33	139.39	139.43		24.83686	34.72678	28.86967	
3	177.67	177.71			147.8	145			27.34346	30.87305		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	182.52				141.95				39.38453			
OP1	188.62	155.14			155.64	127.68			28.23147	30.77095		
IP2	154.47				133.33				22.40119			
OP2	166.58	150.59	183.71		143.9	126.29	152.19		21.54051	27.54165	27.74404	
IP3	168.28	224.17			138.44	194.01			29.95683	19.47188		
OP3	174.89	191.66	178.72		150.41	162.56	153.98		21.91781	23.53417	21.50369	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	168.79	186.42	201.52	174.99	142.5	160.07	170.14	149.43	25.37155	21.73734	23.9268	23.06027
2	171.82	177.16	185.52	189.37	148.66	157.41	164.43	167.01	21.05072	16.62038	16.70495	17.43334
3	185.7	167.8	185.19		154.89	144.24	159.06		26.56722	22.19083	21.58969	

Table A.6. Soil moisture data for the month of June.

Sample	June Sample				June Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	171.73	215.66			148.99	193.49			20.59783	14.32078		
2	175.2	175.98			151.31	143.8			21.20916	30.68268		
3	161.49	137.01	119.13		143.74	114.71	100.91		16.87583	29.47396	29.09149	
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	136.04				116.13				25.7935			
OP1	153.19	148.23			132.72	127.73			21.79979	22.9589		
IP2	172.53				154.07				16.03683			
OP2	149.09	110.98			135.2	98.72			14.38037	20.21101		
IP3	173.39	181.98			152.6	157.44			18.27371	20.74037		
OP3	151.65	164.65	147.3		138.28	141.79	128		13.42909	22.22006	21.66835	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	156.83	176.48	186.17	153.99	142.13	154.15	162.14	134.69	14.23729	19.36687	19.51279	20.08325
2	154.9	149.1	181.76	170.58	136.86	131.22	147.97	147.97	18.36693	19.30052	30.77694	20.70134
3	185.98	181.58	170.12	155.37	164.01	159.08	148.52	135.23	17.56335	18.5935	19.54928	20.82515

Table A.7. Soil moisture data for the month of July.

Sample	July Sample				July Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	174.77	177.64			148.11	143.76			24.34259	32.2421		
2	195.6	171.17	156.06		168.83	143.67	133.43		20.56699	26.25298	23.9243	
3	204.97	179.93			175.82	151.86			21.23707	24.88255		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	201				159.04				34.93755			
OP1	142.57	159.69	175.58		125.91	138.15	151.33		19.12964	21.60265	21.54024	
IP2	176.25				152.8				20.59909			
OP2	168.48	145.22			145.2	128.86			21.8407	18.01762		
IP3	188.53	177.5			150.05	148.16			34.59809	26.90756		
OP3	173.97	173.9	169.14		150.67	151.89	143.84		20.81286	19.48132	24.11591	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	203.72	161.52	173.82		175.23	141.43	150.82		20.89476	19.58471	20.56693	
2	189.98	178.17	209.97	222.12	156.71	162.18	192.39	200.12	28.1782	12.93689	11.40004	13.63327
3	202.58	190.23	179.79	211.26	170.83	170.38	161.59	189.18	24.06944	15.00265	14.72969	14.65552

Table A.8. Soil moisture data for the month of August.

Sample	August Sample				August Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	195.6	178.19			171.56	159.83			18.07927	15.15477		
2	148.72	171.15			129.42	146.55			21.26722	22.85608		
3	166.29	185.62			143.68	158.28			21.50875	22.93047		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	179.76				150.92				25.7546			
OP1	202.96	179.75			178.32	156.37			17.66308	19.82532		
IP2	155.69				125.91				34.24957			
OP2	186.9	176.09	201.46		161.1	150.4	171.19		21.06294	22.86808	22.82633	
IP3	184.99	204.65			153.18	167.75			27.8181	28.68693		
OP3	180.07	189.46	198.04		158.85	161.65	166.27		17.6642	22.65765	24.94896	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	206.05	180.85	158.41	158.87	177.79	157.88	138.03	136.86	21.95	19.90	20.09	21.63
2	192.54	212.15	202.33	214.11	160.5	180.44	173.14	182.2	27.94	22.52	23.69	23.10
3	183.16	197.7	219.89		161.57	173.29	195.09		19.03	18.82	21.54	22.89

Table A.9. Soil moisture data for the month of September.

Sample	September Sample				September Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	153.7	138.6			136.39	119.04			17.69939	24.34047		
2	153.95	139.72	142.35		139.41	122.1	122.55		14.43319	21.18298	23.65309	
3	145.77	134.27			133.65	116.64			12.74582	22.722		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	199.84				187.12				8.584154			
OP1	154.61	174.55			138.7	153.22			15.92911	18.58338		
IP2	146.15				135.22				11.35466			
OP2	132.57	137.37			121.26	126.26			13.68421	12.59637		
IP3	132.67	147.01			117.32	126.54			19.55663	23.41569		
OP3	150.73	167.23			136.08	145.71			15.04725	20.14981		
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	143.65	144.34	162.14	128.82	130.1	131.71	146.42	116.12	14.8542	13.60112	14.63278	16.38076
2	147.69	159.93			133.21	145.47			15.31141	13.52793		
3	179.28	182.11	161.89	161.11	164.44	165.99	147.44	144.83	11.82282	12.60163	13.2072	15.31371

Table A.10. Soil moisture data for the month of October.

Sample	October Sample				October Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	161.39				147.63				12.61922			
2	176.14	154.6			158.06	133.37			15.14365	22.4775		
3	142.75	171.42			128.88	155.73			15.35651	13.44703		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	170.25				151.14				17.03209			
OP1	153.74	157.89	130.08		138.73	137.82	113.31		15.02352	20.19521	22.49195	
IP2	125.88				115.18				14.03831			
OP2	154.82	137.48	164.61		142.17	120.3	145.03		12.21514	20.89008	18.39361	
IP3	159.27				138.01				21.43577			
OP3	149.68	148.09			131.5	132.66			19.59474	16.45867		
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	139.88	154.16	178.81	175.94	125.79	139.34	161.7	159.53	16.21217	14.74774	13.94344	13.56871
2	175.33	179.77	173.54	174.55	157.38	165.83	157.53	157.72	15.11706	10.95481	13.41433	14.14642
3	166.77	162.49	177.5	166.14	148.55	149.1	161.5	151.55	16.61954	12.0598	12.95861	12.90808

Table A.11. Soil moisture data for the month of November.

