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Brushland Management for Water Yield: Prospects for Texas

THE TEXAS AGRICULTURAL EXPERIMENT STATION/Neville P. Clarke, Director/The Texas A&M University System/College Station, Texas

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BRUSHLAND MANAGEMENT FOR WATER YIELD:

PROSPECTS FOR TEXAS

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EXECUTIVE SUMMARY

Water demand is growing in Texas and agencies charged with guiding water resource management are faced with increasing evidence of water scarcity. Consequently, attention has turned to ways of reducing water scarcity through development, conservation, reallocation, and/or regulation. Pursuit of these strategies will probably have implications for the agricultural sector. Agriculture uses large quantities of water, often at a lower use value than nonagricultural uses. In addition, one study estimates that 38 percent of the state's water budget is used by brush and noneconomic plants on agricultural land. Reduction of brush and noneconomic plants would not only reduce water consumption but also might increase agricultural productivity. This situation has raised the policy issue of whether or not water used by brush can be beneficially shifted to other uses, reducing water scarcity and augmenting land productivity.

Objectives and Procedure

This document addresses that issue and arose out of a Texas Agricultural Experiment Station project titled "Policy Studies of Water Conservation Initiatives." The project and the document have the following objectives:

1) To produce a state-of-the-art assessment regarding policy incentives, legal considerations, and technical feasibility matters involved with redirecting water in Texas, concentrating heavily on the question of brushland management for water yield enhancement.

2) To produce an associated list of Texas public action alternatives, including a prioritized research agenda.

These objectives were addressed by the interdisciplinary committee authoring this report. The process involved a detailed literature review, consultation with many professionals at Texas A&M University and other Texas state agencies, and sponsorship of a seminar series titled "Water Development Through Conservation Initiatives."

Findings

In assessing the situation regarding brush management, the committee found that:

- Existing brushland water yield research results from other states are of limited relevance to Texas conditions. Application of a formula based on Arizona and California research to five Texas cases led to predictions that brush management would yield 1.1, 2.3, 2.8, 4.9, and 5.2 inches of water, but Texas results indicate yields of 0.26, 0, 0.31, 0.95, and 1.21 inches respectively. However, these data do

not provide a reliable basis from which to infer Texas water yields. Currently, insufficient data exists from which to infer water yield consequences of brush management under Texas conditions.

- A previous concentrated implementation of brush management in the San Angelo area of Texas demonstrates the potential for water yield enhancement.

- Water yield does not equate to water use or water use value. Evidence from an Arizona study shows less than one-half the additional water from brush management went into consumptive use. Conserved water which is applied to another use may still have low value.

- As much as 40 million acres in Texas could be subject to a brush management program. Brush management improves livestock carrying capacity. However, increased livestock revenues alone are not sufficient to justify brush management in many locations. Consequently, either off-ranch elements of society must share the cost of brush management or other benefits must be gained by the rancher (perhaps through wildlife).

- Brush is not a homogeneous commodity. Rainfall, soil, topographic, and temperature differences, along with other factors cause widely varying brush species mixes to occur in the state. Such diversity implies widely varying potential water yields, management costs, livestock production benefits, and wildlife considerations, among other factors. Consequently, careful site selection should be part of any publicly subsidized effort.

- In areas where brush removal is economically attractive, 100 percent clearing will not usually be justified due to wildlife effects, topography, and other factors.

- According to current laws concerning water rights, much of the water accruing through brush management efforts becomes state water. Brush managers have clear rights to the water only where it is in the form of diffused surface water which is captured (impounded) or groundwater which is pumped. The brush clearer can apply for a water right for water in a watercourse, but the right, if granted, will be junior to all other users. Furthermore, given the lack of Texas water yield data, documentation of additional appropriable flow will be difficult.

- From a public policy perspective, a number of actions could be pursued relative to encouraging brush management. The main categories of these actions are a) continue current policy–no new initiatives; b) subsidize brush management through low-interest loans; c) cost share with those managing brush; d) refine property rights to resultant water so that private markets arise; and e) regulate brush incidence. Concurrently, research, education, and planning can be undertaken to provide a basis for future brush management initiatives.

- History shows a water justified brush management policy action in Arizona executed without research backup which led to millions of acres being cleared without apparent water yield benefits.

- There is little basis on which to judge the social profitability of a brush management policy. Many relevant questions (e.g., How much water? Who uses it? What benefits do the users get? What happens to the environment?) remain unanswered.

- An efficient off-ranch subsidy policy would include site specific criteria in determining the amount of brush management to be cost subsidized. This would include consideration of many on-site factors involving water yield, water use values, percent of water used, and effects on other costs and benefits.

- Any policy to encourage brush management should be considered relative to other policies to reduce water scarcity. However, little systematic data are available on the costs and benefits of other policies.

INTRODUCTION

Texas' 27 percent population growth during the 1970's was the highest in the nation and high growth rates are expected to continue (Skrabanek and Murdock 1981). Dramatic population growth and concurrent expansion in economic activity cause increasing pressure on the state's water resources. Because of high costs, reduced federal subsidies, and the scarcity of low cost, easily developed reservoir sites, water supply enhancement through reservoir development is limited.

Texas must rely on other approaches for dealing with water scarcity. Practical alternatives may emerge from technological innovation, but the most worthy solutions may lie in the day-to-day application of rational, problem-specific management practices. Society, through its decision-making processes, must make policy decisions regarding which management practices to follow. One potential set of management practices involves shifting water among alternative uses. When considering this option, attention immediately turns to agriculture, since a large portion of the state's water is used within this sector.

One prominent alternative for shifting water involves the expansion of brush management on rangelands. Information derived from other states (Hibbert 1983) and Texas (Blackburn 1983, 1985) suggests that increased surface water flows and groundwater recharge can be obtained through brush management. Simultaneously, evidence arising from Texas rangelands indicates that brush management can increase land productivity in terms of both livestock (Scifres 1980) and wildlife (Inglis 1985) while improving environmental quality through reduced sedimentation (Blackburn 1983, 1985). Potentially, brush management may yield positive social returns by alleviating water scarcity while increasing land productivity and environmental quality. These potential benefits have raised the policy issue of whether society should encourage brush management. This document is designed to contribute to the resolution of that issue.

Motivating Factors: Why Brush Management?

The traditional motivation for controlling brush on rangelands involves increasing forage production for livestock. Botanical competition between grass and brush species for nutrients, water, and space implies that brush removal can increase grass production. In turn, stocking rates, livestock production, and revenues are enhanced. However, from the rancher's perspective, investment in brush management often has a relatively low economic return (McBryde, Conner, and Scifres 1984). Low returns, together with cash flow constraints, limit brush management activities on most of the 95,000,000 acres of Texas rangeland (Soil Conservation Service 1985).

Brush and noneconomic plants have been estimated to use 38 percent of the total Texas water budget (Rechenthin and Smith 1967). The consideration of brushland vegetation management as a means to increase available water supply is not new to the arid western states. Research begun in Arizona and California 30 years ago suggests vegetation management may hold promise as a low-cost source of additional water. Only recently has research regarding physical conditions and plant species in Texas begun (Blackburn 1983, 1985).

However, Texas political momentum for increased brush management has gathered quickly. This momentum has been stimulated by a brush management program in the Rocky Creek area near San Angelo which turned a dry wash into a flowing stream (Kelton 1975; Dow Chemical Company 1986). Many feel that additional brush management throughout the state can provide needed water supplies for downstream areas while improving rangeland productivity. This idea has been operationalized by the Texas legislature under the auspices of Senate Bill 1083, the "Brush Bill," (1985).

Much of what is "known" about Texas prospects for water yield from brush management is contained in the Soil Conservation Service publication, *Grassland Restoration Part V - Effect on Water Yield and Supply* (Rechenthin and Smith 1967). This document presents a positive outlook offering a "conservative" estimate that 10.2 million acre-feet could become available annually through a statewide brush management program. To place this in perspective, 1980 Texas water consumption by the municipal, domestic, manufacturing, mining, steam electric, and agricultural sectors amounts to 17.9 million acre-feet (Texas Department of Water Resources 1984, p. 25). Thus, Rechenthin and Smith's water yield estimate amounts to more than 50 percent of current water consumption. However, the assumptions underlying these figures render the estimates tentative as discussed below.

Simultaneously, a preliminary estimate of the economic consequences of brush management for water production paints an optimistic picture. According to Blackburn, Jones, and Lacewell (1984), 40 million acres of moderate and dense Texas brushland could be treated for a one-time cost of $800 million. Assuming 5 million acre-feet would be produced, they estimate that this investment would result in an annual return of $200 million worth of water consumption benefits. In addition, they estimate benefits of $16 million arising from reduced erosion costs and a $186 million increase in livestock revenues. Thus, they estimate there would be an annual return of $402 million from a one-time expenditure of $800 million. Therefore, brushland management has the appearance of a profitable social investment. However, these estimates are based on many assumptions about the applicability of results from other states and about the importance and/or unimportance of many factors.

A final point of motivation concerns environmental influences. The erosion benefits estimated by Blackburn, Jones, and Lacewell (1984) arise from brush replacement with a soil-preserving grass cover. Other environmental effects may be beneficial as well. A properly managed mix of habitats including brushy areas can enhance wildlife habitats and species diversity. Game animal populations can be increased in quantity and/or quality, and the accessibility of rangelands to hunters can be improved. These effects would increase wildlife lease revenues. Additionally, water salvaged from brush management could enhance watercourse flows and estuary fresh water inflows with positive consequences for recreation, wildlife habitats, and fisheries.

The Need for Public Action and Research

The information reviewed above shows potential for social gains through brushland management. However, any policy action will need to be developed based upon the economic, environmental, legal, institutional, and political implications of those actions. Predictions of these implications depend upon data involving the effects of brush management on water available for use, water quality, water use, and resultant water user income among many other factors. However, little is known about relevant data in Texas. Available scientific data are essentially drawn from other ecosystems and institutional settings which, while similar, are not identical to those found within Texas. For example, none of the water yield estimates cited above are drawn from data developed in areas where mesquite is an important component of the brush complex. Furthermore, experimentation in other states has involved publicly owned rangelands, but private land is the rule in Texas. Such differences call for research on a number of technical, legal, and economic issues regarding water yield from brushland management. These involve the net yield of water, the ways water will be released into the environment, the ways water will be used, the benefits and costs accruing to the various benefiting and possibly losing entities, and the institutional mechanisms needed to assure that the water goes to valuable uses. Research on such issues will make important contributions to efforts to redirect water from low-valued to higher-valued uses.

One way of justifying careful investigations of possible public policies is to review instances where the basis for brush management-related actions was not strong. Three such instances will be reviewed: 1) a case where brush management was implemented; 2) a legal precedent pertaining to water rights developed by brush management; and 3) a current barrier to Arizona implementation of brush management.

Arizona has been a leader in brush management research and implementation. Barr (1956) provided one of the foundations for the Arizona actions. Regarding brush, Barr (1956) estimated a per acre water yield between 0.5 and 1.0 acre-inches from the removal of the pinyon-juniper overstory, while concluding that chaparral-infested acreage exhibited low potential for water yield. Subsequently, in the 1960's, considerable acreage of Arizona brushland was treated by mechanical procedures to remove the pinyon-juniper overstory. Meanwhile, research was continued on vegetative management for water yield. Resultant research findings indicated that mechanical methods of removal did not increase water yield, especially on pinyon-juniper-infested lands (Clary et al. 1974), but that chaparral-infested lands exhibited significant potential for water yield (Hibbert, Davis, and Scholl 1974; Hibbert 1983). Thus, implementation in advance of research results led to an effort to increase water yield by managing a brush complex where water yield was not enhanced, while overlooking a brush complex which could increase water yield.

As a second illustration of the need for public policy inquiries, consider the legal setting of brush management under an appropriative water rights system. While laws and institutions are subject to change, legal rights to increased water yields do not necessarily accrue to those who practice brush management. Colorado's Shelton Farms case is an example (Meyers and Tarlock 1980, pp. 127-36). Shelton Farms cleared an area of brushy phreatophytes adjacent to a watercourse and then petitioned for the use of the water generated by the clearing activity. This petition was eventually denied. The resultant water was held to be water that historically was in the watercourse and therefore subject to the existing appropriative rights system. The increased water yield was held to accrue to existing water rights holders, not to the party managing the brush. Such a situation would obviously reduce the incentives for private landowners to undertake phreatophyte brush management and might make it difficult to establish a compensation scheme.

The final illustration justifying public policy investigation is drawn from the current Arizona chaparral brush management situation. Evidence shows that water yield and social welfare can be enhanced by herbicide-based chaparral brush management (Hibbert, Davis, and Scholl 1974; Hibbert 1983; Brown, O'Connell, and Hibbert 1974). While this has been known for more than 10 years, there has been limited implementation largely due to resistance to widespread herbicide use. Early trial applications of herbicides were marked by confrontations, one of which led to the book pointedly titled *"Sue the Bastards"* (Shoecraft 1971). Research is needed on environmental implications and public concerns regarding alternative brush management options.

Study Objectives, Procedures, and Format

The above discussion of potential social returns, as well as the illustrations, points out the complexity of the brush management decision. This document is designed to contribute to decision making by identifying what is known and not known about the brush management decision. The document arises out of a research project entitled "Policy Studies of Water Conservation Initiatives" funded by the Texas Agricultural Experiment Station. The objectives of the project are:

1) To produce a state-of-the-art assessment regarding policy incentives, legal considerations, and technical feasibility matters involved with redirecting water in Texas, concentrating heavily on the question of brushland management for water yield enhancement; and

2) To produce an associated list of Texas public action alternatives including a prioritized research agenda.

This document is divided into four major parts: 1) the introduction; 2) a review of the issues and the associated literature; 3) a potential public action section including a research agenda along with a discussion of alternative policy approaches; and 4) a summary.

This project involved a literature review and a seminar series entitled "Water Development through Conservation Initiatives." The literature review was conducted by the authors with the assistance of student Scot Ullrich. The Law and Institutions section is a synthesis from work by Ronald Kaiser and Frank Skillern with research provided by Jonathan Miller, Tim Perrin, and Lori Thomas. The seminar speakers who contributed greatly to the authors' knowledge of the subject were Thomas Brown, Richard Conner, Jack Inglis, Lee Jones, Charles Scifres, Steve Stagner, Dan Tarlock, Murray Walton, and Zach Willey (Appendix A provides titles and addresses). In addition, one of the team members, Wilbert Blackburn, also presented information. Several faculty members, in particular, Richard Conner, Lonnie Jones, Ron Lacewell, John Nichols, and Ed Smith, assisted by reviewing parts of the document. The authors wish to express their sincere appreciation to all.

A REVIEW OF ISSUES AND AVAILABLE INFORMATION

Brushland management for water yield enhancement involves: 1) partial or total removal of brush from rangelands by a rancher who thereby alters the physical and economic characteristics of his land; 2) a resultant change in vegetative water use which may alter the on-site water balance and off-site abundance of surface or groundwater; 3) a related change in environmental attributes such as sediment load, wildlife habitat, and water quality; 4) society's laws and institutional structures which determine rights to and patterns of water use; and 5) water use by off-ranch parties with potential changes in their revenues and costs. Such a situation contains many potential issues relevant to public policy toward brush management for water production. The discussion of the policy related issues can be loosely grouped into five categories.

Hydrology

- water consumption and flow--on-site and off-site alterations in ground and surface water volume

Brush Treatment and Range Productivity

- brush incidence and on-site effects of brush management

Environment

- off-site concerns for fish and wildlife, water quality, recreation, and aesthetics

Law and Institutions

- implications of current Texas laws, institutions, agencies, and water management organizations

Economics

- benefits and costs of brush management actions and related public policies

These are not independent categories; rather there are many overlapping concerns.

Hydrology

The off-site hydrologic effect is the critical issue related to the brushland management for water yield decision. The considerations of key importance are, "Does brushland management increase water yield?" "Where and when is this increased water available for use?" And "How can increases in water be monitored?" This section presents discussion on these issues.

Does Brushland Management Increase Water Yield?

This question involves the quantity of water, the conditions which cause water yield to vary, the timing of water releases during the year, and the form of the water yielded (surface water or groundwater). A body of research has addressed these questions, but the research is of varying relevance to Texas conditions. Research findings exist pertaining to vegetative management efforts in general, to cases suggestive of Texas rangeland conditions, and to a limited extent on Texas rangelands. Therefore, general findings are discussed first, then findings pertinent to Texas-like conditions, and finally findings arising in Texas.

Efforts to enhance water yield through vegetative manipulation have a long history. Bates and Henry studied water yields from forest management in 1928. In 1965, Meiman and Dils predicted that "The multiple use concept of resource management will be implemented...to the point of applying positive practices [vegetative management] for...water resource [augmentation]." However, according to a 1983 appraisal by Ponce and Meiman,"...management for water yield augmentation has not progressed very far" (p. 415). The preponderance of scientific research indicates that water yield can be enhanced through vegetative management where the water yield enhancement arises through alterations in evapotranspiration and possibly interception by resident plants.

Ponce and Meiman (1983) reviewed evidence showing that water yields differ based on vegetation and location. For example, 10-30 centimeters (4-12 inches) were yielded by clearing eastern U.S. forestlands, as much as 15 centimeters (6 inches) on Arizona chaparral lands, and 2.5-7.5 centimeters (1-3 inches) on ponderosa pine lands. Increases have not always been found; for example, Hibbert (1979) reports small to negligible flow increases from pinyon-juniper lands in Arizona. A set of conditions for water yield increase has been synthesized by Hibbert (1983) who states:

1) Annual precipitation should exceed 450 millimeters (17.7 inches),

2) The vegetation removed must be replaceable with species which use less water, and

3) The replacement species should be shallow rooted and either low in biomass, decidous, or dormant much of the time.

Many acres of Texas brushlands satisfy the above criteria and thereby exhibit potential for water yield enhancement, but realization of this potential depends on selection of regions exhibiting favorable brush complexes and rainfall conditions. Ponce and Mieman (1983) remark that "The greatest potential for water yield augmentation appears to be on carefully selected watersheds that have the biophysical potential to produce water that is used for high value purposes, and can be managed under sound multi-resource management" (p. 418).

Research in Texas has been limited (Blackburn 1985). However, relevant findings have arisen on rangelands throughout the world (Hibbert 1983), with most arising in Arizona and California. Hibbert (1983) estimated an equation which indicates that in rangeland cases one should expect 0.26 inch of additional runoff for each 1-inch increase in precipitation above 15.12 inches. The evidence was based on studies involving a number of brush complexes dominated by deep-rooted evergreen shrubs in Arizona and California. (Figure 1 portrays Hibbert's (1983) regression line and underlying data.) Other species can exhibit different behavior although the environmental conditions which led to predominance of these species may be the causal factor. For example, Hibbert (1983) cites evidence of *poor* potential from Arizona and California sagebrush and pinyon-juniper stands although this may be attributed to low rainfall. Hibbert's equation may be of limited relevance to widely varying geographic, soil, and environmental conditions.