Sample	November Sample				November Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	144.96	145.53			124.12	123.73			24.36572	25.63198		
2	148.76	171.92			133.65	151.32			15.90861	18.3274		
3	166.82	159.19	155.25		148.95	138.69	136.94		16.18806	20.57407	18.55869	
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	100.37				95.51				8.591126			
OP1	161.95				149.34				11.4097			
IP2	122.76				101.43				34.14439			
OP2	144.76	165.32	153.43		131.09	141.94	131.07		14.78157	22.50674	24.17559	
IP3	135.5				120.41				18.49718			
OP3	176.83	172.94	186.73		155.78	147.08	157.27		17.98223	23.90681	24.89437	
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	174.22	178.65	183.09	184.79	158.89	161.47	163.83	164.76	12.77394	14.01076	15.42775	15.87541
2	152	180.83	177.64		140.01	164.74	160.54		11.82796	12.75365	13.97516	
3	139.25	157.17	193.04	187.37	124.22	141.67	173.11	167.13	17.62016	14.96139	14.75422	15.7375

Table A.12. Soil moisture data for the month of December.

Sample	December Sample				December Sample Dried				Percent Soil Moisture			
	Smooth				Smooth				Smooth			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	141.97				127.78				15.90986			
2	142.07				129.49				13.85157			
3	166.97	180.98			148.97	157.76			16.30287	19.56027		
	Pitted				Pitted				Pitted			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
IP1	131.33				111.91				26.61368			
OP1	157.71	155.13			139.08	131.46			18.58169			
IP2	146.11				125.16				24.30394			
OP2	147.04	154.83			132.79	133.63			15.1306	22.18269		
IP3	144.74				137.2				7.664938			
OP3	175.59				159.68				13.15311			
	Un-treated				Un-treated				Un-treated			
Tier	6"	12"	18"	24"	6"	12"	18"	24"	6"	12"	18"	24"
	(g)				(g)				(%)			
1	131.05	168.05	156.68	162.63	118.84	151.02	139.63	145.48	15.27014	15.18231	16.94157	16.04453
2	160.08	154.14	170.91	156.62	142.56	137.24	153.03	140.03	16.85912	17.12954	15.56813	
3	163.89	165.25	150.26	163.72	146.24	148.22	135.77	147.22	16.44614	15.46074	14.82505	15.17939

APPENDIX B

MONTHLY RAINFALL DATA 2005

Date	Plot			
	Smooth	Pitted	Cedar	Avg.
	--------------------(inches)--------------------			
14-Jan	2.3	2.47	2.1	2.29
5-Feb	1.02	1.02	0.42	0.82
11-Mar	1.35	1.4	1.25	1.33
27-Mar	1.68	1.67	1.41	1.59
14-May	2.45	2.45	2.8	2.57
6-Jun	1	0.93	0.9	0.94
17-Jul	1.95	2.05	2.2	2.07
20-Jul	0.71	0.68	0.45	0.61
29-Jul	0.94	0.92	0.65	0.84
13-Aug	0.55	0.52	0.28	0.45
8-Aug	1.55	1.8	1.8	1.72
11-Sep	0.2	0.32	0.09	0.20
8-Oct	0.31	0.3	0.33	0.31
6-Nov	0.71	0.65	0.92	0.76
21-Dec	0.98	1.05	1.21	1.08
Total	17.7	18.23	16.81	17.58

APPENDIX C

HERBAGE DATA

Quadrat	Type	Un-treated			Smooth			Pitted		
		T1	T2	T3	T1	T2	T3	T1	T2	T3
		(g/.25m2)								
1	Grass	16.94	16.29	17.25	30.1	15.24	50.18	40.77	21.4	91.83
	Weeds	17.46	15.82		19.88	16.82	25.51	18.22	31.45	18.49
	Shrubs	17.89	16.16	15.48		56.61	18.77	15.39	17.56	
	Down Litter	539.04	526.19	683.94	22.93	51.19	61.41	100.99	179.51	141.69
	Standing Litter					135.84		17.17	16.15	
2	Grass	18.45	15.66	16.42	85.14	18.36	81.88	33.65	80.42	32.2
	Weeds	15.53			17.08	26.66	26.01	21.97	21.92	47.14
	Shrubs	17.3	15.94			17.97	16.11	51.15		16.18
	Down Litter	179.19	784.19	390.26	315.88	29.9	196.88	223.96	14.01	73.15
	Standing Litter				15.75	77.86	16.54		63.67	16.07
3	Grass	16.02	18.2	15.77	61.25	33.1	18.93	82.34	38.39	
	Weeds		16.35	15.52	15.77	93.1		34.32	47.6	
	Shrubs	17.09				16.78		15.63	18.82	47.38
	Down Litter	790.67	632.32	550.55	143.23	16.25	202.31	70.54	128.68	292.09
	Standing Litter		15.85	15.78	16.21	193.87	16.46	16.72	17.04	
4	Grass	17.56	17	17.15	16.57	16.4	46.5	49.75	96.19	49.91
	Weeds	15.44		15.98	37.53	115.51			17.86	16.01
	Shrubs		16.78		26.12	19.63	16.15	15.69	16.33	15.59
	Down Litter	247.47	244.24	113.96	198.42	16.52	75.67	86.01	253.83	72.89
	Standing Litter					47.2	39.82	18.72		16.82

APPENDIX D

PITTED TREATMENT ECONOMIC ANALYSIS

This appendix provides outputs for the net present value analysis and other production information pertaining to the implementation of the pitted treatment. Applications for this treatment were applied over several canopy cover percentages and treatment cost incurred by the landowner both cost-share and full cost. The basis for these calculations was derived and modified from a format developed by Gerbolini (1996).

Table D.1. Economic soulution for Pitted Treatment with a 6 year buring cycle and an average full cost of $411.46/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	62.30	287.93	5.77	5.00	1980.76	1692.83	33.95	12.50	411.46	-398.96	12.50	411.46	-398.96	-398.96
1		63.80	261.94	5.25	7.00	1957.13	1695.19	34.00	12.52		12.52	11.67	0.00	11.67	-387.29
2		65.30	237.76	4.77	9.00	1926.06	1688.30	33.86	12.47	6.48	5.99	10.83	5.63	5.20	-382.09
3	Burn	66.80	215.33	4.32	5.00	1980.76	1765.43	35.40	13.01	15.39	-2.38	10.54	12.46	-1.93	-384.01
4		68.30	194.58	3.90	7.00	1957.13	1762.55	35.35	12.99		12.99	9.80	0.00	9.80	-374.21
5		69.80	175.43	3.52	9.00	1926.06	1750.63	35.11	12.91		12.91	9.08	0.00	9.08	-365.13
6		71.30	157.81	3.16	11.00	1887.91	1730.10	34.70	12.76		12.76	8.37	0.00	8.37	-356.76
7		72.80	141.64	2.84	13.00	1843.13	1701.49	34.12	12.56		12.56	7.68	0.00	7.68	-349.09
8		74.30	126.84	2.54	15.00	1792.23	1665.39	33.40	12.31	6.03	6.28	7.01	3.43	3.58	-345.51
9	Burn	75.80	113.33	2.27	5.00	1980.76	1867.43	37.45	13.73	15.39	-1.66	7.29	8.17	-0.88	-346.39
10		77.30	101.04	2.03	7.00	1957.13	1856.09	37.22	13.65		13.65	6.75	0.00	6.75	-339.64
11		78.80	89.87	1.80	9.00	1926.06	1836.18	36.82	13.51		13.51	6.23	0.00	6.23	-333.41
12		80.30	79.76	1.60	11.00	1887.91	1808.15	36.26	13.31		13.31	5.72	0.00	5.72	-327.69
13		81.80	70.63	1.42	13.00	1843.13	1772.50	35.55	13.06		13.06	5.23	0.00	5.23	-322.46
14		83.30	62.40	1.25	15.00	1792.23	1729.83	34.69	12.76	6.03	6.73	4.77	2.25	2.51	-319.94
15	Burn	84.80	55.01	1.10	5.00	1980.76	1925.75	38.62	14.14	15.39	-1.25	4.92	5.36	-0.44	-320.38
Total			2371.30	47.55		30619.14	28247.84	566.48	208.19	476.17	-267.98	128.38	448.76	-320.38	
Avg./yr.		73.55	148.21	2.97	9.13	1913.70	1765.49	35.41	13.01	68.02	-16.75	8.02	28.05	-20.02	

Table D.2. Economic soulution for Pitted Treatment with a 6 year buring cycle and an average cost share of $164.57/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	62.30	287.93	5.77	5.00	1980.76	1692.83	33.95	12.50	164.57	-152.07	12.50	164.57	-152.07	-152.07
1		63.80	261.94	5.25	7.00	1957.13	1695.19	34.00	12.52		12.52	11.67	0.00	11.67	-140.40
2		65.30	237.76	4.77	9.00	1926.06	1688.30	33.86	12.47	6.48	5.99	10.83	5.63	5.20	-135.20
3	Burn	66.80	215.33	4.32	5.00	1980.76	1765.43	35.40	13.01	15.39	-2.38	10.54	12.46	-1.93	-137.12
4		68.30	194.58	3.90	7.00	1957.13	1762.55	35.35	12.99		12.99	9.80	0.00	9.80	-127.32
5		69.80	175.43	3.52	9.00	1926.06	1750.63	35.11	12.91		12.91	9.08	0.00	9.08	-118.24
6		71.30	157.81	3.16	11.00	1887.91	1730.10	34.70	12.76		12.76	8.37	0.00	8.37	-109.87
7		72.80	141.64	2.84	13.00	1843.13	1701.49	34.12	12.56		12.56	7.68	0.00	7.68	-102.20
8		74.30	126.84	2.54	15.00	1792.23	1665.39	33.40	12.31	6.03	6.28	7.01	3.43	3.58	-98.62
9	Burn	75.80	113.33	2.27	5.00	1980.76	1867.43	37.45	13.73	15.39	-1.66	7.29	8.17	-0.88	-99.50
10		77.30	101.04	2.03	7.00	1957.13	1856.09	37.22	13.65		13.65	6.75	0.00	6.75	-92.75
11		78.80	89.87	1.80	9.00	1926.06	1836.18	36.82	13.51		13.51	6.23	0.00	6.23	-86.52
12		80.30	79.76	1.60	11.00	1887.91	1808.15	36.26	13.31		13.31	5.72	0.00	5.72	-80.80
13		81.80	70.63	1.42	13.00	1843.13	1772.50	35.55	13.06		13.06	5.23	0.00	5.23	-75.57
14		83.30	62.40	1.25	15.00	1792.23	1729.83	34.69	12.76	6.03	6.73	4.77	2.25	2.51	-73.05
15	Burn	84.80	55.01	1.10	5.00	1980.76	1925.75	38.62	14.14	15.39	-1.25	4.92	5.36	-0.44	-73.49
Total			2371.30	47.55		30619.14	28247.84	566.48	208.19	229.28	-21.09	128.38	201.87	-73.49	
Avg./yr.		73.55	148.21	2.97	9.13	1913.70	1765.49	35.41	13.01	32.75	-1.32	8.02	12.62	-4.59	

Table D.3. Economic soulution for Pitted Treatment with a 6 year buring cycle and a full cost of $432.43/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	68.75	188.67	3.78	5.00	1980.76	1792.09	35.94	13.20	432.43	-419.23	13.20	432.43	-419.23	-419.23
1		70.25	169.99	3.41	7.00	1957.13	1787.14	35.84	13.16		13.16	12.27	0.00	12.27	-406.96
2		71.75	152.81	3.06	9.00	1926.06	1773.25	35.56	13.07	6.48	6.59	11.35	5.63	5.72	-401.24
3	Burn	73.25	137.06	2.75	5.00	1980.76	1843.70	36.97	13.56	15.39	-1.83	10.98	12.46	-1.48	-402.72
4		74.75	122.66	2.46	7.00	1957.13	1834.47	36.79	13.50		13.50	10.19	0.00	10.19	-392.53
5		76.25	109.52	2.20	9.00	1926.06	1816.54	36.43	13.37		13.37	9.40	0.00	9.40	-383.13
6		77.75	97.57	1.96	11.00	1887.91	1790.34	35.90	13.19		13.19	8.64	0.00	8.64	-374.48
7		79.25	86.73	1.74	13.00	1843.13	1756.40	35.22	12.95		12.95	7.91	0.00	7.91	-366.57
8		80.75	76.92	1.54	15.00	1792.23	1715.31	34.40	12.66	6.03	6.63	7.21	3.43	3.78	-362.80
9	Burn	82.25	68.07	1.37	5.00	1980.76	1912.69	38.36	14.04	15.39	-1.35	7.46	8.17	-0.71	-363.51
10		83.75	60.10	1.21	7.00	1957.13	1897.03	38.04	13.94		13.94	6.89	0.00	6.89	-356.62
11		85.25	52.94	1.06	9.00	1926.06	1873.11	37.56	13.77		13.77	6.35	0.00	6.35	-350.27
12		86.75	46.53	0.93	11.00	1887.91	1841.38	36.93	13.54		13.54	5.82	0.00	5.82	-344.44
13		88.25	40.81	0.82	13.00	1843.13	1802.32	36.14	13.27		13.27	5.32	0.00	5.32	-339.13
14		89.75	35.71	0.72	15.00	1792.23	1756.52	35.23	12.95	6.03	6.92	4.84	2.25	2.58	-336.55
15	Burn	91.25	31.18	0.63	5.00	1980.76	1949.58	39.10	14.30	15.39	-1.09	4.98	5.36	-0.38	-336.92
Total			1477.274	29.62524		30619.14	29141.87	584.4111	214.4639	497.1386	-282.6748	132.8062	469.7295	-336.9232	
Avg./yr.		80	92.3296	1.851578	9.125	1913.696	1821.367	36.52569	13.40399	71.0198	-17.66717	8.300389	29.35809	-21.0577	