The water yielded by brush management has been found to display some general characteristics. First, the water yield augmentation has been found to occur principally in subsurface flow and groundwater infiltration (Hibbert 1983). In some areas, water flow has increased in nearby watercourses without increasing surface runoff through subsurface flow. Second, the time period over which water yield increase persists has been found to be dependent upon the rate of brush regrowth (Hibbert, Davis, and Scholl 1974). Third, the brush control method has been shown to be an important determinant of water yield. Control methods which remove the above ground portion of the plant but which do not kill the roots (fire and chaining or cabling) have been found to exhibit short-lived water yield increases (Hibbert 1983). Complete plant removal (rootplowing, etc.) and herbicide treatments have shown the most long-lived effects. Fourth, follow-up treatments have been found to be necessary to maintain brush control and water yield enhancement (Texas Agricultural Experiment Station 1985, Hibbert 1983). Fifth, brush management has been shown to reduce and in some cases increase soil erosion rates with steepness of slope (Sampson 1944; Blackburn 1983) and rate of forage establishment being important explanatory factors (Scifres 1986). Sixth, research results on water yield have tended to overestimate practical implementation results. Research often has been conducted on denser brush stands than ordinarily expected, and more brush has been removed than in practical implementations (Ponce and Meiman 1983). Seventh, the majority of water yields have been observed in high rainfall years–80 percent of the water yields in Arizona occurred in the wetter than average years (Hibbert 1979). Eighth, the brush-infested lands studied have been found to contain untreatable acreage due to brush density, slope, accessability, or other factors (Ponce and Meiman 1983; Brown, O'Connell, and Hibbert 1974).

Turning to Texas, limited research has been done (Table 1). Most of these data are of limited scientific validity with respect to the water yield question mainly due to years studied (i.e., 1-year study) or measurement method as noted below. Nevertheless, these data are indicative of the situation and merit discussion. Richardson, Burnett, and Bovey (1979) found, in a 7-year watershed study, that when controlling honey mesquite there was "about 10 percent more runoff" (p. 318) which amounted to 24.3 millimeters or 0.95 inches on the Blackland Prairie of Texas. Richardson, Burnett and Bovey (1979) also report results from a study near Sonora, Texas, in which root plowing was employed for brush management. In that case, water yields after treatment were less than those before. Blackburn (1983) reviews simulated rainfall studies by Bedunah (1982) and Brock, Blackburn, and Haus (1982), stating that mesquite control "increased infiltration rates and either has no effect or decreased sediment production on the Rolling Plains" (p. 83). Blackburn (1983) also reviews Knight, Blackburn, and Scifres (1983) stating "Prescribed burning following herbicide application had little influence on infiltration rates–thereby water yield–of whitebrush or running mesquite dominated sites on the South Texas Plains but decreased sediment loss" (p. 83).

These results are not consistent with the Hibbert (1983) equation as the Texas results generally fall below the equation and the data underlying it (Figure 1).

Figure 1. Comparison of Water Yields.

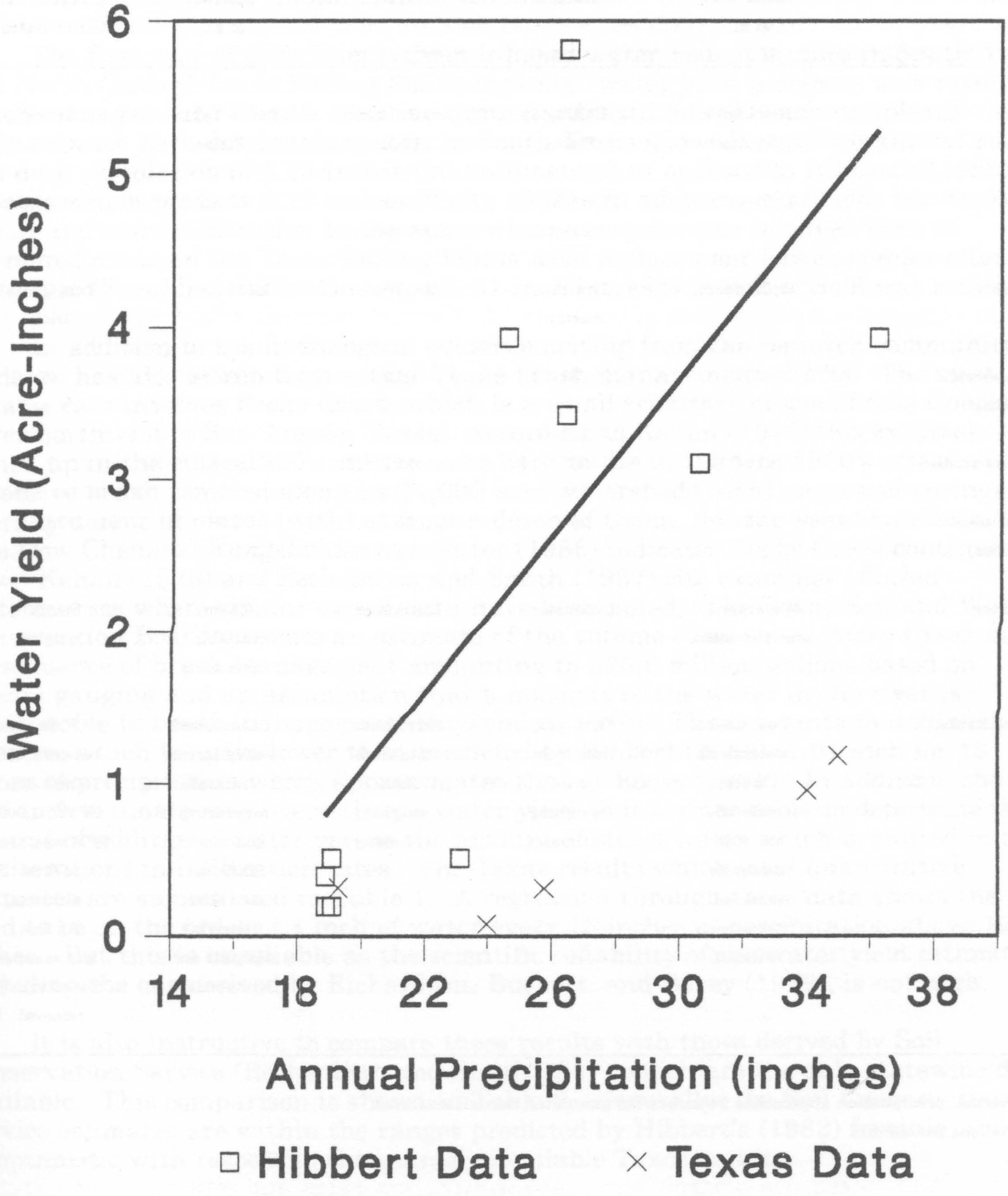


Table 1. Characteristics of Texas Brushland Management Water Yield Estimates

Source	Richardson et al.	Franklin	Weltz	Knight et al.	Texas Soil and Water Board
Area	Blackland Prairie	Rolling Plains	South Texas Plains	South Texas Plains	Rocky Creek
Town	Riesel	Throck-morton	Alice (La Copita)	Tilden	San Angelo
County	McClennan	Throck-morton	Jim Wells	McMullen	Tom Green/ Irion
Water yield (inches)	0.95	.31	1.18	0	.26
Years studied	1970-77	1985	1985	1979	?
Precipitation (inches)	35	26	35	24[a]	19
Method	Watershed measurement	Lysimeter	Lysimeter	0.5–m variable area plots	Steam guaging
Comments	Two 1.3–ha watersheds were metered– one with mesquite removed. the other without.	First–year data from non-weighing lysimeter.	First–year data from non-weighing lysimeter.	Simulated heavy storm rainfall measuring runoff and infiltra-tion after removing mesquite and whitebrush.	Flow was between 475 and 4,000 GPM[b]; 1,000 GPM was used to form estimate. All flow was assumed due to brush removal.

[a] Normal precipitation approaches 24 inches but simulated rainfall was used.

[b] Gallons per minute

Namely, the South Texas Plains site receives 24 inches of rainfall for which Hibbert's (1983) formula predicts 2.31 inches of water but yielded zero while the Blackland Prairie site receives 34 inches of rainfall which leads to a prediction of 4.91 inches of water but yielded 0.95 inches. Soil types, geology, weather patterns, etc. seem to render Hibbert's (1983) results of limited relevance.

The first year of data from lysimeter-based water budget studies in South Texas and North Central Texas Rolling Plains indicate water yield increases as a result of brush management. Results from mesquite-dominated mixed brush complexes replaced with herb-dominated species in South Texas showed increased annual runoff and deep percolation of 1.18 inches (30 millimeters) as opposed to Hibbert's (1983) formula which predicts 5.17 inches (Weltz 1987). In addition, there was less surface runoff and more infiltration in the areas where mesquite was removed than in untreated areas on the Texas Rolling Plains with replacement forage species altering water use (Franklin 1987). On net, a 0.31-inch increase in water yield was realized.

In addition to the hydrological evidence arising from the research community, evidence has also arisen from actual Texas brush management efforts. The most notable case involves Rocky Creek, which is a small tributary of the Middle Concho River northwest of San Angelo, Texas. According to Kelton (1975), Rocky Creek "dried up in the early 1930's only to come back to life in the late 1960's after extensive brush removal along its 74,000 acre watershed [with] seeps and springs...at literally dozens of places [with] at least a dozen of them...flowing year round" (p. 1). The Dow Chemical *Rangelander* newsletter (1986) indicates Rocky Creek continues to flow. Kelton (1975) and Rechenthin and Smith (1967) cite examples of other watercourses where similar experiences have been noted. The Texas Soil and Water Conservation Board presents an estimate of the volume of water in Rocky Creek as a consequence of brush management amounting to 525.6 million gallons based on stream gauging and an assumption that a majority of the water in the river is attributable to brush management (Kuykendall 1986). This amounts to 0.26 inches per acre, which is again lower than predicted by Hibbert (1983) (1.01 inch for 19 inches of precipitation which approximates that at Rocky Creek). In addition, the 0.26-inch estimate may overestimate water yield as it is impossible to determine the amount of additional water versus the amount of storm water which is shifted in time by alterations in infiltration rates. The Texas results which yield quantitative estimates are summarized in Table 1. A regression through these data shows the yield to be on the order of 1 inch of water every 15 inches of percipitation above 19 inches. But this is unreliable as the scientific reliability of the water yield estimates, excluding the one derived by Richardson, Burnett, and Bovey (1979), is not high.

It is also instructive to compare these results with those derived by Soil Conservation Service (Rechenthin and Smith 1967) which are the only statewide data available. This comparison is shown in Table 2. Generally, the Soil Conservation Service estimates are within the ranges predicted by Hibbert's (1983) formula but may be optimistic with respect to the sparsely available Texas results.

An interesting issue involves the accuracy of inferences to total water yield based upon research findings from other areas and/or preliminary research. This issue is best illustrated by reviewing the history of estimates generated for the Salt and Verde River basins in Arizona (Table 3). Barr (1956) presented estimates of water yield increases from three brush complexes: pinyon-juniper, chaparral, and desert shrubs. Barr (1956) concluded that there was practical potential to generate 0.5–1 inch of water per acre for over 1.7 million acres of pinyon-juniper and no potential from chaparral and desert shrubs. Almost 20 years later, Ffolliott and Thorud (1974)

Table 2. Comparison of Water Yield Predictions and Texas Findings

Region		Rain-Fall Min (inch)	Rain-Fall Max (inch)	Water Yield Per Acre Treated (inch/acre)	Land Avail (1,000 acres)	Land Cleared (1,000 acres)	Total Water (1,000 acre-feet)	Hibbert Formula Yield Min (inch/acre)	Hibbert Formula Yield Max (inch/acre)	Texas Observed Yield (inch/acre)
EAST TEXAS	EAST	35	55	6.4	4,288	3,000	1,600	5.2	10.4	–
TIMBERLAND	WEST	30	35	4.0	929	650	217	3.9	5.2	–
	TOTAL						1,817			
BLACKLANDS AND GRAND PRAIRIE		30	45	3.0	5,000	3,500	875	3.9	7.8	–
NORTH CENTRAL PRAIRIE, CROSS	BRUSH	25	35	4.0	5,243	3,670	1,223	2.6	5.2	1.0
TIMBERS,	SALT CEDAR			24.0	25	25	50			
CENTRAL BASIN	TOTAL						1,273			
EDWARDS	EAST	20	35	3.0	7,857	5,500	1,375	1.3	5.2	–
PLATEAU	WEST	15	20	0.3	12,143	8,500	213	0.0	1.3	–
	SALT CEDAR			24.0	53	53	106			
	TOTAL						1,693			
ROLLING	MESQUITE	20	25	1.0	10,600	9,540	795	1.3	2.6	0.3 & 0.3
PLAINS	SHIN OAK									
	SAGEBRUSH	20	25	4.0	3,501	2,451	817	0.0	2.6	–
	SALT CEDAR			24.0	288	288	575			
	TOTAL						2,187			
HIGH	SHIN OAK									
PLAINS	SAGEBRUSH	15	20	2.0	1,714	1,200	200	0.0	1.3	–
	MESQUITE	15	20	0.3	3,339	3,000	75	0.0	1.3	–
	SALT CEDAR			36.0	6	6	17			–
	TOTAL						292			
TRANS PECOS	BRUSH	0	18	0.1	1,000	1,000	8	0.0	0.8	–
	SALT CEDAR			24.0	282	282	563			
	TOTAL						572			
RIO GRANDE	NUECES	18	35	2.0	6,786	4,750	792	0.8	5.2	1.2
PLAIN	GUAD. AND SAN ANT.	18	35	2.0	840	588	98	0.8	5.2	–
	RIO GRANDE	18	22	0.3	2,880	2,016	50	0.8	1.8	–
	OTHER	18	35	2.0	3,726	2,608	435	0.8	5.2	–
	TOTAL						1,375			
COAST	BOTTOMLAND	30	55	12.0	15	15	15	3.9	10.4	–
PRAIRIE	UPLAND	30	55	6.4	316	221	118	3.9	10.4	0.0
	OTHER	30	44	4.0	423	296	99	3.9	7.5	–
	TOTAL						232			
GRAND TOTAL	ALL LANDS			2.5	66,037	49,509	10,316			
GRAND TOTAL	EXCLUDING SALT CEDAR			2.2	65,383	48,855	9,005			

Table 3. Estimates of Water Yield from Arizona Brushland Treatment:[a] Salt and Verde River Basins

Brush Type		Barr	Ffolliott and Thorud	Brown et al.
All Brush Complexes				
Physically Treatable Land[b]	(acres)	2,200,000	1,241,798	850,000[c]
Practically Treatable Land[d]	(acres)	1,700,000	1,176,375	175,912[e]
(percent of physically treatable land)		(77)	(95)	(21)
Most Probable Management Option	(acres)	1,700,000	470,550-705,825	105,547-147,766
(percent of practically treatable land)		(100)	(40-60)	(60-80)
Annual Water Yield:				
Total	(acre-feet)	71,000	117,637-235,274	24,000-30,443
Per acre	(inches/acre)	0.5	3-4	3.1-3.8
Pinyon - Juniper				
Physically Treatable Land	(acres)	2,200,000	na	na
Practically Treatable Land	(acres)	1,700,00	na	na
Annual Water Yield				
Total	(acre-feet)	71,000	0	na
Per acre	(inches/acre)	0.5-1	0[f]	na
Chaparral				
Physically Treatable Land	(acres)	na	1,241,798	850,000
Practically Treatable Land	(acres)	na	1,176,375	175,912
Total Water Yield				
Total	(acre-feet)	71,000	117,637-235,274	24,000-30,443
Per acre	(inches/acre)	0[g]	3-4[h]	3.1-3.8[i]

[a] Brushland water yields were derived for land infested with chaparral and pinyon-juniper.

[b] Brushland felt to be physically capable of yielding additional water.

[c] National Forest land only.

[d] Brushland treatable after constraints are taken into account.

[e] Brushland treatable after accounting for wilderness areas, steep slopes, sparse vegetation areas, and wildlife and aesthetic concerns.

[f] Pinyon-juniper lands were found not to yield significant results.

[g] Chaparral lands were assumed not to yield significant results.

[h] Three inches when 40 percent of brush is cleared, four inches when 60 percent of brush is cleared.

[i] Based on the assumption of .59 inches of additional water per inch of precipitation over 17 inches.

na means not available.

concluded that there was potential to obtain 3-4 inches per acre from selected chaparral acreage and basically none from pinyon-juniper and desert shrubs. Thus, a major discrepancy arose in the 20 years. Barr's (1956) estimates differ because of 1) reliance on preliminary research–water yield from pinyon-juniper was estimated based on "theoretical calculations..." even though he recognized that "...there is some evidence that pinyon-juniper control may produce no additional water," and 2) the opinion that chaparral was not "practically controllable" (Barr 1956, pp. 29, 30).

The related study by Brown, O'Connell, and Hibbert (1974) allows another interesting comparison. While the estimates for yield per acre are approximately the same as Ffolliott and Thorud's (1974), the treatable area assumptions differ widely. Ffolliott and Thorud (1974) assume the Salt and Verde basins contain about 1.24 million acres of chaparral land of which 1.18 million acres are judged treatable, with the untreatable acreage estimate based on ownership and rainfall. Ffolliott and Thorud (1974) argue that between 40 and 60 percent of the treatable land is practically treatable because of physiographic, vegetative, institutional, social, economic, and other constraints. On the other hand, Brown, O'Connell, and Hibbert (1974) start from a national forestland base of 850,000 acres of chaparral and reduce it to 175,912 acres based on wilderness area regulations, brush cover, slope, and other pertinent criteria. This land area is then further reduced to between 105,547 and 147,766 acres based on economic criteria. The Brown, O'Connell, and Hibbert (1974) estimates exhibit almost a tenfold variation from Ffolliott and Thorud's (1974) water yield estimates because of the treatable acreage assumption.

The only comprehensive Texas based technical assessment of water yield is that generated by the Soil Conservation Service within Rechenthin and Smith's 1967 report as presented in Table 2 [which underlies the estimates used in the introduction to this report and in Blackburn, Jones, and Lacewell (1984)]. However, Rechenthin and Smith's (1967) numbers are adapted based on extrapolation of data from distant areas and different plant species. For example, the Edwards Plateau numbers are based on a study of pinyon-juniper and shrub oak removal in California (Woods 1966) and a 70 percent brush removal assumption. Given the Arizona experience, such an inference is highly questionable. Development of Texas data constitutes an important research need.

Yet another approach for estimating water yield involves the application of hydrological simulators such as erosion/hydrology models to predict water flows. The basis of such models is well developed (e.g., U.S. Department of Agriculture's EPIC model: Williams, Jones, and Dyke 1984; Williams, Renard, and Dyke 1983). Arnold and Williams (1985) have investigated the ability of a simulator model to predict water yields. In this study, two watersheds with some rangeland were investigated. These involved a 538–hectare watershed in Oklahoma and a 234–hectare watershed in Idaho. In addition, an 18–hectare crop, pasture, and grass-covered watershed in Riesel, Texas was studied. The Oklahoma watershed was studied over a 19–year period predicting a mean of 48 millimeter annual water yield versus an actual of 19 millimeter with close correspondance in standard errors (27 versus 25 millimeter) but an average of 31 percent prediction error. The Idaho watershed showed a model mean of 75 millimeter as compared with an actual mean of 72 millimeter over a 14–year period when the standard error was less close (40 versus 31) with a 25 percent average prediction error. The Texas non-range watershed over 22 years showed a model mean of 169 millimeter versus a mean of 149 millimeter with a model standard error of 129 millimeter versus 88 millimeter with an average of 30 percent error. Data on sediment yields also are presented. Based on these data and other evidence from a total of 12 watersheds, Arnold and Williams (1985) concluded that simulators "can realistically simulate water and sediment yields under a wide range of soils, climate, land use, topography, and management" (pg 114). However, it is interesting to note that the three range and/or Texas related cases cited above are the worst cases in the 12 studied in terms of average prediction error.