Table D.4. Economic soulution for Pitted Treatment with a 6 year buring cycle and a full cost of $345.94/ha.

Year	Treatment	Without Treatment			With Treatment										
		CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	42.50	812.76	16.30	5.00	1980.76	1168.00	23.42	8.82	345.94	-337.12	8.82	345.94	-337.12	-337.12
1		44.00	761.69	15.28	7.00	1957.13	1195.43	23.97	9.01		9.01	8.40	0.00	8.40	-328.72
2		45.50	712.23	14.28	9.00	1926.06	1213.82	24.34	9.14	6.48	2.66	7.94	5.63	2.31	-326.41
3	Burn	47.00	664.49	13.33	5.00	1980.76	1316.27	26.40	9.86	15.39	-5.54	7.98	12.47	-4.48	-330.90
4		48.50	618.55	12.40	7.00	1957.13	1338.58	26.84	10.02		10.02	7.56	0.00	7.56	-323.34
5		50.00	574.49	11.52	9.00	1926.06	1351.56	27.10	10.11		10.11	7.11	0.00	7.11	-316.23
6		51.50	532.38	10.68	11.00	1887.91	1355.54	27.18	10.13		10.13	6.64	0.00	6.64	-309.58
7		53.00	492.24	9.87	13.00	1843.13	1350.90	27.09	10.10		10.10	6.17	0.00	6.17	-303.41
8		54.50	454.10	9.11	15.00	1792.23	1338.13	26.83	10.01	6.03	3.98	5.70	3.43	2.27	-301.14
9	Burn	56.00	417.98	8.38	5.00	1980.76	1562.78	31.34	11.59	15.39	-3.81	6.15	8.17	-2.02	-303.16
10		57.50	383.86	7.70	7.00	1957.13	1573.27	31.55	11.66		11.66	5.77	0.00	5.77	-297.39
11		59.00	351.74	7.05	9.00	1926.06	1574.32	31.57	11.67		11.67	5.38	0.00	5.38	-292.01
12		60.50	321.58	6.45	11.00	1887.91	1566.33	31.41	11.61		11.61	4.99	0.00	4.99	-287.02
13		62.00	293.35	5.88	13.00	1843.13	1549.79	31.08	11.50		11.50	4.61	0.00	4.61	-282.41
14		63.50	266.99	5.35	15.00	1792.23	1525.24	30.59	11.33	6.03	5.30	4.23	2.25	1.98	-280.44
15	Burn	65.00	242.45	4.86	5.00	1980.76	1738.31	34.86	12.82	15.39	-2.57	4.46	5.36	-0.90	-281.33
Total			7900.876	158.4442		30619.14	22718.27	455.5921	169.3772	410.6659	-241.2887	101.9188	383.2514	-281.3326	
Avg./yr.		53.75	493.8048	9.902761	9.125	1913.696	1419.892	28.47451	10.58608	58.66656	-15.08054	6.369923	23.95321	-17.58329	

Table D.5. Economic soulution for Pitted Treatment with a 6 year buring cycle and a cost share of $172.97/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	68.75	188.67	3.78	5.00	1980.76	1792.09	35.94	13.20	172.97	-159.77	13.20	172.97	-159.77	-159.77
1		70.25	169.99	3.41	7.00	1957.13	1787.14	35.84	13.16		13.16	12.27	0.00	12.27	-147.50
2		71.75	152.81	3.06	9.00	1926.06	1773.25	35.56	13.07	6.48	6.59	11.35	5.63	5.72	-141.78
3	Burn	73.25	137.06	2.75	5.00	1980.76	1843.70	36.97	13.56	15.39	-1.83	10.98	12.46	-1.48	-143.26
4		74.75	122.66	2.46	7.00	1957.13	1834.47	36.79	13.50		13.50	10.19	0.00	10.19	-133.08
5		76.25	109.52	2.20	9.00	1926.06	1816.54	36.43	13.37		13.37	9.40	0.00	9.40	-123.67
6		77.75	97.57	1.96	11.00	1887.91	1790.34	35.90	13.19		13.19	8.64	0.00	8.64	-115.03
7		79.25	86.73	1.74	13.00	1843.13	1756.40	35.22	12.95		12.95	7.91	0.00	7.91	-107.12
8		80.75	76.92	1.54	15.00	1792.23	1715.31	34.40	12.66	6.03	6.63	7.21	3.43	3.78	-103.34
9	Burn	82.25	68.07	1.37	5.00	1980.76	1912.69	38.36	14.04	15.39	-1.35	7.46	8.17	-0.71	-104.05
10		83.75	60.10	1.21	7.00	1957.13	1897.03	38.04	13.94		13.94	6.89	0.00	6.89	-97.16
11		85.25	52.94	1.06	9.00	1926.06	1873.11	37.56	13.77		13.77	6.35	0.00	6.35	-90.81
12		86.75	46.53	0.93	11.00	1887.91	1841.38	36.93	13.54		13.54	5.82	0.00	5.82	-84.99
13		88.25	40.81	0.82	13.00	1843.13	1802.32	36.14	13.27		13.27	5.32	0.00	5.32	-79.67
14		89.75	35.71	0.72	15.00	1792.23	1756.52	35.23	12.95	6.03	6.92	4.84	2.25	2.58	-77.09
15	Burn	91.25	31.18	0.63	5.00	1980.76	1949.58	39.10	14.30	15.39	-1.09	4.98	5.36	-0.38	-77.47
Total			1477.274	29.62524		30619.14	29141.87	584.4111	214.4639	237.6836	-23.21975	132.8062	210.2745	-77.46825	
Avg./yr.		80	92.3296	1.851578	9.125	1913.696	1821.367	36.52569	13.40399	33.9548	-1.451235	8.300389	13.14215	-4.841765	

Table D.6. Economic soulution for Pitted Treatment with a 6 year buring cycle and a cost share of $138.38/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [2]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	42.50	812.76	16.30	5.00	1980.76	1168.00	23.42	8.82	138.38	-129.56	8.82	138.38	-129.56	-129.56
1		44.00	761.69	15.28	7.00	1957.13	1195.43	23.97	9.01		9.01	8.40	0.00	8.40	-121.16
2		45.50	712.23	14.28	9.00	1926.06	1213.82	24.34	9.14	6.48	2.66	7.94	5.63	2.31	-118.85
3	Burn	47.00	664.49	13.33	5.00	1980.76	1316.27	26.40	9.86	15.39	-5.53	7.98	12.46	-4.48	-123.33
4		48.50	618.55	12.40	7.00	1957.13	1338.58	26.84	10.02		10.02	7.56	0.00	7.56	-115.77
5		50.00	574.49	11.52	9.00	1926.06	1351.56	27.10	10.11		10.11	7.11	0.00	7.11	-108.66
6		51.50	532.38	10.68	11.00	1887.91	1355.54	27.18	10.13		10.13	6.64	0.00	6.64	-102.02
7		53.00	492.24	9.87	13.00	1843.13	1350.90	27.09	10.10		10.10	6.17	0.00	6.17	-95.84
8		54.50	454.10	9.11	15.00	1792.23	1338.13	26.83	10.01	6.03	3.98	5.70	3.43	2.27	-93.58
9	Burn	56.00	417.98	8.38	5.00	1980.76	1562.78	31.34	11.59	15.39	-3.80	6.15	8.17	-2.02	-95.59
10		57.50	383.86	7.70	7.00	1957.13	1573.27	31.55	11.66		11.66	5.77	0.00	5.77	-89.82
11		59.00	351.74	7.05	9.00	1926.06	1574.32	31.57	11.67		11.67	5.38	0.00	5.38	-84.44
12		60.50	321.58	6.45	11.00	1887.91	1566.33	31.41	11.61		11.61	4.99	0.00	4.99	-79.45
13		62.00	293.35	5.88	13.00	1843.13	1549.79	31.08	11.50		11.50	4.61	0.00	4.61	-74.84
14		63.50	266.99	5.35	15.00	1792.23	1525.24	30.59	11.33	6.03	5.30	4.23	2.25	1.98	-72.87
15	Burn	65.00	242.45	4.86	5.00	1980.76	1738.31	34.86	12.82	15.39	-2.57	4.46	5.36	-0.89	-73.76
Total			7900.876	158.4442		30619.14	22718.27	455.5921	169.3772	203.0896	-33.71238	101.9188	175.6805	-73.7617	
Avg./yr.		53.75	493.8048	9.902761	9.125	1913.696	1419.892	28.47451	10.58608	29.0128	-2.107024	6.369923	10.98003	-4.610106	

APPENDIX E

SMOOTH TREATMENT ECONOMIC ANALYSIS

This appendix provides outputs for the net present value analysis and other production information pertaining to the implementation of the smooth treatment. Applications for this treatment were applied over several canopy cover percentages and treatment cost incurred by the landowner both cost-share and full cost. The basis for these calculations was derived and modified from a format developed by Gerbolini (1996).

Table E.1. Economic soulution for Smooth Treatment with a 6 year buring cycle and an average full cost of $411.46/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			---($/ha)---						
0	Dozer	62.30	277.50	5.56	5.00	1871.82	1594.33	31.97	11.81	411.46	-399.65	11.81	411.46	-399.65	-399.65
1		63.80	252.69	5.07	7.00	1849.72	1597.02	32.03	11.83		11.83	11.03	0.00	11.03	-388.62
2		65.30	229.60	4.60	9.00	1820.65	1591.05	31.91	11.79	6.13	5.66	10.24	5.32	4.92	-383.71
3	Burn	66.80	208.14	4.17	5.00	1871.82	1663.68	33.36	12.30	15.02	-2.73	9.96	12.16	-2.21	-385.91
4		68.30	188.28	3.78	7.00	1849.72	1661.44	33.32	12.28		12.28	9.27	0.00	9.27	-376.65
5		69.80	169.93	3.41	9.00	1820.65	1650.72	33.10	12.21		12.21	8.59	0.00	8.59	-368.06
6		71.30	153.03	3.07	11.00	1784.95	1631.93	32.73	12.07		12.07	7.92	0.00	7.92	-360.14
7		72.80	137.50	2.76	13.00	1743.04	1605.54	32.20	11.89		11.89	7.27	0.00	7.27	-352.88
8		74.30	123.27	2.47	15.00	1695.39	1572.12	31.53	11.65	5.70	5.95	6.64	3.25	3.39	-349.49
9	Burn	75.80	110.27	2.21	5.00	1871.82	1761.55	35.33	12.98	15.02	-2.04	6.89	7.98	-1.08	-350.57
10		77.30	98.42	1.97	7.00	1849.72	1751.29	35.12	12.91		12.91	6.39	0.00	6.39	-344.18
11		78.80	87.65	1.76	9.00	1820.65	1733.00	34.75	12.78		12.78	5.90	0.00	5.90	-338.29
12		80.30	77.89	1.56	11.00	1784.95	1707.07	34.23	12.60		12.60	5.42	0.00	5.42	-332.87
13		81.80	69.05	1.38	13.00	1743.04	1673.99	33.57	12.37		12.37	4.96	0.00	4.96	-327.92
14		83.30	61.09	1.23	15.00	1695.39	1634.30	32.77	12.09	5.70	6.39	4.51	2.13	2.38	-325.53
15	Burn	84.80	53.92	1.08	5.00	1871.82	1817.90	36.46	13.38	15.02	-1.64	4.66	5.23	-0.57	-326.10
Total			2298.23	46.09		28945.15	26646.93	534.38	196.95	474.07	-277.12	121.43	447.53	-326.10	
Avg./yr.		73.55	143.64	2.88	9.13	1809.07	1665.43	33.40	12.31	67.72	-17.32	7.59	27.97	-20.38	