Work also has begun on applying these models to Texas conditions and vegetation manipulation. Hailey and McGill (1983) have investigated procedures for incorporating Texas vegetative and climatic conditions in runoff predictions. Arkin (1986) has a project reviewing the opportunity to use these models for predicting the water and other effects of brush management. Based on research to date, Arkin (1986) states that the U. S. Department of Agriculture EPIC family of models appears to be suitable for rangeland use, but the model's characteristics in terms of sensitivity to brush management and reliability for predicting hydrological results are topics yet to be fully investigated (Arkin 1986).

When and Where Is the Water Made Available?

Assuming that water is made available by brush management, an important question involves when and where it is available, as this, in part, determines value. There are two aspects of this issue, the first involves the actual timing and location of additional water. The second involves the ability to monitor the additional water.

The when and where question has a number of dimensions. Additional water from rangelands may augment surface water or groundwater supplies directly. Surface water increases may result in increases in: 1) the flow in reaches of rivers, 2) the quantity of water used by water rights holders, 3) the volume of floodwaters, 4) the amount of water in reservoirs, 5) the rate of groundwater recharge, and/or 6) the amount of water flowing into bays and estuaries. Groundwater increases may raise the water table, increase water pressure in related areas, or augment surface flow by way of seeps and springs. All of these depend upon the timing of water release and the hydrologic characteristics of the region. There has been a considerable body of research on the several topics implicit in these questions. The general topic involves the stream/groundwater measurement, modeling, and simulation research areas which have been extensively studied (Linsley, Kohler, and Paulus 1982). Few studies have been conducted pertinent to brushland management (Ponce and Meiman 1983, Brown 1986a,b; Lundeen 1977). The results of these studies are summarized below.

Brushlands have been found to release water predominantly in high precipitation years–80 percent of the water in the wetter than average years (Hibbert 1983). Brown (1986a,b) used data reflecting such a release pattern to simulate the effects of brushland management on water use in the Verde River basin in Arizona. Brown (1986a,b) found that such a pattern led to:

1) An increase in consumptive use of the water approximating 50 percent of the increased flow with the rest being accounted for by increased spillage, seepage, evaporation, etc.;

2) A consumptive use pattern which depended on storage capacity as well as the volume of additional water generated; and

3) An increase in the probability of flooding.

Interestingly, Brown's (1986a,b) results show increased storage decreases the amount of the brush management water yield which is consumptively used. While increased reservoir storage was associated with increased total consumptive use, the increase in water yielded by brush management showed decreased delivery under the increased storage. The wet year predominated delivery pattern and the prevailing institutional structure apparently caused this.

A number of other issues have been mentioned relative to the off-site hydrological characteristics of the water yield.

1) Practical implementations of vegetative manipulation have not been tried and documented on a large watershed basis. "Although research has shown that water yield canbe increased, the means to transfer this information to larger areas is limited" (Ponce and Meiman 1983, p. 418).

2) It is difficult to measure the effects of watershed vegetation manipulation projects downstream because the additional water generated is often less than the measurement error (Harr 1983; Krutilla, Bowes, and Sherman 1983).

Studies of the basin-wide implications of brush management most likely will need to be done with models which estimate and track water yield increases (Williams 1983). However, with models the results are dependent on the accuracy of the data and assumptions. Research is needed on the reliability of these models because, "To a large degree confidence is dependent on the degree to which the model is based on scientific principles underlying the hydrologic process, the degree to which it has been validated in other areas, and how credible its predictions are for the watershed of interest" (Ponce and Mieman 1983, p. 417).

No Texas based studies were found pertaining to basin–wide implications of brushland water yield increases. A research need is to measure flow changes on rivers caused by upstream vegetation management. A body of literature is available to start from. Models have been developed by the Texas Water Development Board to study short-term storm runoff and water availability prediction. In addition, groundwater models for selected areas in Texas provide information for various recharge rates. For example, the Texas Water Development Board modeled the Edwards Aquifer.

Another hydrologic issue involves the incidence of flooding. In Arizona, brush management has been found to increase surface runoff volume only slightly after the first couple of years. Subsequently, the majority of the increased water yield was found in subsurface flows or in groundwater (Hibbert 1983). The increased subsurface flows are released to watercourses sometime after rainfall events. Thus, flooding is likely to be increased only if: 1) major storm events occur in the first 2 years after treating a large amount of land, probably only on a local basis (Krutilla, Bowes, and Sherman 1983; Ponce and Meiman 1983) and/or 2) major events occur when the soil is already saturated. However, these results could use Texas verification.

How Can Increases in Water Be Monitored?

Monitoring is also an important question, i.e., "How will one know how much water is generated by a project and where the water goes?" It is difficult to determine points at which the specific amount of increase can be monitered. Also, the technology to measure the increased subsurface flows is expensive. Increased yields from springs could be more easily measured, but these are not always identifiable, nor are they the sole manifestation of increased yield. The consensus appears to be that it is impossible to physically monitor actual flows from specific vegetation management projects (Ponce and Mieman 1983). For this reason, simulation models have been suggested.

Brush Treatment and Range Productivity

The consideration of whether to manage brushlands for water yield involves a number of issues above and beyond the hydrologic questions such as:

1) What is the incidence of brush in Texas?

2) What are the treatment alternatives?

3) What are the implications of brush management for range productivity and range-derived income?

4) What benefits will be foregone if brush is removed?

5) What factors will a rancher consider in making a brush management decision?

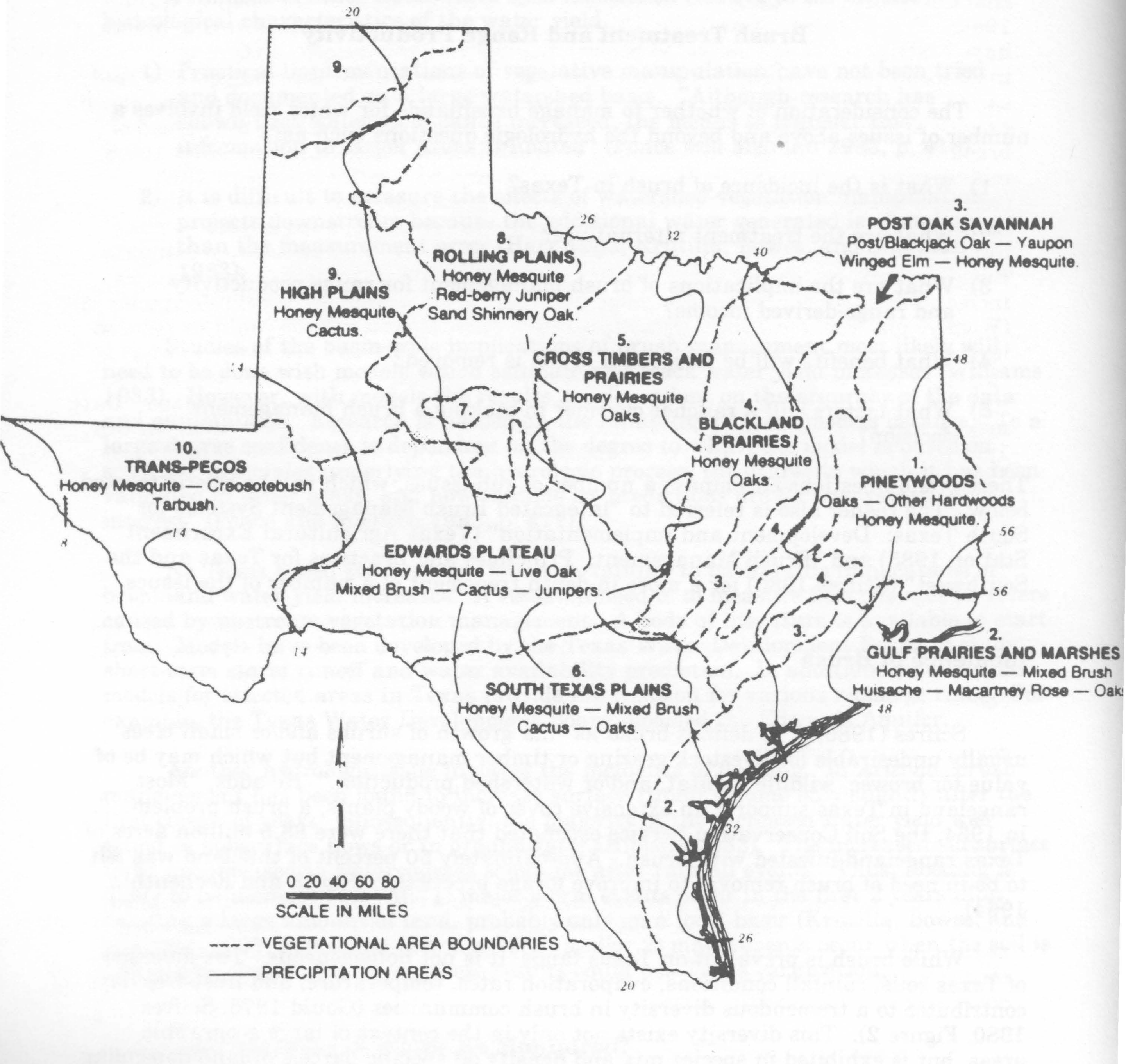
These broad questions encompass a number of sub-issues, which will be briefly treated below. The reader also is referred to "Integrated Brush Management Systems for South Texas: Development and Implementation" (Texas Agricultural Experiment Station 1985) and "Brush Management: Principles and Practices for Texas and the Southwest" (Scifres 1980) for a more in-depth treatment of a number of the issues.

Incidence of Brush

Scifres (1980, p. 3) defines brush as "...a growth of shrubs and/or small trees usually undesirable for livestock grazing or timber management but which may be of value for browse, wildlife habitat, and/or watershed production." He adds, "Most rangeland in Texas supports an extensive cover of woody plants, a brush problem...". In 1964, the Soil Conservation Service estimated that there were 88.5 million acres of Texas rangeland infested with brush. Approximately 50 percent of this land was felt to be in need of brush removal to improve forage production (Smith and Rechenthin 1964).

While brush is prevalent on Texas lands, it is not homogeneous. The diversity of Texas soils, rainfall conditions, evaporation rates, temperature, and frost-free days contributes to a tremendous diversity in brush communities (Gould 1975; Scifres 1980, Figure 2). This diversity exists not only in the context of large geographic areas, but is exhibited in species mix and density on specific parcels of land depending upon slope, water availability, soil characteristics, etc. Such diversity means that water use, potential water yield characteristics of brushlands, as well as treatment cost, erosion rates, and other factors are heterogeneous.

Figure 2. Map of Brush Types by Regions.



An assessment of the water yield effects of brush management would require, among other things, information on the types of brush infesting rangeland by location, slope, soil type, rainfall, etc. However, such systematic information is not available. Data from a 1982 survey of the brushlands by brush type are given in Tables 3 and 4. Brush is present in significant amounts despite considerable efforts to remove it (Welch 1982, Table 6).

Another important sub-issue regarding brush incidence is its dynamic characteristics. The density and dispersion of brush is possibly increasing (Walton 1986). Brush incidence was much lower in the past (Scifres 1980). Grazing practices have contributed to the spread of brush. During drought periods, if there is insufficient feed, livestock eat brush seed pods. Subsequently, the undigestable seeds can be deposited in manure at other locations. The nutrients and moisture in manure provide a nursery area which nurture the young brush plants aiding the spread of brush (Kelton 1975). A 1982 estimate of brush-infested rangelands includes 105.6 million acres, up from 92 million acres in 1972 and 88.5 million acres in 1963 (Johnson 1986). However, one cannot conclude from this evidence that brush is increasing. The basis for these numbers varies; for example, most estimates place total Texas rangelands at 95 million acres–less than the 1982 infestation estimate. But if present, increasing brush density has important implications. For example, increased brush density reduces range carrying capacity and alters wildlife species mix (Wiggers and Beasom 1986). Simultaneously, current water yields could be reduced leading to increased water scarcity over time. Thus, research needs are: 1) what is currently happening to brush incidence by species, density, region, etc. and 2) what will happen to future state water availability if treatments are not undertaken. Data may be available pertaining to the first question from the Soil Conservation Service 1960's, 1970's, and 1980's surveys [Smith and Rechenthin (1964) and unpublished 1975 and 1982 follow-ups (Johnson 1986)].

Treatment Alternatives

The Texas Agricultural Experiment Station (1985) and Scifres (1980) describe many brush management alternatives. The basic techniques include: 1) mechanical methods such as root plowing, chaining, shredding, raking and stacking, roller chopping, cabling, railing, and discing; 2) chemical methods involving broadcast herbicides or individual plant treatments; 3) prescribed burning; and 4) biological control, mainly using goats. The choice among these management methods depends on site characteristics and brush species as well as treatment objectives.

Table 7 gives data on the cost of selected brush management alternatives. These data reveal a wide range of costs. Such methods may be used individually or conjunctively. One can also adopt alternative application strategies. The main application strategy decision involves the degree to which the treatment is applied. Land may be totally cleared, or selectively cleared in either strips, a checkerboard pattern, or a more complex mosaic pattern (Hamilton 1985). These brush removal strategies leave different amounts of brush for livestock, drought reserves, wildlife cover screens, and erosion barriers.

A number of research findings have arisen pertinent to the brush management for water yield question. First, brush management has been found to require follow-up treatments. Follow-ups often involve prescribed burning several years after an initial herbicide treatment, but other methods can be used. A concern with follow-up

Table 4. Acres Reflecting Various Infestations by Type of Brush

Percent Canopy	Acres: Creeping Mesquite	Honey Mesquite	Blueberry	Redberry Juniper
0	1,67,360,200	116,989,300	158,100,700	156,030,300
1	60,400	3,613,700	470,400	1,218,700
1-5	110,300	17,795,900	3,012,000	4,621,600
6-10	74,100	10,508,300	1,622,400	2,728,900
11-20	58,600	9,873,400	1,401,600	1,882,800
21-30	61,300	4,739,700	794,700	818,000
31-50	33,100	2,790,900	732,800	358,200
51-75		1,036,700	473,500	91,000
76-100		408,500	148,300	8,500

Percent Canopy	Sand Shinoak	Post Oak	Prickleypear	Broom Snakeweed
0	165,243,000	161,407,700	137,082,000	157,770,900
1	70,200	232,700	5,643,900	987,300
1-5	458,400	1,293,900	19,881,300	4,039,200
6-10	393,000	1,065,200	3,276,300	2,443,000
11-20	463,200	1,131,800	1,398,000	1,633,300
21-30	378,900	842,100	300,500	548,800
31-50	415,500	942,600	146,800	269,300
51-75	257,200	619,900	21,700	53,200
76-100	78,600	221,500	7,500	13,000

Percent Canopy	Blackbrush	Creosotebush	Huisache	Macartney Rose
0	160,705,900	157,907,900	164,428,500	167,389,200
1	373,200	511,300	251,100	47,500
1-5	2,047,600	3,180,200	1,468,000	152,300
6-10	1,806,000	2,368,300	712,100	71,400
11-20	1,413,300	2,635,500	502,000	48,200
21-30	790,000	841,600	179,500	22,000
31-50	463,200	313,200	412,900	4,200
51-75	121,000		64,100	19,800
76-100	37,800		9,800	3,400

Percent Canopy	Whitebrush
0	162,311,000
1	674,600
1-5	2,477,100
6-10	1,120,000
11-20	645,500
21-30	290,900
31-50	146,500
51-75	70,900
76-100	22,500

Source: Soil Conservation Service 1986 preliminary data drawn from 1982 brush survey, unpublished.

Table 5. Acres in Need of Treatment by Area of Texas

Area	Improvement With Brush Management	Brush Management and Reestablishment
Trans-Pecos	3,129,400	683,500
High Plains	1,767,900	199,600
Rolling Plains	5,439,900	1,182,200
Rolling Red Prairies	190,800	72,500
North Central Prairies	2,093,900	1,101,300
Edwards Plateau	7,642,200	1,565,400
Central Basin	654,200	134,500
Northern Rio Grande Plain	1,988,000	813,200
Western Rio Grande Plain	2,238,000	981,100
Central Rio Grande Plain	1,870,100	1,064,100
Lower Rio Grande Valley	240,300	55,800
West Cross Timbers	321,400	413,300
East Cross Timbers	38,300	74,900
Grand Prairie	1,002,600	463,300
Blackland Prairie	728,500	488,500
Claypan Area	1,034,300	792,000
East Texas Timberlands	6,500	4,800
Coast Prairie	740,500	78,000
Coast Saline Prairies	193,800	14,800
Total	31,320,600	10,182,800

Source: Statistical Results from Texas 1982 Natural Resources Inventory, compiled by U. S. Department of Agriculture, Soil Conservation Service, Temple, Texas, January 1985.

Table 6. Acres of Texas Rangeland Receiving Brush Treatments

Year	Chemical	Mechanical	Total	Burning
1940			2,552,982	
1941			1,902,261	
1942			1,105,796	
1943			657,091	
1944			2,930,884	
1945			1,116,796	
1946			1,371,314	
1947			1,212,959	
1948			514,503	
1949			740,743	
1950			1,042,072	
1951	500,000		1,289,610	
1952	500,000		1,186,090	
1953	82,177		1,034,155	
1954	106,486		1,013,668	
1955	101,904		1,279,068	
1956	148,755	946,795	1,095,550	
1957	217,227	688,212	905,439	
1958	410,194	760,272	1,170,466	
1959	466,559	828,055	1,294,614	
1960	505,421	990,929	1,496,249	
1961	653,745	816,990	1,470,735	
1962	573,378	746,289	1,319,667	
1963	695,916	836,594	1,532,510	
1964	589,645	725,366	1,315,011	
1965	815,294	776,485	1,591,779	
1966	1,130,821	917,227	2,048,048	
1967	966,390	939,179	1,905,569	
1968	890,133	740,980	1,631,133	
1969	982,354	751,973	1,734,327	
1970	965,264	954,980	1,920,244	
1971	450,607	750,728	1,201,335	
1972	979,315	794,759	1,774,074	
1973	924,839	627,979	1,552,818	
1974	868,223	1,077,878	1,945,010	
1975	585,858	614,189	1,200,047	
1976	573,506	675,298	1,248,804	
1977	592,935	572,077	1,165,012	
1978			1,438,387	
1979			1,578,000	
1980	1,128,909	845,501	1,974,410	200,266
1981	942,919	778,741	1,721,660	225,296
1982	na*	na	na	na
1983	1,084,822	896,341	1,981,163	210,026
1984	729,323	796,852	1,526,175	267,932
1985	987,005	892,918	1,879,923	220,519

* na = not applicable.

Source: Welch 1986

Table 7. Estimated Cost of Selected Brush Control Practices

Treatment Description	Cost/Treated Acre ($)
Two-Way Chain	7 - 9
Burn (first)	3 - 7
Burn Subsequent	2 - 4
Stack (after chaining)	15 - 18
Burn Stacks	4 - 6
Aerial Spray "Grazon ET+PC" (1 lb AI/acre)	26
Aerial Apply "Spike" (2 lb AI/acre)	55
Root Plow	34 - 38
Root Rake (two-way)	24 - 28
Seed Buffel	14 - 16
Chisel Plow	9 - 11
Roller Chop	8 - 10
Heavy Off-Set Disc and Seed Buffel	34 - 38
Aerial Spray "Banvel + Grazon PC" (1 lb AI/acre)	25

Source: Presentation by Richard Conner, "Implications of Brush Clearing for Range Productivity and Income," Integrated Brush Management Systems Workshop, Texas A&M University, January 1986.

treatments may involve whether the mosaic pattern yielded by a nonuniform treatment strategy can be maintained. Second, it has been found that brush management methods which fail to remove or kill the brush root system have short-lived effects on water yield. For example, fire and chaining often have effects for only a few years after treatment (Brown 1986a). The practice most commonly felt to effectively enhance water yield involves herbicide use which kills the whole plant with follow-up prescribed burning to control regrowth. Third, mechanical root removal methods (raking, plowing) have been shown to exhibit considerable erosion potential (Scifres 1986).

Implications for Range Productivity and Income

One important set of issues involves the effects of brush management on range productivity and range-derived income. There are a number of important sub-issues relating to the productivity of the livestock, wildlife, and other ranch enterprises. There are also important questions regarding the economics of brush management.

Brush control affects land productivity. Range carrying capacities are altered as brush density changes. Brush and forage are competitive. Brush density affects wildlife feed, cover screen, and bedding areas. As brush is cleared, range productivity responds in a dynamic fashion dependent upon the establishment of replacement forages, rate of soil erosion, surface runoff volume, availability of wildlife cover screens, availability of drought forage reserves, and rate of brush regrowth. Texas Agricultural Experiment Station (1985) states that brush management can: 1) increase livestock carrying capacity; 2) increase wildlife carrying capacity when selective control is practiced; and 3) have varied effects on soil erosion, depending upon the degree of soil disturbance, the rate at which new cover is established, and the incidence of precipitation.

A number of studies contain data on the effect of brush management on livestock carrying capacity and productivity. For example, McBryde, Conner, and Scifres (1984) estimate that brush management could permit a 10.2 percent increase in South Texas range carrying capacity, leading to a 3.2 percent increase in the total regional value of livestock. However, brush removal activities cost money. Negative to low rates of return appear to be the norm on brush management investments when justified solely by livestock returns (Hamilton et al. 1986). In a study based on 1978 conditions, Whitson and Scifres (1980) estimate that, depending upon brush removal method, between 40 and 90 percent of brush treatment costs would need to be subsidized in order for a livestock producer to earn a 9 percent return on investment. Generally, these data indicate that brush management is not economically justified based on livestock benefits alone; rather, there have to be sufficient net benefits in terms of other on-site enterprises or off-site benefits. In the brush management context, there appear to be three other possible sources of on-site benefits–wildlife, water, and crops–as well as a source of cost or benefits of nonpoint source pollution. Off-site benefits will be discussed later. Wildlife merits further discussion and will be the subject of a paragraph below. On-site water could be used in justifying brush management if water yield is altered so that the resultant water increases ranch productivity such that net income increases.

Increased cropping on cleared brushland does not appear to be likely. There may be some on-site cropping stimulated by the ability to impound increased water, but this is likely to be limited. Nonpoint source pollution changes could have on- as well as increasing off-site costs or benefits. There are cases in Texas where brush management will either promote or inhibit nonpoint source pollution (this evidence will be reviewed in the later section on the environment). For example, increases in soil erosion could increase costs in terms of foregone future on-site agricultural productivity as well as increasing off-site costs of nonpoint source pollution.

Wildlife alterations are an important consideration regarding the on-site productivity effects of brush management. In certain areas of Texas, income from hunting leases can match or exceed that from livestock (Inglis 1985). Thus, brush management for water yield enhancement efforts will need to integrate wildlife management objectives with livestock and potential water yield objectives (Conner 1985a). Such objectives may well be complementary, as brush can be too thick to provide quality habitat for livestock and game animals. Extremely thick brush has the most negative livestock and wildlife production effect and therefore would yield a relatively larger rate of return to private brush management efforts (Whitson and Scifres 1980), while seemingly yielding more water. Evidence cited by Inglis (1985) shows that reductions in brush density can enhance game animal habitat. However, brush removal can be taken too far. Extremely open country depresses game animal numbers. Nongame wildlife may also play a role in determining the desirable amount of brush management. Different species exhibit different economic values (Stoll and Johnson 1984) and habitat requirements [as now being compiled by Texas Natural Heritage Department or as compiled for Oregon by Thomas and Maser (1986)]. Furthermore, game, nongame, and livestock animals using the land can exhibit both complementary and competitive relationships which could play a role in any ranch-level planning regarding brush management. Little is known about such relationships in Texas.

Consideration of the value of wildlife to the rancher also raises an issue regarding the relationship of game abundance and leases. Studies have found that the value of the leases on a particular piece of land is not tightly tied to the number of game animals inhabiting that land (Glover, Conner, and Steinbeck 1986). Factors such as services, publicity, facilities, and physical characteristics of the land appear to be more important. Research is needed on the relationship between brush management, lease values, and these other factors.

When one species in an ecosystem is altered, the composition of the remaining vegetation, insects, nongame animals, etc. is changed as well. Little is known about the effects brush management or increased water yield has on these items.

Benefits of Brush

A basic thrust of the brush management initiative has involved the removal of "worthless" brush. However brush may not be worthless. For example, brush may have value in terms of:

1) Supporting wildlife species whose habitat requirements call for particular characteristics (nesting, coverscreen, etc.) in terms of woody plants, particularly those species which require extensive areas of woody plants;

2) Reduction of soil slippage and erosion, particularly in unstable areas or on steep slopes;

3) Production of mesquite charcoal;

4) Provision of a drought forage reserve;

5) Provision of shade for livestock and wildlife; and

6) Alteration of local atmospheric conditions by altering photosynthesis and transpiration.

The value of not maintaining these and other possible benefits of brush is a research issue.

Brush Management as an Economic Decision

The final brushland productivity issue involves the way in which the brush management decision is evaluated by a rancher to see if it is advantageous. This topic has been treated by Conner (1985b) and McBryde, Conner, and Scifres (1984), among others. A number of factors must be evaluated over the decision time horizon to see if the management decision is beneficial. Often a net present value analysis will be used to evaluate the decision (Bussey 1978). The key considerations in the rancher's brush management decisions are: 1) livestock revenues; 2) livestock investment and rearing costs; 3) brush management costs; 4) wildlife-related income and associated costs; and 5) other benefit items.

Brush management can increase livestock production in a number of ways. There may be changes in the number of animals on the range, the calf crop, the weaning weight, or the sales weight of the animals. The most likely increase will come in terms of number of animals on the treated land, but the other factors may change depending upon whether forage quality changes. Livestock productivity alterations will vary over time depending on the rate of forage establishment and brush regrowth. Estimates of production increases and revenue changes are needed for each year of the planning horizon.

Assuming that the range carrying capacity increases, additional livestock investment costs may be incurred. More cows and bulls may need to be acquired. Added animals not only increase production but also variable costs such as salt, minerals, veterinary fees, etc. Brush management may reduce certain variable costs (such as labor or feed). Estimates of the net cost changes must be developed for each year.

The third category involves brush control costs for initial and follow-up treatments. These include the costs of the materials used, application equipment, any associated labor, etc. Another cost item which may arise involves the cost of maintaining the animals at some other location during the treatment and reestablishment periods.

Fourth, a number of wildlife benefits and costs should be considered which are difficult to quantify. These include the brush management-induced change in wildlife-related leasing income, wildlife management costs, and other values attributable to game and nongame animals.

Brush management may also exhibit other economic effects. The effects on the value of ranch-owned assets should be considered. These are included in the economic calculations by adding the brush management-induced change in the value of livestock, land, and equipment inventories (considering their abundance as well as altered sale value) at the end of the planning horizon.

Environment

There has been a historical tendency to overlook environmental concerns relative to brush management. However, environmental concerns are important from a number of standpoints. First, brush management practices may have the potential for increasing environmental quality, which would be valuable to society. Therefore, from a social standpoint, it may be important to consider the increased value of environmental quality in determining whether or not to undertake brush management actions. Second, in areas like Arizona, environmental concerns have been instrumental in determining whether or not brushlands are treated. Environmental concerns of the 1970's virtually brought brush management to a standstill on federally managed rangeland. For example, in 1980, the Bureau of Land Management treated only 2,500 hectares (6,250 acres) in the United States (Blackburn 1983). Nationwide, there has been a change in brush management with prescribed burning becoming much more prevalent. This has been influenced by the environmental movement. For example, while herbicides are known to be more effective for increasing water yield in treating brush, prescribed burning is the only brush management tool proposed in the Arizona Tonto Forest Plan (Forest Service 1985). Private ownership patterns in Texas may mitigate the influence of the environmental interests. Nevertheless, environmental concerns are important because of the social benefits and costs associated with environmental alterations and because of the potential constraints that could be placed on brush management practices.

Brushland management for water yield improvement could have a number of environmental implications. These implications arise principally through the effects of brush removal on plant species mix, evapotransporation, photosynthesis, water infiltration, surface flow, and runoff chemical content. In turn, these alterations affect environmental attributes as well as atmospheric conditions and scenic characteristics of the land.

Wildlife

Brushland management can alter populations of both land- and water-based wildlife. The possible effects on land-based wildlife depend on their food, cover, and shelter requirements. Some species will increase in abundance and/or migrate into the area as the plant population is altered, while other species will migrate out or diminish. For example, research indicates mule deer favor more open country while whitetails favor brush; thus, increased brush concentration has been found to lead to a substitution between these species (Wiggers and Beasom 1986). Information about the likely implications of brush management is contained in Inglis (1985) or the habitat requirement compilation now underway by the Texas Natural Heritage Department.

Water resulting from brush control can affect water-based wildlife in a number of ways. There may be changes in the timing and availability of water as well as water quality. Stream flows may change from variable seasonal patterns to dependable perennial patterns and/or stream flow volume may increase in a uniform or seasonal manner. Flooding also may increase. Water increases may occur in streams, rivers, reservoirs, and/or estuaries. The brushland water yield also may affect groundwater and the wildlife species dependent upon springs and areas fed by springs.

Water quality changes also can alter wildlife populations. The exact nature of the water chemistry changes covered by brush management are not well known. Generally, it has been found that there may be changes in herbicide residuals, nitrate concentrations, and sediment load as a result of brush management (Davis 1984, Blackburn 1983, and Clary et al. 1974), and some feel there may be increases in salts washed into watercourses. In turn, these changes could alter the fish and wildlife habitats through effects on the eutrophication of streams and reservoirs or through changes in soil fertility within the watershed. This may lead to an increase in algae blooms and aquatic macrophytes, although reportedly in Texas, phosphorus, not nitrogen, is the limiting nutrient for such phenomena.

Water Availability

Brushland management techniques may increase the amount of water in streams, groundwater systems, and/or percolating from groundwater to surface water.

Changes in any of these can alter environmental characteristics such as stream channel dynamics (Schumm 1974) as well as the recreational use of certain areas (Young 1982). Increases in water availability also can lead to increased flooding, which can be destructive in terms of the aesthetics and property values along watercourses. Increased water yields, if potentially directed toward groundwater recharge, could prevent groundwater depletion and/or springs from drying up, thereby maintaining surface water uses, recreation, and tourism industries. (The San Marcos springs fed by the Edwards Aquifer are an example of a surface water system linked to groundwater.) Increased levels of water availability may also affect bays and estuaries by providing more water and by altering salt content.

Water Quality

A number of studies have considered the influence of brush management on water quality. The influences documented in the literature involve nitrates, sediment loads, and herbicide residuals. Davis (1984) reports results from an 11-year study of a treated watershed in Arizona showing sharply increased nitrate levels. In fact, nitrates were increased on the order of 100-fold during the first couple of years and, over the 11-year period, show a 14-fold increase when compared to an untreated watershed.

Long-term soil erosion rates, as reviewed by Blackburn (1983), generally have been shown to exhibit no increase or decrease on treated versus untreated land. However, almost all treatments exhibit short-term increases in soil erosion. There may also be cases where there is an increase in long-term soil erosion. For example, in Bedunah's 1982 study, an area which was denuded exhibited a large increase in soil erosion. While this may not be a planned consequence of brush management, it may be possible that gulleys and unstable areas are created in areas which, under brush, were previously stabilized.

If herbicides are used in brush management, herbicide residues may alter the chemical composition of water. Clary et al. (1974) report that herbicide residuals amounting to 1.3 percent of that applied were found in runoff water during the first year after treatment. Concentrations ceased to be detectable after 3 years. Herbicide research in Texas has revealed results similar to the Arizona studies. Herbicide concentrations decreased with distance from the treated area in proportion to the size of adjacent, untreated watershed subunits, which contributed runoff water to streamflow (Mayeux et al. 1984). Plant "washoff" was the main source of herbicide detected in runoff water. In one study, about 6 percent of the applied picloram left the treated area during a period of 1 month when conditions were especially conducive to herbicide transport. The picloram concentrations decreased with each successive runoff event (Mayeux et al. 1984). The initial peak concentration could harm crops below the treated area, but no effect was shown in one study (Bovey et al. 1974). These results were similar in cases where follow-up treatments were employed (Baur, Bovey, and Merkle 1972). Research on chemical concentrations in subsurface flows showed extremely low presence of herbicide residues (Bovey et al. 1974). Long-term studies have not been done due to the speed of chemical degradation. The cumulative effects from widespread applications could be researched.

Changes in water quality may affect the value of water for drinking and/or other uses. No systematic information is available on the economic effects of changed water quality. For example, nitrates in drinking water are known to be the cause of methemoglobinemia, a potentially deadly condition for infants 3 months old or less (National Research Council 1978). Finally, brush management also may affect aquatic salt concentrations when salt concentrations are reduced by increased flow or salt-bearing runoff (when water crosses salty surfaces or infiltrates through underground salt deposits).

Atmospheric Characteristics

The removal of brush from a considerable acreage of Texas brushlands could cause atmospheric changes; for example, Rechenthin and Smith (1967) estimate millions of acres could be treated. If millions of acres were treated, then there could be several million less acre-feet of water transpired into the atmosphere by the brush plants. This might have implications for humidity and rainfall patterns in Texas, but the effect is probably minimal given the dominant effect of Gulf and Pacific Ocean evaporation on Texas atmospheric conditions.

Scenic Characteristics

The final environmental issue involves changes in scenic characteristics. Brushland management will obviously alter brush density as well as the population and species mix of animals using that brushland. Scenic characteristics of the river and stream environments also could change. An environmental concern, given a proposal to modify a large amount of land, may well involve scenic characteristics. This has proven to be important in Arizona, where environmental concerns have opposed large-scale land treatment practices, in part based on scenic concerns. Environmental groups do not have as much political standing in Texas as they do in other states because of the private ownership characteristics of Texas land. Potential detrimental externalities resulting from losses in scenic beauty are, nevertheless, a policy concern.

Law and Institutions

The legal status of water conserved through brush management is unsettled in Texas. There is a lack of statutory or judicial direction from which to develop a clear answer to questions such as "Who owns any water produced by brush management?" "Can the water conserved be conveyed to other persons?" And "What are impediments to allocation and use of the conserved water?" In addition to the novelty of the legal status of conserved water, the form, location, and source of the water also are important in determing applicable law.

The legal ownership and allocation of any water conserved by brush control depends on the classification of the water. Water is legally classified as *surface water*, *groundwater*, or *diffused surface water*. Different laws apply to the use of water in each category. This distinction has relevance for brush management, since the resulting water will fall into one of these categories. Surface waters are owned by the state and allocated under a permit process, whereas groundwater and diffused surface water are not considered state waters.

Surface Water

Water designated surface water is held in trust by the state and generally requires a permit from the Texas Water Commission before it may be diverted and used. Surface waters are defined as the surface and related underflow of every watercourse including stormwater, floodwater, and rainwater (*Texas Water Code* § 11.02). Watercourses include natural rivers, streams, canyons, and ravines (*Texas Water Code* § 11.02). Any water in a watercourse that results from adoption of conservation measures arguably is state water to be allocated under the permit system.

All rights to use surface water arise from a state-granted permit. The Texas Water Commission may issue a permit to appropriate water for any "beneficial use." Beneficial use is defined as an "amount of water which is economically necessary for the purpose authorized by [the Water Code], when reasonable intelligence and reasonable diligence are used in applying the water to that purpose" (*Texas Water Code* § 11.002(4)). In practice, the Texas Water Commission has considered almost any customary use a beneficial one. Although waste is prohibited under the Code (§§ 11.092-.093), it has been narrowly defined.

A permit specifies a particular quantity of water to be used for an identified purpose but limits the amount acquired to that which is actually beneficially used. A permit authorizing appropriation of state water is merely a license evidencing the holder's intent to divert and use state water (Peel 1986). The right remains unperfected until the water is beneficially used for the purpose specified in the permit. When an appropriator applies a quantity of permitted water to an authorized beneficial use, the right to that water is perfected and becomes a vested right.

Determining the Amount of Unappropriated Waters

Because a permit can only be given to use unappropriated water, it is critical to determine the amount of flow available in the stream along with the amounts appropriated and/or actually used. Current Texas Water Commission methodology includes calculation of historic flow in the basin and computer modeling. The Texas Water Commission determines unappropriated water by subtracting the full face value of existing rights from the amount of flow to get the amount available for new appropriation.

The Texas Water Commission's approach to determining unappropriated water available for appropriation was reviewed in a recent case before the Texas Supreme Court. In *Lower Colorado River Authority* v. *Texas Department of Water Resources (1985)*, the court held that where current paper rights on a river exceed the average annual flow, there is no water available for appropriation. This conclusion was reached even though the water actually applied to beneficial uses on the river in question did *not* exceed the average annual flow of the river. This case has implications for water generated by brush management. The Texas Water Commission will need precise data on water yields through brush control to allocate the additional water.

Statutory Limitations on Permit Rights

Several sections of the Water Code provide criminal and civil penalties for unlawful use and diversion of waters subject to the permit process. Persons are:

1) Prohibited from selling or offering to sell water rights unless the seller has a permit from the Texas Water Commission authorizing the new use of the water (*Texas Water Code* § 11.084);

2) Penalized for wasteful use of water when the use of water is excessive or applied to a nonbeneficial purpose or when there is unreasonable loss of water through faulty design or negligent operations of water conveyance systems (*Texas Water Code* §§ 11.092-.093)

3) Required to return *surplus* water, i.e., water not consumed during use, back to the stream of origin (*Texas Water Code* § 11.046)

4) Allowed to use permitted water for a secondary purpose before return only if it complies with the permitted purpose (31 *Texas Administrative Code* § 295.8);

5) Not allowed to divert water from any stream into any other stream to the prejudice of any person within the watershed from which the water was originally taken (*Texas Water Code* § 11.085) and

6) Required to amend their permit from the Texas Water Commission if they change the place of use, purpose of use, point of diversion, irrigated acreage, or otherwise alter a water right (*Texas Water Code* § 11.122(a)).