Table E.2. Economic soulution for Smooth Treatment with a 6 year buring cycle and an average cost share of $164.57/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			---------------------------------------($/ha)---------------------------------------						
0	Dozer	62.30	287.93	5.56	5.00	277.50	1594.33	31.97	11.81	164.57	-152.76	11.81	164.57	-152.76	-152.76
1		63.80	261.94	5.07	7.00	252.69	1597.02	32.03	11.83		11.83	11.03	0.00	11.03	-141.73
2		65.30	237.76	4.60	9.00	229.60	1591.05	31.91	11.79	6.13	5.66	10.24	5.32	4.92	-136.82
3	Burn	66.80	215.33	4.17	5.00	208.14	1663.68	33.36	12.30	15.02	-2.73	9.96	12.16	-2.21	-139.02
4		68.30	194.58	3.78	7.00	188.28	1661.44	33.32	12.28		12.28	9.27	0.00	9.27	-129.76
5		69.80	175.43	3.41	9.00	169.93	1650.72	33.10	12.21		12.21	8.59	0.00	8.59	-121.17
6		71.30	157.81	3.07	11.00	153.03	1631.93	32.73	12.07		12.07	7.92	0.00	7.92	-113.25
7		72.80	141.64	2.76	13.00	137.50	1605.54	32.20	11.89		11.89	7.27	0.00	7.27	-105.99
8		74.30	126.84	2.47	15.00	123.27	1572.12	31.53	11.65	5.70	5.95	6.64	3.25	3.39	-102.60
9	Burn	75.80	113.33	2.21	5.00	110.27	1761.55	35.33	12.98	15.02	-2.04	6.89	7.98	-1.08	-103.68
10		77.30	101.04	1.97	7.00	98.42	1751.29	35.12	12.91		12.91	6.39	0.00	6.39	-97.29
11		78.80	89.87	1.76	9.00	87.65	1733.00	34.75	12.78		12.78	5.90	0.00	5.90	-91.40
12		80.30	79.76	1.56	11.00	77.89	1707.07	34.23	12.60		12.60	5.42	0.00	5.42	-85.98
13		81.80	70.63	1.38	13.00	69.05	1673.99	33.57	12.37		12.37	4.96	0.00	4.96	-81.03
14		83.30	62.40	1.23	15.00	61.09	1634.30	32.77	12.09	5.70	6.39	4.51	2.13	2.38	-78.64
15	Burn	84.80	55.01	1.08	5.00	53.92	1817.90	36.46	13.38	15.02	-1.64	4.66	5.23	-0.57	-79.21
Total			2371.30	46.09		2298.23	26646.93	534.38	196.95	227.18	-30.23	121.43	200.64	-79.21	
Avg./yr.		73.55	148.21	2.88	9.13	143.64	1665.43	33.40	12.31	32.45	-1.89	7.59	12.54	-4.95	

Table E.3. Economic soulution for Smooth Treatment with a 6 year buring cycle and a full cost of $432.43/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			---($/ha)---						
0	Dozer	68.75	182.62	3.66	5.00	1871.82	1689.20	33.88	12.48	432.43	-419.95	12.48	432.43	-419.95	-419.95
1		70.25	164.71	3.30	7.00	1849.72	1685.01	33.79	12.45		12.45	11.60	0.00	11.60	-408.35
2		71.75	148.23	2.97	9.00	1820.65	1672.42	33.54	12.36	6.13	6.23	10.74	5.32	5.41	-402.94
3	Burn	73.25	133.10	2.67	5.00	1871.82	1738.72	34.87	12.82	15.02	-2.20	10.38	12.16	-1.78	-404.72
4		74.75	119.25	2.39	7.00	1849.72	1730.47	34.70	12.77		12.77	9.63	0.00	9.63	-395.09
5		76.25	106.60	2.14	9.00	1820.65	1714.05	34.37	12.65		12.65	8.90	0.00	8.90	-386.19
6		77.75	95.08	1.91	11.00	1784.95	1689.87	33.89	12.48		12.48	8.18	0.00	8.18	-378.00
7		79.25	84.62	1.70	13.00	1743.04	1658.42	33.26	12.26		12.26	7.49	0.00	7.49	-370.51
8		80.75	75.14	1.51	15.00	1695.39	1620.25	32.49	11.99	5.70	6.29	6.83	3.25	3.58	-366.93
9	Burn	82.25	66.58	1.34	5.00	1871.82	1805.25	36.20	13.29	15.02	-1.73	7.06	7.98	-0.92	-367.85
10		83.75	58.86	1.18	7.00	1849.72	1790.86	35.91	13.19		13.19	6.53	0.00	6.53	-361.33
11		85.25	51.91	1.04	9.00	1820.65	1768.73	35.47	13.03		13.03	6.01	0.00	6.01	-355.31
12		86.75	45.69	0.92	11.00	1784.95	1739.26	34.88	12.83		12.83	5.51	0.00	5.51	-349.80
13		88.25	40.12	0.80	13.00	1743.04	1702.92	34.15	12.57		12.57	5.04	0.00	5.04	-344.76
14		89.75	35.16	0.71	15.00	1695.39	1660.23	33.29	12.27	5.70	6.57	4.58	2.13	2.45	-342.31
15	Burn	91.25	30.73	0.62	5.00	1871.82	1841.09	36.92	13.54	15.02	-1.48	4.71	5.23	-0.52	-342.83
Total			1438.39	28.85		28945.15	27506.76	551.62	202.99	495.04	-292.05	125.67	468.50	-342.83	
Avg./yr.		80.00	89.90	1.80	9.13	1809.07	1719.17	34.48	12.69	70.72	-18.25	7.85	29.28	-21.43	