The Water Code is not exclusively prohibitory in nature. It contains a number of permissive provisions allowing for flexibility in the allocation and use of water. Under selected provisions of the Code persons are:

1) Allowed to sell permitted water to anyone who has the right to acquire the use of it and to use a natural watercourse to convey the water *Texas Water Code* § 11.036(a)); and

2) Allowed to construct, without obtaining a permit, reservoirs to hold not more than 200 acre-feet of surface water for domestic and livestock purposes (*Texas Water Code* § 11.142(a)).

Since 1931, Texas municipalities have had special rights to acquire surface water, without paying for it, from other water rights holders, provided the water is used for domestic purposes (*Texas Water Code* § 11.028). This provision is functionally a time priority appropriation giving municipalities a 1931 priority date.

Loss of Water Rights

The prior appropriation doctrine requires due diligence in the use of water. Nonuse of water is antithetical to Texas water law and can result in cancellation of a water right. The Water Code allows the Texas Water Commission to institute cancellation proceedings based on 10 consecutive years of nonuse of water by a permit holder (*Texas Water Code* § 11.172). In many respects, this discourages water conservation. If a permit holder adopts a conservation measure thereby saving water, that saved water can be lost through cancellation.

Diffused Surface Water

Diffused surface water is water not part of a running stream or watercourse. It is water which has come from falling rain or melting snow and which follows no definite course, but which is eventually lost by evaporation, by percolation into the ground, or by entering a watercourse. One court has called it water of "casual and vagrant character" (*Hoefs* v. *Short* 1916). Diffused surface water is not regarded as state water and the surface water legal framework does not apply.

Once diffused surface water reaches the point where it enters a waterway with a well-defined channel or bank, it ceases to be diffused surface water and is considered subject to appropriation under the permit process (*Stoner* v. *Dallas*, 1965). Correspondingly, if the water percolates into the ground it legally becomes groundwater.

If the flow of diffused surface water is increased by brush management, the water belongs to the landowner so long as it remains on the property. This right is not absolute. Certain limitations on a landowner's rights to control and use diffused surface water can be found in the Surface Water Act of 1915 (*Texas Water Code* § 11.086). The statute reads, in pertinent part, "No person may divert or impound the natural flow of surface waters in this state, or permit a diversion or impounding by him to continue, in a manner that damages the property of another by the overflow of the water diverted or impounded" (*Texas Water Code* § 11.086). As a rule of property, the statute applies only to persons or private entities who are proprietors of land (*Kraft* v. *Langford* 1978). The statute does not apply to governmental entities (*City of Amarillo* v. *Ware* 1931). If a governmental entity causes excessive overflow, the injured landowner's action is based on inverse condemnation. This means a governmental body has no greater right than an individual to collect diffused surface waters and release them in unnatural quantities on lands of another unless by agreement and with the appropriate compensation.

The Surface Water Act does not apply to a landowner's right to drain land into natural drainways where the water tends to naturally flow toward that drainway. The landowner may collect this water and discharge it into a natural watercourse on his or her own land provided the discharge does not exceed the natural capacity of the watercourse. The courts have, however, issued a warning in this respect: "We do not think a landowner has the right under the law to capture, concentrate, and discharge surface waters with impunity, even on his own land, and thereby divert the same from their natural flow [to the injury of lower riparian owners]" (*Coleman v.* Wright *1941). Thus, the upper landowner must conduct business in a* reasonable manner, taking care to avoid altering the natural flow of the water to the extent that it would create liability under the unlawful diversion statute.

Groundwater

Waters "percolating, oozing, or filtering through the earth" are classified as groundwater. The Texas appropriative statutes do not apply to such waters, and groundwater is not property of the state subject to the permit system. Texas courts have unequivocably adopted and the Legislature has not modified the common law rule that a landowner has an absolute right to take for use or sale all the water he can capture from below his land (*Smith Southwest Industries Inc.* v. *Friendswood Development Company* 1977).

Any water saved through brush control that becomes groundwater is the property of the overlying landowner. Limitations on the use of this water may occur through regulatory provisions of undergroundwater conservation districts, but these restrictions do not change the private ownership of water.

Rights to Waters Resulting From Conservation Measures

The rights to the use of waters produced by brush control are not easily resolved under existing statutory or case law. If the conserved water by its flow or seepage naturally enters a watercourse, it would be considered state water subject to appropriation. However, if the conserved water can be captured before it leaves the landowner's property and was not previously derived from state waters, then it would be subject to use and control of the landowner. Between these two extremes lies a large area of gray in which the classification of water is not clear. At least two major doctrines are potentially applicable to the characterization of water produced by brush control: the doctrine of *developed water* and the doctrine of *salvaged water*.

The Distinction Between Developed Water and Salvaged Water

In the leading case to date concerning water conservation by phreatophyte control, the Colorado Supreme Court distinguished between "developed water" and "salvaged water" (*Southeastern Colorado Water Conservatory District* v. *Shelton Farms Inc.* 1975). Developed water is new water added to a stream or other source of water supply not previously part of the system. Examples include water brought from another source, or water found within the system which would never have normally reached the river or its tributaries.

In contrast, salvaged water is water from the river system that otherwise would be wasted but instead becomes available for beneficial use. In the *Shelton Farms* case, for example, the phreatophytes which were eradicated grew in a river bed. Therefore the court concluded that the water saved by their removal was water which already was a part of the river system. The water generated by the phreatophyte eradication was held to be part of a river which was held to be already fully appropriated. Hence, this salvaged water belonged to the other senior appropriators and not the conserver. This finding has been upheld in a number of other cases, and one can safely conclude that under current law the removal of brush immediately adjacent to a watercourse results in additional state water.

The Texas Approach

Texas seems to follow a similar approach to rights in conserved water. In *Texas Law of Water Rights*, Hutchins defined developed water as "new water added to a stream or other source of water supply by reason of artificial works" (1961, p. 541). This definition arose in the regulations of the State Board of Water Engineers: "Developed water is water that in its natural state does not augment a water supply, but that is added to a water supply or is otherwise made available for use by means of artificial works" (Hutchins 1961, p. 541). By allowing that return waters could be developed water, Hutchins (1961) implied that water newly created and then used retained its character as developed water even as it returned to a stream. These conclusions were based on a paucity of Texas cases available concerning developed waters.

One Texas case contains an oblique reference to water saved through brush control. In *Halsell* v. *Texas Water Commission* (1964), an expert witness discussing water saved in a reservoir through reduction of evaporation or through phreatophyte control referred to that water as salvaged water saved for the State of Texas (*Halsell* v. *Texas Water Commission* 1964). This result would be consistent with the *Shelton Farms* case.

The Texas Water Commission's new rules seem to indicate that any water which is arguably state water, even though made usable through private efforts and investment, is still state water subject to the permit process, that is, salvaged water. Yet, Texas cases have termed previously appropriated irrigation waters, contained in drainage ditches, developed waters. In *Harrell* v. *F. H. Vahlsing Inc.* (1932) the San Antonio Court of Civil Appeals held that the owner of irrigation seepage and drainage waters may recapture such water and sell it to adjoining landowners. In California, return flow is required and is subject to further appropriation (*California Water Code* 1971, § 1202). Wyoming case law holds that an owner of land upon which seepage or waste water rises may recapture the water only for use where originally appropriated (*Fuss* v. *Franks* 1980). Generally, most western states deprive downstream appropriators of a cause of action against such recapture of drainage waters.

Halsell v. *Texas Water Commission (1964), Guelker* v. *Hidalgo County Water Improvement District (1954)*, and *Harrell* v. *F. H. Valsing Inc.* (1932) apparently deprive any downstream claimant of rights in an upstream user's return water. But Water Commission rules prevent the upstream user from using it for nonpermitted purposes. Case law and Water Commission rules and policy are in conflict and confusion in this area. Where brush management creates water supplies out of diffused surface water, it is water not previously appropriated and clearly produced by labor and investment of the producer. Brush management conservation is thus distincnt from the facts of *Shelton Farms*, where it is held that the water saved by phreatophyte control was water *earlier* a part of a fully appropriated stream.

Evaluation

The ownership status of water conserved through brush management control is unsettled in Texas. Several questions arise due to the complex range of fact patterns encompassed by such water conservation efforts and the failure of Texas water law to provide a unifying perspective from which to deal with water allocation and development problems.

Fact Patterns Vary

A wide range of water ownership patterns are imaginable under the umbrella "water conservation through rangeland brush control," depending on the type of water involved. The water "saved" may percolate into the ground and become groundwater. It may arise as increased diffused water and be available for capture by the landowner. It may flow as increased runoff into existing watercourses and become state waters subject to appropriation. Rights to the use of conserved water are determined not only by the above characterizations but on additional legal factors as well. Rights to water subject to appropriation may depend on use (whether or not beneficial, whether consumptively used, used and returned, or unused and returned as surplus), on time (first in time yields first in right), and on effect on others. Important prerequisites to water ownership, transfer, and transportation are summarized in Table 8. This information shows that water ownership, once achieved, does not imply an unimpeded right to sell consumption rights.

Table 8. Summary of Texas Ownership and Conveyance Rights by Water Type

Water Type	Ownership	Water Right Transferrable	Transportable Through Natural Watercourse	Transportable Through Other Means
Surface Water	Permit granted by TWC[a]	Approved by TWC	Permit from TWC (Bed & Banks Permit[b])	Permit from TWC
Diffused Surface Water	Water is captured	(No apparent limitations)	Permit from TWC (Bed & Banks Permit)	(No apparent limitations)
Ground-water	Water is captured	(No apparent limitations)	Permit from TWC (Bed & Banks Permit)	(No apparent limitations)

[a] TWC = Texas Water Commission.
[b] Texas Water Code § 11.042.

At this time, the law regarding the classification of waters and hence determining its availability for capture, reuse, or recycling under an existing appropriation, or requiring a new permit to appropriate, is not based on conservation objectives treating water as a scarce natural resource. In some regards, the law regarding water rights directly contradicts conservation goals.

Legal Impediments to Conservation Techniques

Control of an essential natural resource is fundamentally a policy question for the state. In the last legislative session, Texas made some progress towards integrating conservation goals with the state's water law, but several established features of the permit system do not further conservation objectives.

In the Texas permit system, water rights depend on water use. The "use it or lose it" basis for maintaining appropriative rights generates continual pressure against conservation. In Texas, virtually any customary use is adequate to protect a permitted water right. Furthermore, code language exists declaring unused water to be unappropriated. This may be a serious disincentive for a current user to make private outlays for conservation if additional use of the "saved" water will not be available to the conserver.

Legal Issues Regarding Environmental Impacts

Any brush management project may impair water quality and pose other environmental threats. For instance, brush removal may displace wildlife or lead to water quality deterioration endangering fish. Contamination of groundwater may also be possible. The legal responsibility of a landowner undertaking a brush management project will be examined next.

Brush management can be considered a nonpoint source of pollution insofar as it increases the delivery of sediment, nutrients, and pesticides to waterways. Responsibility for managing agricultural nonpoint sources is addressed by the Clean Water Act, which assigned federal regulatory authority to the Environmental Protection Agency and the U. S. Department of Agriculture. This policy has evolved into a situation where these agencies defer to the individual states for nonpoint source pollution management (Griffin and Stoll 1984). States, including Texas, have not taken a strong stance in regulating agricultural nonpoint sources. If brush management activities are shown to contribute substantially to the nonpoint source problem, public control to mitigate pollution may be forthcoming.

The significant federal statute regulating herbicides is the Federal Insecticide, Fungicide, and Rodenticide Act (7 *United States Code* § 136). It requires registration of pesticides and certification of applications. This statute is applicable to brush control by herbicides. In addition, Section 75.006 of the *Texas Agriculture Code* (1986) requires a permit before a controlled herbicide is used. A permit, once issued, expires when the area for which the permit was granted has received application of the herbicide. Application of herbicides also is regulated (*Texas Agriculture Code* § 75.012). In situations of aerial spraying, the applicator must provide notice of intent to spray and prepare a record of the spraying. The Texas Department of Agriculture can delay or cancel the application if the spraying would endanger crops or valuable plants in the area.

In the last 20 years, Congress has become increasingly cognizant of the need for fish and wildlife conservation. The result has been the creation of a body of environmental law that is both advisory and demanding (Coggins 1983). Both of the following federal conservation statutes, as a rule, apply only to action by federal agencies.

The Fish and Wildlife Coordination Act (16 *United States Code* §§ 661-666) provides that wildlife conservation is to receive equal consideration with water resource development programs through "harmonious" and effective planning. Furthermore, the Secretary of the Interior is authorized to develop all species of wildlife and their habitats as well as control the loss of wildlife from disease or other causes. Although this act is directed at dam-building agencies, it may affect brush management projects. If the brush management was done for a water storage project or caused an increase in the flow of a waterway, resulting in more land being covered by the stream and a concomitant loss in habitats, then mitigation measures may be required of the landowner (Coggins 1983).

Perhaps of greatest significance in the fish and wildlife conservation area is the Endangered Species Act of 1973 (16 *United States Code* §§ 1531-1534). It forbids the taking of endangered species, instead of requiring agencies to conserve them and protect their habitat. And equally clearly, "management practices that harm listed species–individually or in combination–are flatly illegal." Thus, brush management, with the potential herbicide contamination, habitat disruption, and increased water flow, could come under the Endangered Species Act by "jeopardizing the continued existence" of a particular listed species.

Mitigation Measures

Brush management on rangeland may require some mitigation measures to limit harmful environmental impacts. A provision of the *Texas Administrative Code* requires that the policy of the Texas Parks and Wildlife Department is to "seek full mitigation for fish and wildlife losses" (Chap. 31, § 57.141). The application of this policy is limited to those losses that occur through water resource development activities (31 *Texas Administrative Code* § 57.141 (b)). Although brush management is not primarily what the regulation addresses, it may come within the provision's scope. The section provides that mitigation measures may include, among other things, land replacement for loss of hunting opportunities and management techniques to replace and protect fish. These might include construction of spawning areas and nursery cove areas. Of course, these mitigation requirements could be necessary in a brush management project.

Additionally, federal law provides that water resource development plans that cause the loss of fish habitats should be mitigated (16 *United States Code* § 662). The measure required in these cases is replacement of the lost habitat. A fish habitat might be lost by the increased water flow caused by the brush management. Under such circumstances, the habitat will have to be replaced by the landowner provided this section is held to apply to water development by managing brush.

Economics

The Texas water problem is not a problem of physical scarcity. The true problem is one of economic scarcity: the means and costs of supply, the practices and implicit values of competing demands, and the balancing of supplies and demands. This more general conception of water scarcity addresses a number of allocational and distributional questions. These include questions relating to how water supply is or isn't developed, who gets limited supplies (and when and how), and to what uses water is put, along with many others.

Decisions concerning water use and allocation–whether private or public–must resolve the inevitable tradeoffs which face any commodity or resource employed by mankind. Economics is the examination of such tradeoffs, and it is the resolution of economic issues which guides rational choice. Monetary values often serve as a metric by which the desirability of particular actions (or inactions) is gauged. Three major economic issues relevant to the notion of brush management for water production are:

1) What are the off-site benefits and costs of increased brush management, and do the off-site benefits exceed the costs?

2) Are the off-site net benefits of brush management sufficient to offset the range manager's net costs?

3) Is a brush management policy economically attractive?

This listing omits a number of on-site economic questions which were discussed in the "Brush Treatment and Range Productivity" section. Implicit, but not omitted from these issues, are a number of secondary questions which will be discussed briefly. All of these issues have crucial risk, spatial, and temporal dimensions which bear heavily on the entire topic of brush management for water production.

Do Off-Site Benefits Exceed Costs?

Rangeland brush management is best interpreted as an investment activity with maintenance and water capture costs. This investment can produce on-site livestock, wildlife, and aesthetic benefits as well as off-site water and environmental benefits. The on-site economic concerns were discussed earlier; this section considers the potential off-site values.

Consider the benefits first. The most noteworthy benefit is enhanced water supply. Ideally, one should know the recipients and use of the additional water and the timing involved. Slightly less ideally, one should know to what use will the water be put, where, and when. Regardless, one needs to have an idea of how much the water is worth at various times of the year and how much is used. Water has different values in different uses, ranging from a few dollars per acre-foot in low-valued irrigation (Frank and Beattie 1979) to thousands of dollars per acre-foot in certain manufacturing activities. In the same use water has different values in different places. For example, while San Antonio citizens are paying approximately $230 per acre-foot, some people in the Corpus Christi area normally pay three times that amount. Even in the same use at the same place, water has different values at different times. Water is most highly valued during summer months when demand is high and supply is low. During a period of restricted water use during the 1984 summer drought, some Corpus Christi homeowners paid large sums ($20 per thousand gallons or $6,517 per acre-foot) for trucked wastewater to preserve their lawns. The economic benefit of enhanced water supply is dynamic because of the changing value of water. Increasing scarcity over time increases value. Because growth in population and economic activity will increase water scarcity, the value of Texas water grows over time. More reliable and secure water supplies command greater premiums; the more senior the water right, the more valuable. The stochastic influence of weather is pertinent. Generally, water is more valuable during drought periods. Quality is pertinent–consumers who pay $1.20 for 1,000 gallons of pressurized tap water delivered to their home ($391 per acre-foot) also are willing to pay 79 cents for a gallon of drinking water at the supermarket ($257,000 per acre-foot). Drinking is obviously a highly valued use of water. Research is needed on the value of water in different uses, places, and times.

As a second category of brush management benefits, consider the range of positive, extramarket impacts. Preliminary information and opinions suggest that brush management can have positive impacts on sediment loads, water quality, wildlife, estuaries, scenic aesthetics, and other environmental goods. These items can have significant social value, but with the exception of certain game animals the benefits do not accrue to the brush management investor. The reason is that markets for many of these "commodities" do not exist, probably because of measurement difficulties or high transaction (information) costs.

Rangeland generally experiences less long-term erosion after brush treatment and grass establishment, other things being equal. Reduced erosion will preserve the character and long-run productivity of soils and offers an on-site benefit for the rancher. As noted earlier, brush treatment is usually followed by increased soil erosion during a brief period. Reduced erosion also offers off-site benefits (Crosson and Brubaker 1982). Nonpoint source pollution, primarily by sediment, will be lessened, thereby reducing the costs of siltation, water treatment, flooding, and turbidity. Little is known about the off-site value of diminished or increased soil erosion, although Taylor (1977) estimates an off-site marginal value of 16.5 cents per ton of reduced erosion within a North Texas watershed. This figure primarily represents the costs of removing siltation from a reservoir and may or may not be appropriate for other regions.

Improved surface and subsurface water availability as well as the restored grassland habitat provide a number of extramarket environmental benefits. Brush management, resulting in some type of mosiac pattern with interspersed open areas and brushy areas, will typically improve wildlife habitat (Inglis 1985). Such improvements can lead to changes in wildlife species mix of supportable species, an improvement in wildlife health and condition, and greater productivity in the sense of increased size or population. Very little is known regarding the social value of such impacts.

Greater surface water production can produce or renew wetlands, contribute to instream flows, and charge coastal estuaries. Important waterfowl, shellfish, fresh water fish, and saltwater fish species are assisted by these effects. Instream or on-stream recreational experiences also are improved. At issue here is not the value of these commodities or activities, but the marginal value of water in producing these things. *Young (1982, pp. 20, 21) has summarized marginal values of water for* similar activities on Colorado mountain streams: $9-13 per acre-foot for fishing, $2-5 per acre-foot for whitewater sports, and $7 per acre-foot for streamside recreation.

Increased surface water flows can, depending on the timing of these flows and the availability of hydroelectric capacity, be employed to produce additional electricity. Because of the high level of water development in the western United States, a given unit of water often can produce electricity at each of several dams along a river. For example, water has a value as high as $50 (1982 dollars) per acre-foot in the Oregon/Washington Columbia river basin, averaging 5 cents per foot of head (McCarl and Ross 1985). Similarly, in the Arizona Salt River Valley, where brush treatment has been most throughly investigated for its water-producing ability, an acre-foot was valued at $2.48 (1972 dollars) if it produced power at four reservoirs (Brown, O'Connell, and Hibbert 1974). Depending on where the water originated, it may not pass through all four of these reservoirs. Values for particular dams ranged from 45 to 90 cents per acre-foot (depending on head), and it was assumed that additional flows were 100 percent usable, i.e., timing of enhanced flows was not a problem. Hydropower development varies in Texas, and it is conceivable that water produced through brush management may or may not offer hydropower benefits depending on the availability of excess hydroelectric capacity.

While the on-site costs of brush management are mentioned in the "Brush Treatment and Range Productivity" section, significant off-site costs are certainly present. There are two major categories: water development costs and off-site environmental costs.

Water produced by brush management, whether in groundwater or surface water form, does not arrive at places and times of final use without cost. This water must be stored, transported, pumped, and often treated prior to consumption. The prospective use values which were discussed earlier as benefits are counterbalanced by development costs. Assuming excess capacity exists in the form of unused reservoir storage (or well pumping capacity), conveyance and treatment systems, and wastewater facilities, there are still labor, energy, chemical, and other resources consumed in the delivery of brush management-produced water supplies.

If excess capacity does not exist in one or more of these items, then additional capital must be devoted to construction. Otherwise brush management water benefits will be limited to instream benefits. Even where excess capacity does exist, the quantity of brush management-produced water may exhaust this capacity and accelerate the construction of new facilities–another cost. Simulation results for an Arizona watershed demonstrate that brush management-produced surface water comes mostly during high flow periods when reservoirs are nearly or totally full with almost 50 percent of the increased water supply going uncaptured (Brown 1986 a,b). If this holds true for Texas, then additional facilities may be needed to realize out-of-stream water benefits.

The final major category of off-site benefits and costs concerns environmental damages. The impacts here appear to be few, but they may be substantial under particular circumstances. First, off-site environmental damages may be caused by specific brush management practices. For example, drift from aerially applied herbicides or uncontrolled maintenance burns can damage property, crops, livestock, wildlife, or people. Similarly, nitrates and other nonpoint pollutants can have deleterious water quality effects with consequent damages and/or pollution control costs. Second, excessive brush removal can be injurious to wildlife habitats because brush often serves as a crucial source of cover, shade, shelter, and food (Inglis 1985). While this is largely an on-site cost, there may be deleterious repercussions for off-site areas. Though not an environmental cost, strictly defined, any increase in flooding produces off-site costs which should be accounted for within a complete economic appraisal. Again, these are topics in need of research.

Is Brush Management Economically Attractive?

The several dimensions of benefits and costs offered by brush management require careful analysis. Some benefits and costs fall upon the rancher; others accrue to off-site individuals. From a social/policy perspective both count. Some of the benefits/costs come in the form of marketed commodities, while others do not. Certain effects occur in one time period or under one set of circumstances but not in others.

The appropriate economic criterion for analyzing brush management is that of net present value (NPV) (Howe 1971; Sassone and Schaffer 1978) where the discounted net benefits are summed from the initial treatment period (year 0) until the final period of the planning horizon (year T).

$$NPV = \sum_{t=0}^{T} (B_t - C_t)(1 + r)^{-t}$$

The parameter r in this formula designates an appropriate social discount rate. B_t denotes the benefits in time period t while C_t denotes associated costs. If the computed net present value is positive, then brush management is a socially valuable investment in the sense that investment returns are greater than the threshold returns mandated by r.

The difficult task is to quantify the many benefits and costs which are necessarily implicit to B_t and C_t. Following the example of Krutilla, Bowes, and Sherman (1983), a representative listing of economic effects is presented in Table 9. This taxonomy of values is separated into on-site and off-site effects. Completion of Table 9 for each period within the planning horizon is a prerequisite for computing NPV and determining the social worth of brush management.

Any complete economic appraisal of brush management for water production would be tentative at this time. Of the 26 assessment categories identified in Table 9, the earlier Blackburn, Jones, and Lacewell (1984) paper was able to quantify five, excluding, for reasons of time and missing information, important factors (e.g., brush management maintenance costs and wildlife benefits). Further, the water benefits were based on an assumption that 70 percent of the acreage would be treated which is probably optimistic. This is indicative of the availability of technical and economic information. The only economic studies similar to the type needed here are those of Brown, O'Connell, and Hibbert (1974); O'Connell (1972); Clary et al. (1974); and Krutilla, Bowes, and Sherman (1983). The first two of these studies deal with Arizona chaparral; the third addresses Arizona pinyon-juniper; and the fourth examines forestland in western Colorado. Even though the regions and vegetation addressed by these studies are unlike the situation in Texas, the types of benefits and costs requiring evaluation are similar. All of the appraisal needs identified in Table 9 but saltwater fish were relevant for the four studies. Inspection of the impacts which were actually valued within these studies, however, reveals numerous omissions (Table 10). In addition, all these studies assumed 100 percent of the water is usable, contrary to Brown's (1986b) findings. These studies were limited by available information.

Omissions in these four studies constrain the usefulness of their conclusions, but, with this in mind, the results are still interesting. The Brown, O'Connell, and Hibbert (1974) chaparral study had mixed conclusions; chaparral treatment was economically attractive in some areas of the study region but not in others. In particular, 96 of the 139 analyzed areas exhibited positive NPV's for chaparral conversion. O'Connell's (1972) evaluation of chaparral treatment for a small watershed in Arizona determined a slightly positive NPV. Clary et al. (1974) also found a slightly positive NPV for *successful* pinyon-juniper removal projects. Finally, the study of clear-cutting forested lands for water production found NPV's in excess of $300 per acre (Krutilla, Bowes, and Sherman 1983). It is notable that the shortest planning horizon used in any of these studies was 50 years, and discount rates ranged

Table 9. Categories of Information Needed to Do an Economic Appraisal

Categories	On-Site	Off-Site
Benefits:		
Water		?
Livestock	?	
Game Animals	?	?
Nongame Animals	?	?
Game Birds	?	?
Nongame Birds		?
Freshwater Fish		?
Saltwater Fish		?
Other Recreation		?
Erosion	?	
Nonpoint Source Pollution		?
Hydropower		?
Total Benefits(B_t)	?	?
Costs:		
Livestock Management	?	
Vegetation Treatment	?	
Maintenance	?	
Treatment-Related Damage to Plants/Animals	?	?
Seeding	?	
Water Development		?
Erosion	?	
Nonpoint Source Pollution		?
Flooding		?
Total Costs (C_t)	?	?

Table 10. Economic Values Quantified by Previous Studies

Study	Brown et al. (1974)	Clary et al. (1974)	O'Connell (1972)	Krutilla et al. (1983)
Region	Arizona	Arizona	Arizona	Western Colorado
Vegetation	Chaparral	Pinyon-juniper	Chaparral	Forests
Benefits:[1]				
Water	√	√	√	√
Livestock	√	√	√	?
Game Animals	?	?	?	?
Nongame Animals	?	?	?	?
Game Birds	?	?	?	?
Nongame Birds	?	?	?	?
Freshwater Fish	?	?	?	?
Saltwater Fish	?	?	?	?
Other Recreation	?	?	?	√
Erosion	?	?	?	?
Nonpoint Source Pollution	?	?	?	?
Hydropower	√	√	?	√
Fire Reduction[2]	√	?	√	?
Harvested Timber[2]	?	?	?	√
Costs:[1]				
Livestock Management	√	√	√	?
Vegetation Treatment	√	√	√	√
Maintenance	√	√	√	√
Treatment-Related Damage to Plants/Animals	?	?	?	?
Seeding	√	√	?	?
Water Development	?	?	?	?
Erosion	?	?	?	?
Nonpoint Source Pollution	?	?	?	?
Flooding	?	?	?	?
Environmental Impact Statement[2]	√	?	?	?
Agency Overhead[2]	√	?	?	?

[1] From Table 9.
[2] Not identified in Table 9 as a value relevant to Texas brush management.

from 4-7 percent.

In the course of this study, some results were computed on the potential benefits of brush management (Appendix B). These results are quantitatively unreliable because of numerous omissions and necessary crude assumptions. However, they offer qualitative insights to the problem. These calculations involve the rates of return to brush management arising from a site in South Texas yielding 1 inch of water and a site in the Southern Rolling Plains yielding 1/4 inch of water, considering livestock returns, brush management costs, and net water value only. The summary results of this analysis are presented in Table 11 and are explained in Appendix B. Qualitatively these results show:

1) Brush management exhibits low rates of return when it is not subsidized. Subsidies raise this rate of return.

2) Off-farm interests can gain from brush management but this depends on the value of the water, the share of the brush management cost, the percentage of water used, and the amount of water obtained.

3) Cost share policies should vary as water yield, value of water and amount of water used vary. This implies that the cost share policy should involve site dependent elements.

Is a Brush Management Policy Economically Attractive?

Given that an extensive brush management program could be expensive, a natural line of inquiry concerns whether there are better means of alleviating water scarcity. Because of varying conditions within the state, there is no *single* best alternative. Appropriate solutions will differ by region and locale. Problems of water scarcity are addressed by one (or both) of two general methods: supply management and demand management. Table 12 identifies major supply and demand management policies. Nearly every one of these policies is employed somewhere in Texas. It can be presumed, therefore, that nearly all of these policies are economically rational in particular situations. The question then arises: In what circumstances is brush management a preferred method of water management?

This raises a more general question: How does one decide which policy of a set of water policies is best? If only supply management policies are being contemplated and water supply is the sole policy objective, then the best policy or combination of policies is the one providing a given amount of water at least cost. This comparison presumes, however, that water demand is fixed and immutable or, at least, that supply-oriented policies are universally better than demand-oriented policies. In order to choose the best policy or program (combination of policies) from all available policies, a more complicated net benefits analysis must be performed (Griffin and Stoll 1983). Even if brush management is not the best *water* policy, nonwater benefits occurring on- and off-site may be sufficient to render this policy "best" in a broader setting.

Economic assessment of the desirability of any policy falls into the general program/policy evaluation arena of economic inquiry. A vast literature pertains to such questions (see Mishan 1976; Gittinger 1982; Sassone and Schaffer 1978). The

Table 11. Rates of Return Under Alternative Policies[1]

Data for South Texas-Like Site Yielding 1 Inch of Water from Brush Management.

Cost Share Policy	Rancher	Assumed Water Price $20	$40	$100	Water Price Where Off-Ranch Interests Break Even	Earn 10% Return
		Off-Ranch Rates Of Return				
percent	percent				$	
0	2.6	+Inf	+Inf	+Inf	0.00	0.00
10	3.8	50.8	107.6	278.5	4.15	6.62
20	5.0	21.3	50.8	136.1	8.30	13.24
30	6.5	10.2	31.5	88.6	12.45	19.86
40	8.2	3.7	21.3	65.0	16.60	26.49
50	10.1	-0.7	14.8	50.8	20.75	33.11
60	12.5	-4.1	10.2	41.2	24.90	39.73
70	15.4	-6.7	6.6	34.3	29.05	46.35
Total Rate Of Return		7.2%	11.6%	24.8%		

Data for Southern Rolling Plains-Like Site Yielding 0.26 Inch of Water from Brush Management.

Cost Share Policy	*Rancher*	Assumed Water Price $20	$40	$100	Water Price Where Off-Ranch Interests *Break Even*	*Earn 10% Return*
		Off-Ranch Rates Of Return				
percent	percent				$	
0	0.8	+Inf	+Inf	+Inf	0.00	0.00
10	2.0	27.1	63.9	166.1	8.46	12.11
20	3.4	4.5	27.1	81.3	16.92	24.23
30	4.9	-6.2	12.9	52.1	25.38	36.34
40	6.7	-13.8	4.5	36.8	33.84	48.46
50	8.7	-20.3	-1.5	27.1	42.30	60.57
60	11.0	-26.3	-6.2	20.3	50.76	72.68
70	13.9	-32.0	-10.3	15.1	59.22	84.80
Total Rate Of Return		3.5%	6.2%	14.4%		

[1] As explained in Appendix B, these results are quantitatively unreliable but are presented for qualitative insight.

Table 12. Major Policies for Dealing with Water Scarcity

SUPPLY MANAGEMENT	
Enhancement	**System Management**
Reservoirs	Redesign and Retrofitting
Wells	Advanced System Control
Conveyance	Leak Detection
Treatment	Maintenance
Interbasin Transfers	Recycling
Contracting	
Purchasing Rights	
Groundwater Recharge	
Desalinization	
Weather Modification	
Vegetation Management	

DEMAND MANAGEMENT		
Incentives	**Regulation**	**Education**
Metering	Building Codes	Public School Programs
Marginal Cost Pricing	Drought Contingency Plans	News Releases
Increasing Block Rates	Pressure Reduction	Customer Mailings
Hook-up Fees		
Subsidized Conservation		

basic elements of such an analysis as they pertain to the brush question involve:

1) Selection of a relevant discount rate (as explained in Mishan 1976, or Lind 1982);

2) Identification of who is affected by the policy in terms of gains and losses as well as the magnitude of the effects over time; this would include identifying the parties affected by changes in the categories of economic activity mentioned in Table 9;

3) Development of estimates of the government and private costs involved with implementation of the policy;

4) Identification of nonquantifiable benefits and/or costs; and

5) Comparison of alternative policies on the basis of quantifiable and nonquantifiable benefits/costs.

POSSIBLE PUBLIC ACTIONS

The review of the literature and the experience of the research team suggest a number of alternative policies and research directions which could be followed. In this section, the available policies are presented and discussed and research needs are summarized and organized into a prioritized agenda.

Policy Options for Enhancing Brush Control

Important policy decisions are forthcoming regarding the topic of brush management for water production. The Brush Bill (Senate Bill 1083) has established a particular program, but all policy is subject to revision, and this particular legislation remains unfunded. A basic policy question is then, "Should state monies be allocated to this program or should it be allowed to expire through a lack of funding?" The following discussion adopts the presumption that there are cases where brush reduction is socially desirable in the sense that benefits exceed costs. As indicated earlier, this remains unproven.

There are several alternative broad policy approaches to brush management and similar water conservation opportunities which warrant consideration. The first is to maintain the status quo position, alter nothing, and allow brush control to proceed in the direction dictated by current organizations and institutions. The second, third, and fourth policy approaches involve economic incentives for encouraging brush management by ranchers. Approach two is to extend low-interest loans to ranchers for brush management activities. Approach three is to activate cost sharing for brush control–perhaps by authorizing state funding of the Brush Bill. Approach four is to encourage creation of private markets for water produced through brush control. The fifth alternative policy approach is regulatory. Regulations can be developed and promulgated for acceptable levels of brush infestation or for acceptable management practices. Approach six involves opportunities to educate ranchers and/or water supply beneficiaries. The seventh approach is to pursue further research.

Some of these policy approaches can be used in combination with one another; others are mutually exclusive. The following discussion develops each of these alternatives more fully and identifies attendant issues.

Status Quo

The status quo or "do nothing" approach to brush management implies neither a stable situation nor the absence of brush control activity. Privately funded brush control will continue. Various species of brush will continue to propagate and expand their domains. Ongoing research will refine available information on the entire topic of brush control for water production.

Because of on-site benefits, some landowners will pursue a nonzero level of brush management. Recall that more than a million acres of brush are treated annually (Table 6). However, brush infestation may continue to increase. From a social perspective, private investment in brush control may be inadequate, but private investment will be forthcoming nonetheless. Encouragement for investment in brush management, when warranted, will continue to come from the education and assistance programs of the Texas Agricultural Extension Service and Soil Conservation Service. A minimal level of federal cost-sharing at a 50-75 percent rate is being provided through the Agricultural Conservation Program of the U.S. Department of Agriculture, but an individual landowner may receive no more than $3,500 annually. In order to qualify for this benefit, soil erosion on the individual's brushland must be in excess of a tolerance level in the absence of brush management. Therefore, an economic incentive, albeit small, exists to support brush control.

Because the water-conserving landowner who controls brush infestations will find it difficult to establish rights to the resulting water, contracts between these individuals and downflow water users will be rare. These landowners have no title to enhanced streamflow (surface water) and can claim groundwater only if they withdraw it. Up to 200 acre-feet of surface flow can be stored for domestic and livestock uses without permit, but transfer to other potential uses requires a permit. Diffused surface water can be stored, but this is costly. Transfer of such stored water can be expensive or, if done through natural watercourses, requires a permit and a clearly defined route between buyer and seller. Because of these facts, special circumstances must be present before other water users will pay a rancher to remove brush. One such circumstance may be if a certain individual, group, water supplier, town, or city has reason to believe that he/she/it will be a direct beneficiary from the brush management practice. For example, if a river authority owns a reservoir receiving drainage from a brush-infested watershed, the authority might willingly contract with watershed landowners for brush removal. In this way, the authority could enhance water production from the reservoir.

The evolution of brush propagation during the past century indicates that what once were Texas grasslands are now brushlands. The range of brush will expand if not abated as will associated water consumption. So, too, will the range of white-tail deer (at the possible expense of mule deer) and other brush-dependent animal species. Private efforts of brush control will continue, but will be dependent on the characteristics of livestock markets. Therefore, the situation is not static, and adoption of the "do nothing" policy approach should recognize this fact.

Low-Interest Loans

A second policy involves extension of low-interest loans. This already has been done in the context of water conservation. In November 1985, Texas voters approved Propositions 1 and 2 of House Bill 2. These propositions authorize the Texas Water Development Board to issue bonds and then loan the proceeds to further water conservation efforts. House Bill 2 established a pilot program ($5 million) of low-interest loans for irrigators investing in water-saving technologies. The program operates through bonds issued by the Texas Water Development Board. Soil and water conservation districts or underground water districts apply to the Texas Water Developemnt Board for these funds and subsequently loan them to irrigators. Approved borrowers are currently receiving loans with 6.75 percent interest rates. In general, borrowers must also pay 2.5 points for loan origination, that is, a lump sum payment amounting to 2.5 percent of the loan amount. Providing results of the pilot program are sufficiently favorable to garner a two-thirds majority in the Legislature, an expanded program ($200 million) will be adopted. Under the pilot program, there are a number of restrictions, and participation by producers has been much less than anticipated.