Table E.4. Economic soulution for Smooth Treatment with a 6 year buring cycle and a full cost of $345.94/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	42.50	775.07	15.54	5.00	1871.82	1096.76	21.99	8.32	345.94	-337.62	8.32	345.94	-337.62	-337.62
1		44.00	726.85	14.58	7.00	1849.72	1122.86	22.52	8.50		8.50	7.92	0.00	7.92	-329.70
2		45.50	680.12	13.64	9.00	1820.65	1140.53	22.87	8.63	6.13	2.50	7.49	5.32	2.17	-327.53
3	Burn	47.00	634.98	12.73	5.00	1871.82	1236.85	24.80	9.30	15.02	-5.72	7.53	12.16	-4.63	-332.16
4		48.50	591.51	11.86	7.00	1849.72	1258.21	25.23	9.45		9.45	7.13	0.00	7.13	-325.03
5		50.00	549.79	11.03	9.00	1820.65	1270.85	25.49	9.54		9.54	6.71	0.00	6.71	-318.32
6		51.50	509.88	10.23	11.00	1784.95	1275.07	25.57	9.57		9.57	6.27	0.00	6.27	-312.04
7		53.00	471.82	9.46	13.00	1743.04	1271.23	25.49	9.54		9.54	5.83	0.00	5.83	-306.21
8		54.50	435.62	8.74	15.00	1695.39	1259.77	25.26	9.46	5.70	3.76	5.39	3.25	2.14	-304.07
9	Burn	56.00	401.31	8.05	5.00	1871.82	1470.52	29.49	10.94	15.02	-4.08	5.81	7.98	-2.17	-306.24
10		57.50	368.87	7.40	7.00	1849.72	1480.84	29.70	11.01		11.01	5.45	0.00	5.45	-300.79
11		59.00	338.30	6.78	9.00	1820.65	1482.34	29.73	11.02		11.02	5.08	0.00	5.08	-295.71
12		60.50	309.58	6.21	11.00	1784.95	1475.37	29.59	10.98		10.98	4.72	0.00	4.72	-290.99
13		62.00	282.67	5.67	13.00	1743.04	1460.38	29.29	10.87		10.87	4.35	0.00	4.35	-286.63
14		63.50	257.52	5.16	15.00	1695.39	1437.87	28.84	10.71	5.70	5.01	4.00	2.13	1.87	-284.76
15	Burn	65.00	234.08	4.69	5.00	1871.82	1637.74	32.84	12.12	15.02	-2.91	4.22	5.23	-1.01	-285.78
Total			7567.96	151.77		28945.15	21377.20	428.70	159.96	408.55	-248.58	96.23	382.01	-285.78	
Avg./yr.		53.75	473.00	9.49	9.13	1809.07	1336.07	26.79	10.00	58.36	-15.54	6.01	23.88	-17.86	

Table E.5. Economic soulution for Smooth Treatment with a 6 year buring cycle and a cost share of $172.97/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	68.75	182.62	3.66	5.00	1871.82	1689.21	33.88	12.48	172.97	-160.49	12.48	172.97	-160.49	-160.49
1		70.25	164.71	3.30	7.00	1849.72	1685.01	33.79	12.45		12.45	11.60	0.00	11.60	-148.89
2		71.75	148.23	2.97	9.00	1820.65	1672.42	33.54	12.36	6.13	6.23	10.74	5.32	5.41	-143.48
3	Burn	73.25	133.10	2.67	5.00	1871.82	1738.72	34.87	12.82	15.03	-2.20	10.38	12.17	-1.78	-145.26
4		74.75	119.25	2.39	7.00	1849.72	1730.47	34.70	12.77		12.77	9.63	0.00	9.63	-135.63
5		76.25	106.60	2.14	9.00	1820.65	1714.05	34.37	12.65		12.65	8.90	0.00	8.90	-126.73
6		77.75	95.08	1.91	11.00	1784.95	1689.87	33.89	12.48		12.48	8.18	0.00	8.18	-118.55
7		79.25	84.62	1.70	13.00	1743.04	1658.42	33.26	12.26		12.26	7.49	0.00	7.49	-111.06
8		80.75	75.14	1.51	15.00	1695.39	1620.25	32.49	11.99	5.70	6.29	6.83	3.25	3.58	-107.47
9	Burn	82.25	66.58	1.34	5.00	1871.82	1805.25	36.20	13.29	15.03	-1.74	7.06	7.98	-0.92	-108.40
10		83.75	58.86	1.18	7.00	1849.72	1790.86	35.91	13.19		13.19	6.53	0.00	6.53	-101.87
11		85.25	51.91	1.04	9.00	1820.65	1768.73	35.47	13.03		13.03	6.01	0.00	6.01	-95.86
12		86.75	45.69	0.92	11.00	1784.95	1739.26	34.88	12.83		12.83	5.51	0.00	5.51	-90.35
13		88.25	40.12	0.80	13.00	1743.04	1702.92	34.15	12.57		12.57	5.04	0.00	5.04	-85.31
14		89.75	35.16	0.71	15.00	1695.39	1660.23	33.29	12.27	5.70	6.57	4.58	2.13	2.45	-82.86
15	Burn	91.25	30.73	0.62	5.00	1871.82	1841.09	36.92	13.54	15.03	-1.49	4.71	5.23	-0.52	-83.37
Total			1438.39	28.85		28945.16	27506.77	551.62	202.99	235.59	-32.60	125.67	209.05	-83.37	
Avg./yr.		80.00	89.90	1.80	9.13	1809.07	1719.17	34.48	12.69	33.66	-2.04	7.85	13.07	-5.21	

Table E.6. Economic soulution for Smooth Treatment with a 6 year buring cycle and a cost share of $138.38/ha.