This program does not make loans available to ranchers for brush management, but it could be extended to this purpose. This policy could serve as an economic incentive for greater brush management by decreasing the interest rates faced by ranchers who must borrow money to reduce brush infestations. Because the state is merely passing its borrowing privileges along to ranchers, program costs are limited to administration costs. The potential cost of defaulted loans is borne by intermediaries, in this case, soil and water conservation districts and underground water districts.

Two critical issues regarding this policy are as follows. First, program participation may be low as it has been with the irrigator pilot program for several reasons. The value of the interest rate reduction to the irrigator is not large, collateral is required, and the loan cannot cover 100 percent of investment costs. Although some intermediaries have adopted stricter rules, the irrigator must cover at least 20 percent of equipment costs and 50 percent of labor and installation costs through personal capital or money obtained from another lender. For many producers this can be an impossible requirement. Finally, soil and water conservation districts and underground water districts are not experienced financial institutions, and it has been a slow process for these organizations to learn a new role.

The second major issue concerning the feasibility of a low-interest loan program involves implications of recent federal tax reform. Federal tax regulations legislation recently involved consideration of limiting the amount of municipal bonds issues for "private activity" purposes (Texas Water Alliance 1986). Texas bond issuances may have to be severely curtailed in order to meet these restrictions. A likely impact is the effective elimination of the loan program for irrigators as well as any opportunity to extend these same benefits to ranchers.

Cost Sharing

Senate Bill 1083 established the Texas Brush Control Program, which encourages brush management through cost sharing. The State Soil and Water Conservation Board is charged with the responsibility of promulgating rules and administering monies to be drawn from the newly created "Brush Control Fund." The Board is directed to designate "critical areas" where "brush is contributing to a substantial water conservation problem." Following this, the Board can enter into contracts with landowners with the Board paying no more than 70 percent of the costs of approved brush management practices.

Although the Legislature did not appropriate any money for the Brush Control Fund, the Board has been working to develop rules and designate critical areas. Cost sharing is a potentially effective incentive for encouraging brush control. Through its "critical area" approach, this policy makes it possible to target the policy upon locations where water savings can be obtained and water is most needed. Moreover, in its forthcoming budget request for fiscal year 1986-87, the Board is requesting $5 million to conduct a pilot program of cost sharing in a few selected watersheds (Kuykendall 1986).

There are, however, questions to be addressed prior to full-fledged policy adoption. First, where will the revenues to fund this program come from? Will they come from general revenue or a new source? Because of the state's budget crisis, new programs are closely scrutinized, and new sources of revenue are being considered. Some ideas for funding a cost-sharing policy are: 1) a "check off" on municipal water use and 2) a tax on nonagricultural groundwater pumping. Under the check off program, each consumer would pay, for example, $0.01 per 1,000 gallons of water used (perhaps only in designated critical areas). The pumping tax is similar except that it is limited to groundwater. For example, owners of large capacity wells might be taxed a penny or so per 1,000 gallons of pumped groundwater, although implementation would be difficult. These proposals attempt, though imperfectly, to place policy costs upon the potential beneficiaries. These alternatives illustrate the potential coupling of government expenditures with income alternatives.

A second issue concerns the prevention of brush regrowth. Policy provisions which encourage brush regrowth prevention would need to be developed. Questions which would need to be addressed include: What annual or periodic management practices are needed to preserve the results of initial brush treatment? Who will pay for these? And will landowners be contractually responsible for, as an example, maintenance burns to control brush regrowth?

A third issue involves the way in which the policy might be designed to account for site dependent changes in water value, water yield, or water delivery to use.

Water Marketing

There are numerous examples of water conservation being advanced in the western United States by an increased reliance on water marketing. The general idea is to encourage the efficient use of water with a market-derived price that informs water users about the scarcity of water (Anderson 1983; Willey 1986). That is, price can be an effective signal for communicating when resource use is too great or too small. Water rights holders who have a low use value for water must forego the net returns of selling some (all) of their rights if they are to continue use. Potential water consumers may have use values in excess of price and therefore desire to purchase rights. Property rights to the water presently consumed by brush must be established before a water market could encourage additional brush management. As discussed earlier, three cases emerge with respect to Texas water rights: diffused surface water, surface water, and groundwater. Diffused surface water produced by brush management can be impounded (entrapped) by the rancher and can be transferred to other uses, but impoundment is required (and costly). Furthermore, transport of this impounded water through natural watercourses requires a permit. Surface water resulting from brush management becomes property of the state and, through the permitting process, is dedicated to appropriators; it does not belong to the landowner. The rancher may impound 200 acre-feet of surface water for domestic and livestock use; any other use requires a permit. Brush management-produced groundwater is the property of the overlying landowner. Initially then, this groundwater belongs to the conserving rancher, but ownership is merely theoretical unless the rancher captures (pumps) this water before it flows from beneath the land.

The system of water rights in Texas does not appear to encourage brush management by the use of the market approach. The market policy would therefore require institutional reform before becoming operational. It is notable, however, that water marketing is consistent with state policy. Surface water rights are transferrable (marketable) in Texas, and it is also legal to sell or lease diffused surface water and groundwater. An extension of these rules to include the water presently consumed by brush is necessary before water markets can become much of an incentive for brush control.

There are also some potential stumbling blocks to be considered. One has to wonder how long Texas can continue to treat different water locations–diffused surface water, surface water, and groundwater–by different legal doctrines. This can be especially pertinent to rangeland water. As one example, removed brush can produce diffused surface water which later infiltrates to become groundwater before seeping out as spring water feeding a stream. If ownership is to be resolved to the point where market activity is supportable, then the confusion of multiple legal doctrines must be mediated by legal reform. This is a strong argument in favor of conjunctive management of surface water and ground water.

The lease or sale of water conserved by brush control will only be feasible if monitoring and enforcement are effective. If a rancher agrees to conserve water so that it may flow to another consumer, a number of practical questions arise. How will the amount of conserved water be determined? What would prevent intervening water consumers from diverting or pumping the conserved water before it reaches the buyer? How should conveyance losses through evaporation, transpiration, groundwater recharge, etc. be handled?

If brush owners are granted water rights, wouldn't this encourage people to grow brush to gain water rights? The evident method of handling this matter would be to grant water rights for brush infestation levels existing at a single point in time (e.g., 1986). Perhaps a complete aerial survey of Texas could serve as a basis for a final determination of rights. This raises other questions, however. If brush populations worsen at particular locations, must the owners purchase a compensating amount of water rights from downstream right holders? Should those with brush be rewarded as opposed to those without brush?

The final possible problem to be considered here concerns the extent of brush control resulting from a market approach. If a great deal of brushland were treated, the price of water would be driven downward. This fact will limit, as it should, the statewide conversion of brush. There are no complete assurances, however, that a particular site will not undergo 100 percent removal of brush. As mentioned earlier, this is rarely desirable because of wildlife and environmental values. The value of hunting leases will probably be sufficient to prevent undesirable brush clearing.

Regulation

The previous three policy approaches–low-interest loans, cost sharing, and water marketing–rely upon economic incentives for motivating landowners to voluntarily adopt brush management investments. At the opposite end of the spectrum are regulatory policies in which brush management investments are mandated. Two such policies are possible. One approach to brush control regulation might be to specify maximum permissible levels of brush infestations or to identify undesirable species. To accomplish this it may be necessary to regulate brush according to plant species, terrain, region, etc. Precedent exists for this in § 11.089 of the Texas Water Code which prohibits a landowner from allowing certain species of grass or weeds to go to seed on or within 10 feet of a waterway. The choice of brush management practices would be left to the landowner. A second approach would be to dictate the types of brush management investments and practices which must be employed. This would, in effect, force the adoption of water conservation technology. In either case, enforcement would be difficult and potentially costly.

Education and Research

Each of the previous policy proposals can be complemented by either (or both) of two additional policies. *Education* can be expanded to better inform those owning brushland and/or those receiving water flow from brush-dominated watersheds. *Research* can be extended in primary and/or evaluative directions.

Educational/advisory programs of the Texas Agricultural Extension Service and the Soil Conservation Service inform landowners about opportunities to improve rangeland conditions. This information is developed with an understanding of the landowner's interest in grazing conditions, wildlife habitat, and aesthetics. One policy alternative is to expand these programs. A second aspect of an educationally oriented policy might be to inform municipal and industrial water consumers and suppliers about opportunities to augment water supply through brush control. The objective of such a program would be to encourage and support private arrangements between user groups and landowners for mutually beneficial brush management.

Recognizing the existence of ongoing research, another policy option is to increase research efforts in one or more of a variety of directions. A research agenda identified by this investigation is presented in the following section.

A Research Agenda

The above policies represent alternatives for society to deal with a potential brush management for water yield augmentation initiative. In order to determine which policy to pursue, as well as how to implement policies, a number of unanswered questions need to be addressed through research. This section presents an integrated agenda of high priority research which would, when completed, provide an adequate basis for policy decisions. This agenda was developed through a research need prioritization process. Each of a list of possible research needs was given both long- and short-term priorities for inquiry through a delphi-like process with the authors as participants. Appendix C presents the results of this process. Highly ranked research needs were then organized into the research agenda presented here. Appendix D shows the correspondence between the prioritized needs and the research agenda.

Before presenting the agenda, some important features should be noted. First, the agenda is derived from priorities set by the authors and concentrates on needs relating to brush management arising from the authors' literature review, biases, and knowledge of ongoing research. Second, results of the research need prioritization indicated that the highest priority short-term needs involve development of baseline data on water yield, alternative water development, trial implementations, potential policy design, and water use values. In the long run, the highest priority needs involve modeling, economic evaluation, and policy appraisal. Many of the long-term priorities would change if significant water yield was not found in the short-term research.

Turning to the research agenda, analysis of the prioritization results leads to an agenda containing 11 integrated elements. The elements are listed below; their interrelationship will be discussed next.

Element A: *Enhance Ability to Predict Water Yield Changes Induced by Brush Management*

Predictive tools allowing reliable estimates of water yield are needed. In the short term, emphasis should be placed on developing watershed-level data for the effects of brush management on water yield. If initial studies support the hypothesis of significant water yield increases, some emphasis should be given to the effects of alternative brush management strategies (i.e., treatment patterns and alternative clearing methods). As data become available, efforts should turn to the prediction of water yield by applying and/or adapting watershed models. In the long term, model modification and validation should become the fundamental thrust.

Element B: *Develop Economic and Social Implications of Alternative Policies and Actions for Relieving Water Scarcity*

Wide-ranging studies of alternative water supply and demand modification (conservation) strategies are needed. In the near term, research should address the economic, legal, and institutional implications of alternatives other than brush management such as consumer conservation incentives, reservoir development, and canal lining. In the long term, brush management would be examined as one of the alternatives.

Element C: *Enhance the Ability to Predict How the Water Originating From Rangeland Sites Will Be Used*

Once data are available on the additional volume of water in a watercourse or aquifer resulting from brush management, it will be important to know where that water goes and who uses it. Projects are needed which adapt existing basin, aquifer, and integrated hydrological simulators to depict the characteristics of areas where brush management will be done. Subsequently, these models will be used to simulate basinwide implications of water yield increases on water use, flow, etc. Later efforts should involve model validation and the support of efforts for economic and policy appraisal.

Element D: *Estimate the Economic and Risk Benefits of Additional Water and Changes in Water Quality*

Policies regarding water use, water scarcity, and water quality enhancement alternatives require information on the value of water in various uses. Data on economic risk as related to water availability also are needed. Studies addressing this element would develop information on the demand schedules by various user groups at various times of the year under varying water abundance and quality.

Element E: *Determine What Legal Reforms Are Needed to Implement Brush Management Policy*

Information is needed on the design of policies encouraging brush management. Studies should develop legal, institutional, and economic evaluations of the potential cost-sharing, subsidy, market, and regulatory approaches. Attention needs to be paid to such issues as possible legal reforms which could refine the rights to water generated by brush management; funding and administrative changes required to pursue cost-sharing and subsidy programs; and rules which would facilitate water marketing.

Element F: *Predict the Water Quality Effects of Brush Management*

Information is needed on the water quality implications of brush management. Research initiated under this need should parallel the water yield studies. This information is needed before the higher priority economic and policy appraisals can be done.

Element G: *Develop Physical and Economic Criteria for Site Selection*

Brush management investments should be made on parcels where the greatest benefit may be obtained. There is a need for site identification criteria. Research addressing this need would provide simultaneous criteria in terms of water value, water yield, wildlife, livestock, land characteristics, and brush management costs. Such effects would need to be supported by hydrological, wildlife, and economic site-oriented projects.

Element H: *Determine the Relationship Between Brush Management and Wildlife Income*

Data are needed on the impacts of brush management on income associated with wildlife. Research addressing this need would examine the relationship of wildlife ecology and income from leases with brush management alternatives involving treatment type, percentage of brush removed, and the resultant pattern of brush density.

Element I: *Develop the Economic Implications of Brush Management On and Off the Site Managed*

Information is needed on whether the benefits from treating a parcel exceed the costs of treatment. Needed research involves detailed accounting of brush management-induced costs and benefits in on-site and off-site subcategories. Data also are needed on the net on-site profitability to determine the role that off-site interests need to play in influencing brush management actions. This research will require detailed input from studies on amount of additional water, disposition of water, wildlife benefits, and the value of water.

Element J: *Study the Costs, Benefits, and Consequences of Alternative Policies Encouraging Brush Management*

Society can direct numerous alternative cost sharing, subsidy, market, or regulatory policies toward brush management. The choice of the most desirable policy depends on technical, legal, political, institutional, and economic factors. Studies addressing this need would assess the feasibility of alternative policies along with associated costs and obstacles to implementation. For example, an immediate research need may involve the effectiveness and consequences of alternative means for funding the Brush Bill. Institutional reforms or policy features which might insure policy effectiveness would need to be suggested and investigated. Later, the desirability of brush management policies would need to be assessed in terms of gains and losses, what risks the policies pose, state treasury costs, and comparative standing relative to other water development alternatives. Conditions under which brush management is an attractive option need to be developed.

Element K: *Document the Benefits of Currently Existing Brush Management Programs*

Reliable hydrological data on the effects of brush management will take years to develop. However, momentum for brush-clearing efforts may cause decisions to be made in advance of the availability of hydrological data. An area which has been managed, such as Rocky Creek, or areas where brush management projects will be initiated in the near future may provide the potential for studying the effects of additional water without detailed hydrological information. Short-term studies are needed to develop data for a preliminary assessment of a project. A pilot project analysis would provide insights into data requirements within later studies and may help in providing criteria for desirable sites.

Discussion of Elements

The above elements constitute a research agenda designed to address brush management policy questions. Integration of elements within the agenda is illustrated by the flowchart in Figure 3. Ultimately, the agenda is designed to assess when and where public policy actions encouraging brush management should be used. However, in order to sensibly answer this question, information on a number of researchable topics is required. The elements involving detailed economic appraisal of brush management sites and site selection criteria cannot proceed until other elements are completed. The others could be started now. In addition, the examination of an existing brush management program (element K) would provide a way of developing information on the ultimate question in advance of the availability of hydrological data.

All of the elements within this agenda contain needs which were classified as highest or high priority in either a short- or long-term setting. From the short-term priority perspective, elements A (Predict Water Yield), B (Study Ways to Relieve Water Scarcity), and K (Study Results of Existing Brush Management Programs) received highest priority. From a long-term perspective, all the elements *except* F (Predict Water Quality), H (Predict Wildlife Effects), and K (Study Results of Programs) received highest priority. However, as Figure 3 indicates, all of these are necessary to complete the overall program.

An additional element identified can be viewed as key to the overall effort. This involves exploration of potential cooperation with state and federal agencies considering brush management demonstration projects. Cooperation before and during demonstration projects would enhance the information content and the value of these projects. If cooperation is negotiated, a follow-up need would involve development of a list of data to be collected involving the effects of brush management not only on water but also on costs, wildlife, livestock, farm income, etc.

Finally, while the agenda focuses upon brush management for water yield, some elements in the agenda reflect broader perspectives. In particular, the study of other scarcity policies (element B), water value (element D), policy implementation costs (element J), legal considerations (element E), and basin water use (element C) contributes not only to the question at hand but also to institutional competence and

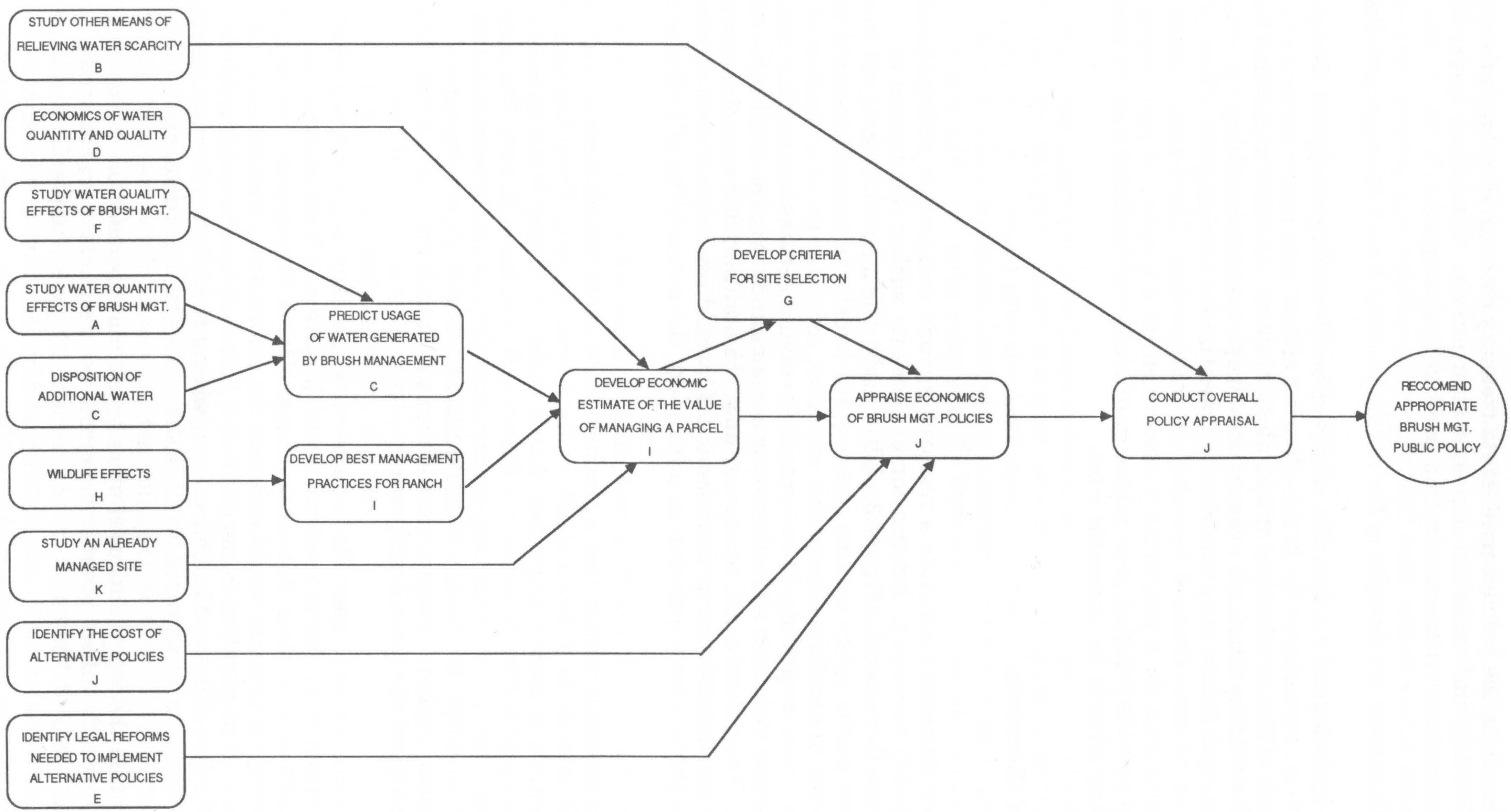


Figure 3. Interrelationships in the Research Agenda

the ability of Texas Agricultural Experiment Station personnel to participate in overall state water policy making.