		Without Treatment			With Treatment										
Year	Treatment	CCt	FPt	LPt	CCt,tw	FPt,tw	AFPt	ALPt	ARt	ACt	NRt	PVARt	PVACt	NPVt	CTNPV [z]
		(%)	---------(Kg/ha)-------		(%)	--------------(Kg/ha)------------			--($/ha)--						
0	Dozer	42.50	775.07	15.54	5.00	1871.82	1096.76	21.99	8.32	138.38	-130.06	8.32	138.38	-130.06	-130.06
1		44.00	726.85	14.58	7.00	1849.72	1122.86	22.52	8.50		8.50	7.92	0.00	7.92	-122.13
2		45.50	680.12	13.64	9.00	1820.65	1140.53	22.87	8.63	6.13	2.50	7.49	5.32	2.17	-119.96
3	Burn	47.00	634.98	12.73	5.00	1871.82	1236.85	24.80	9.30	15.02	-5.72	7.53	12.16	-4.63	-124.60
4		48.50	591.51	11.86	7.00	1849.72	1258.21	25.23	9.45		9.45	7.13	0.00	7.13	-117.46
5		50.00	549.79	11.03	9.00	1820.65	1270.85	25.49	9.54		9.54	6.71	0.00	6.71	-110.75
6		51.50	509.88	10.23	11.00	1784.95	1275.07	25.57	9.57		9.57	6.27	0.00	6.27	-104.48
7		53.00	471.82	9.46	13.00	1743.04	1271.23	25.49	9.54		9.54	5.83	0.00	5.83	-98.65
8		54.50	435.62	8.74	15.00	1695.39	1259.77	25.26	9.46	5.70	3.76	5.39	3.25	2.14	-96.51
9	Burn	56.00	401.31	8.05	5.00	1871.82	1470.52	29.49	10.94	15.02	-4.08	5.81	7.98	-2.17	-98.68
10		57.50	368.87	7.40	7.00	1849.72	1480.84	29.70	11.01		11.01	5.45	0.00	5.45	-93.23
11		59.00	338.30	6.78	9.00	1820.65	1482.34	29.73	11.02		11.02	5.08	0.00	5.08	-88.14
12		60.50	309.58	6.21	11.00	1784.95	1475.37	29.59	10.98		10.98	4.72	0.00	4.72	-83.43
13		62.00	282.67	5.67	13.00	1743.04	1460.38	29.29	10.87		10.87	4.35	0.00	4.35	-79.07
14		63.50	257.52	5.16	15.00	1695.39	1437.87	28.84	10.71	5.70	5.01	4.00	2.13	1.87	-77.20
15	Burn	65.00	234.08	4.69	5.00	1871.82	1637.74	32.84	12.12	15.02	-2.91	4.22	5.23	-1.01	-78.21
Total			7567.96	151.77		28945.15	21377.20	428.70	159.96	200.98	-41.02	96.23	174.45	-78.21	
Avg./yr.		53.75	473.00	9.49	9.13	1809.07	1336.07	26.79	10.00	28.71	-2.56	6.01	10.90	-4.89	

APPENDIX F

MARKETABLE ANIMAL UNIT (MAU)

The calculation for the total number of kilograms sold from one animal unit is as follows:

$$MAU = (WH)\ (\%H) + (WS)\ (\%S) + (WC)\ (\%C) \qquad (B.1)$$

where MAU is the marketable weight in kilograms of an animal unit, WH is the weight of heifer at weaning, %H is the percent of a heifer for sale in an animal unit, WS is the weight of a steer at weaning, %S is the percent of a steer for sale in an animal unit, WC is the weight of a cull cow, and %C is the percent of a cull cow for sale per animal unit.

MAU was calculated under the assumptions that; weaning percentage is 82.27 %, a 50% chance of giving birth to a heifer or bull, a culling cow rate of 14%, replacement heifers coming into the herd, the percent of heifer calves, steer calves, and cull cows for sale is 27.135%, 41.135%, and 14% respectively. Given weights of WH is 244.761 kg, WS of 262.488 kg, and WC of 453.6 kg, equation B.1 can be written as follows:

$$MAU = (244.761 * .27135) + (262.488 * .41135) + (453.6 * .14) = 237.8943 \text{ kg.}$$

Source: Gerbolini 1996.

APPENDIX G

PICTURES OF STUDY PLOTS AND DATA COLLECTION

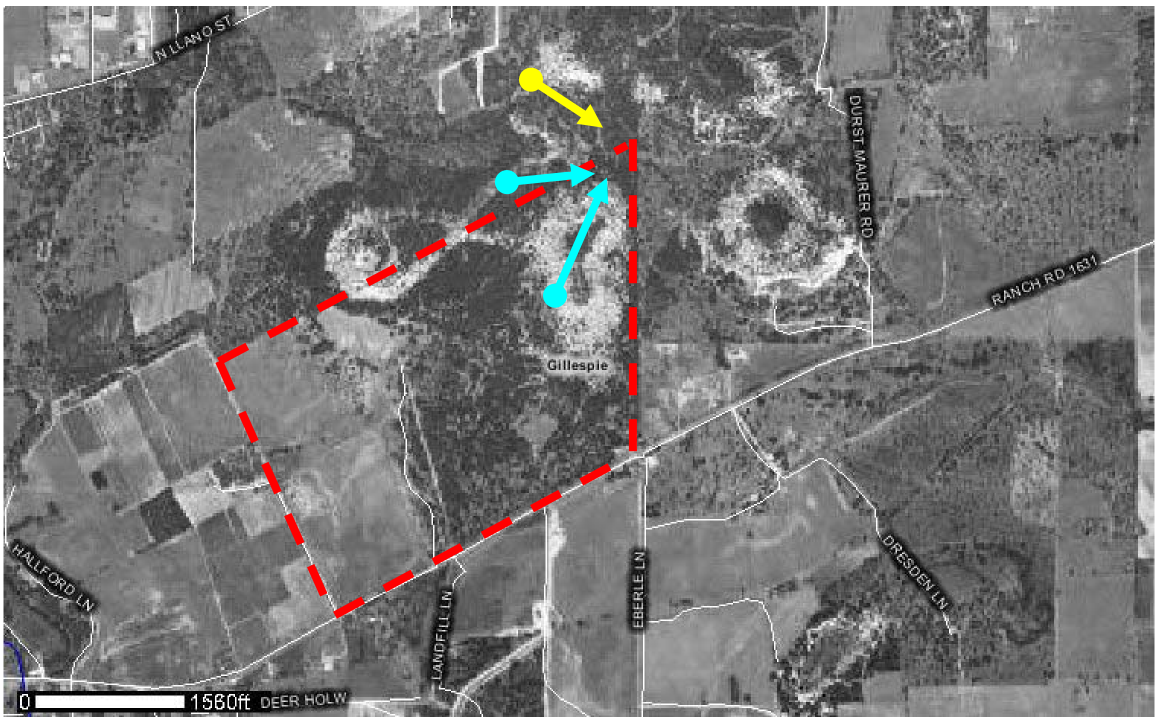

Figure G.1. Dashed line indicates the property line of ranch studied. Blue arrows indicate approximate location of treated plots while the yellow arrow indicates the location of the non-treated plot.
Source: USDA Websoilsurvey, Gillespie County Texas.

Figure G.2. Non-treated plot of dense juniper.

Figure G.3. Smooth treatment with slightly less herbage production than the pitted treatment in Figure G.4.

Figure G.4. Pitted treatment during herbage collection.

Figure G.5. Depicts a typical pit; note exposed fractured limestone in the bottom indicating shallow soils.

Figure G.6. Soil auger used to take soil samples.

Figure G.7. Crawler tractor used to clear juniper.

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