SUMMARY AND CONCLUSIONS

Water demand is growing in Texas and agencies charged with guiding water resource management are faced with increasing evidence of water scarcity. Consequently, attention has turned to ways of reducing water scarcity through development, conservation, reallocation, and/or regulation. Such strategies probably will affect the agricultural sector. Agriculture uses large quantities of water, often at a lower use value than nonagricultural uses. In addition, one study estimates that 38 percent of the state's water budget is used by brush and noneconomic plants on agricultural land. Reduction of brush and noneconomic plants would not only reduce water consumption but also would increase agricultural productivity. This situation has raised the policy issue of whether or not water used by brush can be beneficially shifted to other uses, alleviating water scarcity and augmenting land productivity.

Vegetation management for water yield enhancement is not a new idea. Studies regarding brush infested rangelands have been ongoing for 30 years. A number of lessons and findings have arisen. Removal of brush has been found, in particular cases, to cause additional water to be generated. However, the amount of water generated has been found to be dependent upon brush type and precipitation. In Arizona, some brush complexes have been found to generate no water (pinyon juniper), while others have been found to generate up to 6 inches per acre treated (chaparral). Such findings have not been perfectly anticipated by policy decisions. For example, in Arizona, a considerable acreage of pinyon juniper was cleared in an apparently unsuccessful 1960's water yield enhancement effort while chaparral was overlooked as a viable brush complex. Attention has now been refocused following a carefully executed research program. Important questions remain. Chaparral management has been shown to release 80 percent of the additional water in wetter than average years. A simulation study investigating water use under this release pattern shows no more than one-half the additional water was consumptively used. Furthermore, while water yield has been found to be augmented by chaparral management, widespread implementation has not occurred due to environmental considerations about widespread herbicide use.

The extent to which such findings hold for Texas conditions is an open question. In the only comparable cases, a formula asserting that 1 inch of additional water yield is produced by every 4 inches of annual precipitation above 16 inches forecasted yields of 1.1, 2.3, 2.8, 4.9, and 5.2 inches in five cases, while actual yields were 0.26, 0, 0.31, 0.95, and 1.21 inches respectively. The Texas results are more consistent with 1 inch of water for every 15 inches of precipitation above 19 inches. But the reliability of four of the five estimated above and the cited formula are highly questionable due to the nature of the procedures behind the water yield estimates (as reviewed in Table 1). However, there is promise for water yield inherent in the experience with Rocky Creek near San Angelo where, for more than a decade, brush management has apparently caused a previously dry stream to flow on a year-round basis. An improved understanding is needed of water yields from brush management in various regions of Texas.

If significant water yields result from brush management, Texas certainly has brush that could be managed. Soil Conservation Service estimates place the acreage *in need of brush management in the neighborhood of 40 million acres. Furthermore,* brush incidence has not been significantly reduced in 30 years, despite the management of millions of acres. Brush management can be socially as well as agriculturally beneficial. Managing brushlands could increase wildlife leasing income and livestock income, as well as water benefits. However, from the wildlife perspective, selective brush clearing is needed with sufficient brush left for cover screen, bedding, and nesting areas. There are also potential environmental effects of brush management in terms of altered river environments, water quality, and soil erosion.

Current economic evidence does not show brush management to be a very profitable exercise from the standpoint of the rancher. Costs keep almost equal rancher-received benefits. Two case studies were examined where rates of return were 0.8 and 2.6 percent. A great increase in acres of managed brush for water yield enhancement would require some form of compensation to ranchers by those benefiting from increased water or improved environmental conditions. Preliminary calculations show that society can benefit, depending on water yield and water use value. Public policy initiatives may be needed to bring about compensation of ranchers, as it appears that private parties would transact for brush clearing only in cases where geophysical and institutional conditions clearly define the beneficiary of the water. An example is brush removal in the watershed for a lake where all the water is used by a city. However, little basis exists for estimating the magnitude of off-ranch gains and/or losses.

The legal situation involved with water arising from brush management does not seem to encourage its practice for water yield enhancement. For example, managing phreatophytes, which draw water directly from watercourses, would yield state water, currently private brush clearers claim to the resultant would be junior to existing rights holders. Most of the increased flow resulting from brush management has been found to take the form of increased infiltration which as subsurface flow augments watercourses or groundwater. Capture of the subsurface flow before it reaches the watercourses is necessary before the brush clearer can sell the water. Once the water reaches the watercourse, it becomes state water and falls under the existing water rights system. However, capture is difficult and/or costly. When groundwater supplies are supplemented, the legal situation is clear. Any augmentation of groundwater would accrue to the landowner as long as it remained under the landowner's property, but this water needs to be captured through pumping. Again, such capture may be prohibitively expensive.

From a public policy perspective, a number of actions could be pursued relative to encouraging brush management. The main categories of these actions are a) continue current policy–no new initiatives; b) subsidize brush management through low-interest loans; c) subsidize brush management through cost sharing; d) refine property rights to resultant water and encourage private markets to arise; and e) regulate brush incidence. Concurrently, research, education, and planning can provide a basis for future brush management initiatives.

The desirability of public policy decisions to facilitate brush management depends in part upon social costs and benefits. Unfortunately, conclusive scientific evidence on the cost/benefit relationship is not available, nor is there a sufficient basis from which such a relationship can be derived. A research agenda is suggested above which, if pursued, could help alleviate many of these questions.

All things considered, it is impossible to assess the social desirability of a widespread brush management program at this time. However, the potential benefits are sufficient to motivate active research and demonstration programs. As these programs proceed, data will become available on whether estimated benefits of brush management exceed the costs, allowing thorough consideration of whether public policy should be altered to encourage brush management.

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APPENDIX A: SEMINAR SPEAKERS

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APPENDIX B: A QUALITATIVE ANALYSIS OF VARYING COST SHARES

The returns to brush management investments are illustrated in two locations using data on the net increase in livestock returns, the estimated initial and maintenance costs of brush management, hypothetical water yields, hypothetical water prices, and hypothetical water delivery ratios. As such, the calculations are obviously crude, ignoring most of the necessary economic information needs (as enumerated in Table 9). Nevertheless, the results provide qualitative insight even though they are quantitatively unreliable.

The calculations were done for two sets of physical conditions. The first involved South Texas range conditions using data from the Texas Agricultural Experiment Station (1985) report. The second involved Southern Rolling Plains range conditions using data from VanTassel and Conner (1986). In both cases, Richard Conner assisted the authors in updating the livestock data to 1986 conditions and developing brush management cost estimates. Furthermore, a 1 inch annual water yield was assumed for South Texas and a 0.26-inch estimate for the Southern Rolling Plains was used. The analysis was then conducted to determine the internal rate of return to brush management in terms of the rancher, off-ranch entities, and in total. The rancher and off-ranch rate of return analysis also included consideration of alternative cost share policies.

Livestock returns data, brush control cost, and water yield assumptions are detailed in Tables B-1 and B-2. Livestock returns for 12 years after brush management and the costs of brush removal over that period provide the basic numbers for the analysis. The brush management costs were estimated by Richard Conner as were the livestock returns. Both are area specific. Brush management is assumed to start in year 0 with maintenance on a periodic schedule (see the first column of Tables B-1 or B-2) with the livestock returns occurring in years 1-12 (see column 2 of B-1 and B-2). At the end of the 12-year period, a salvage value is entered giving the value of the additional livestock and improved rangeland. Off-ranch entities are assumed to pay some proportion of the brush management cost (which will vary from 0 to 70 percent). The amount of the cost and the proportion are given in column 3. The resultant net rancher profit (i.e., livestock returns minus brush management cost adjusted for the off-ranch cost share) is given in column 4. The water assumed to accrue to off-ranch interests begins in year 1 and continues each year until year 12. Water yields of 1 inch are assumed for South Texas and 0.25 inch for the Southern Rolling Plains, as given in column 6. This water is valued at three different prices. The water value is assumed to be off-ranch water value times the amount of water used. Thus, if only 50 percent of the water is used at an off-ranch value of \$80, then a \$40 value would be appropriate in this analysis. The rest of column 7 gives the off-ranch net returns, which are calculated as the water value less the off-ranch cost share amount. Given these data, the analysis identifies two rates of return, one for each of the rancher and off-ranch participants.

The results shown in Table B-3 demonstrate the consequences of alternative cost shares and water prices. If there is a zero cost share in the South Texas case, the rate of return to the rancher is 2.6 percent, while off-ranch interests gain benefits without paying (an infinite rate of return). However, when the off-ranch cost share amounts

Table B-1. Analysis Method for South Texas-Like Site

Year	Brush Management Cost	Livestock Net Cash Flow	Off-Ranch Cost Share 30%	Net Rancher Profit	Water Yield	Net Return $20.00/ acre-feet
	----------	---------- Nominal $	----------	----------	acre-feet	Nominal $
0	29.50	0.00	8.85	(20.65)		($8.85)
1		(4.74)	0.00	(4.74)	0.083	1.67
2	6.00	(5.16)	1.80	(9.36)	0.083	(0.13)
3		3.78	0.00	3.78	0.083	1.67
4		0.62	0.00	0.62	0.083	1.67
5	3.00	4.40	0.90	2.30	0.083	0.77
6		9.56	0.00	9.56	0.083	1.67
7		1.09	0.00	1.09	0.083	1.67
8		6.36	0.00	6.36	0.083	1.67
9	3.00	9.77	0.90	7.67	0.083	0.77
10		3.97	0.00	3.97	0.083	1.67
11		0.86	0.00	0.86	0.083	1.67
12		5.93	0.00	5.93	0.083	1.67
Salvage		16.50		16.50		

Rancher Internal Rate of Return	6.5%
Off-Ranch Internal Rate of Return	10.2%

Table B-2. Analysis Method for Southern Rolling Plains Site Yielding 0.26 Inch of Water

Year	Brush Management Cost	Livestock Net Cash Flow	Off-Ranch Cost Share 30%	Net Rancher Profit	Water Yield	Off-Ranch Net Return $20.00/ acre-feet
	Nominal $				acre-feet	Nominal $
0	13.00	0.00	3.90	(9.10)		(3.90)
1		(4.20)	0.00	(4.20)	0.022	0.43
2		(3.65)	0.00	(3.65)	0.022	0.43
3		3.38	0.00	3.38	0.022	0.43
4		3.60	0.00	3.60	0.022	0.43
5	6.00	3.26	1.80	(0.94)	0.022	(1.37)
6		12.78	0.00	12.78	0.022	0.43
7		(17.62)	0.00	(17.62)	0.022	0.43
8		3.79	0.00	3.79	0.022	0.43
9		4.07	0.00	4.07	0.022	0.43
10	3.00	3.98	0.90	1.88	0.022	(0.47)
11		15.74	0.00	15.74	0.022	0.43
12		(18.15)	0.00	(18.15)	0.022	0.43
Salvage		16.50		16.50		

Rancher Internal Rate of Return	4.9%
Off-Ranch Internal Rate of Return	-6.2%

Table B-3. Rates of Return Under Alternative Policies[1]

Data for South Texas-Like Site Yielding 1 Inch of Water from Brush Management.

Cost Share Policy	Rancher	Off-Ranch $20	Off-Ranch $40	Off-Ranch $100	Water Price Where Off-Ranch Interests Break Even	Water Price Where Off-Ranch Interests Earn 10% Return
	Rates Of Return	(Assumed Water Price)				
percent	percent				$	
0	2.6	+Inf	+Inf	+Inf	0.00	0.00
10	3.8	50.8	107.6	278.5	4.15	6.62
20	5.0	21.3	50.8	136.1	8.30	13.24
30	6.5	10.2	31.5	88.6	12.45	19.86
40	8.2	3.7	21.3	65.0	16.60	26.49
50	10.1	-0.7	14.8	50.8	20.75	33.11
60	12.5	-4.1	10.2	41.2	24.90	39.73
70	15.4	-6.7	6.6	34.3	29.05	46.35
Total Rate Of Return		7.2%	11.6%	24.8%		

Data for Southern Rolling Plains-Like Site Yielding 0.26 Inch of Water from Brush Management.

Cost Share Policy	Rancher	Off-Ranch $20	Off-Ranch $40	Off-Ranch $100	Water Price Where Off-Ranch Interests Break Even	Water Price Where Off-Ranch Interests Earn 10% Return
	Rates Of Return	(Assumed Water Price)				
percent	percent				$	
0	0.8	+Inf	+Inf	+Inf	0.00	0.00
10	2.0	27.1	63.9	166.1	8.46	12.11
20	3.4	4.5	27.1	81.3	16.92	24.23
30	4.9	-6.2	12.9	52.1	25.38	36.34
40	6.7	-13.8	4.5	36.8	33.84	48.46
50	8.7	-20.3	-1.5	27.1	42.30	60.57
60	11.0	-26.3	-6.2	20.3	50.76	72.68
70	13.9	-32.0	-10.3	15.1	59.22	84.80
Total Rate Of Return		3.5%	6.2%	14.4%		

to 40 percent, ranchers realize 8.2 percent on their subsidized brush management investment, while off-ranch interests earn between 3.7 and 65.0 percent, depending on the value of water. Conversely, in the Rolling Plains case, off-ranch interests earn between 20.3 and 27.1 percent. Furthermore, adding the on- and off-ranch net income leads to a 7.2 percent rate of return for the South Texas case at $20 water and a 3.5 percent rate of return in the Southern Rolling Plains case. The final two columns of the table show the water price at which society breaks even and earns a 10 percent rate of return.

While quantitatively unreliable, these results suggest that:

- Appropriate off-ranch cost shares (i.e., the percent borne by off-ranch entities or their payments for water) vary with site characteristics and water value (including water delivery ratio).

- Off-ranch interests can benefit but more must be known about off-site water value, water yield, and compensation arrangements before quantitatively reliable figures can be developed.

- The break-even water prices computed indicate that subsidization policies must be carefully designed.

APPENDIX C: RESEARCH NEED PRIORITIZATION

The committee used a multi-stage process in constructing a research issue prioritization. First, a subcommittee drafted a list of potential research needs. Next, committee members were given this list and asked to assign priorities between 1 and 5 (with 1 the highest) for research addressing the need immediately (short term) and in 5 years (long term). Simultaneously, comments on issue wording, relevance, redundancy, and omissions were solicited. Using the first round results, a revised list was produced containing combined, reworded, and additional research needs. These needs are listed in Table C-1. Subsequently, the new list of needs was circulated to the committee with information on the first-round prioritization for reprioritization. The results of this final prioritization provide the data on which this section is based and appear in Table C-2. Several things should be kept in mind when examining these priorities:

1) The priorities were assigned mainly from the standpoint of research needed to formulate policy directed at brush management for water yield.

2) The prioritization reflects the committee's knowledge of other ongoing research and the need for efforts above and beyond current research.

3) The short-term/long-term distinction in prioritization led to a list of needs which involve short- and long-term objectives within the research agenda.

4) Many of the long-term priorities reflect research which committee members felt could only be done after a water yield database was developed. Consequently, most of the long-term priorities reflect research needed if significant increases in water yield by brush management are found. Many priorities would change if this were not the case.

5) The research needs are largely oriented toward issues amenable to the biases of the university researchers who are on the committee. They were the only participants in the prioritization process.

The research needs which were prioritized are listed in Table C-1. Needs 1-13 mainly deal with water yield from brushland management and the disposition of subsequent water. Needs 14-24 deal with brush incidence and on-ranch effects of brush management. Needs 25-29 deal with environmental effects of brush management and potentially resultant water. Needs 30-36 deal with economic studies related to water use and/or potential water generated by brush management. Finally, needs 37-47 deal with economic, institutional, and legal considerations underlying public policy involving water scarcity in general as well as brush management encouragement.

The prioritization results are reported in Table C-2. The reviewers are identified by number. The reviewers, their numbers, and disciplinary focuses are as follows:

1. Bruce McCarl	Agricultural Economist
2. Wilbert Blackburn	Rangeland Hydrologist
3. Wayne Jordan	Crop Scientist
4. Lansingh Freeman	Environmental Planner
5. Ronald Griffin	Water Economist
6. Ronald Kaiser	Lawyer

Group priorities were formed using the average committee ranking (procedures other than simple averages were examined e.g., adjusting for differences in means, but were discarded as there was little qualitative effect). In turn, rankings of highest, high, medium, low, and lowest were assigned based on the quantitative ranking. This was done by noting that the average rankings fell between 1.167 and 4.833 and then establishing five equal divisions over this range. The ranges and number of needs by range, short-term, and long-term priorities are given in Table C-3.

A list of the research needs sorted by short-term priority is given in Table C-4. An equivalent list for the long-run priorities is given in Table C-5.

Table C-1. List of Research Needs

Number	Need Description
1	Develop a database on water yield across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic and soils characteristics.
2	Add data to the database in #1 pertaining to brush management methods, treatment patterns, and maintenance.
3	Develop models which, given the physical characteristics of a parcel, predict water yield.
4	Expand models in #3 to predict water yield under alternative brush management methods, patterns, and maintenance schemes.
5	Develop a database on water quality effects of brush management across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic and soils characteristics.
6	Add data to the database in #5 pertaining to brush management methods, removal patterns, and maintenance.
7	Develop models which, given the physical characteristics of a parcel, predict water quality effects of brush management.
8	Expand models in #7 to predict water quality under alternative brush management methods, patterns, and maintenance schemes.
9	Assess and develop procedures for monitoring the water yield from a brush management application over time.
10	Develop criteria for the physical treatability of a piece of land, i.e., criteria which identify untreatable acreage.
11	Develop data on and a model for predicting the disposition of a given quantity of additional surface water and groundwater in terms of use, groundwater recharge, return flow reuse, flow to estuaries, evaporation, etc.
12	Develop information on the effect of increased water on watercourse channel dynamics.
13	Develop estimates of the effects of increased reservoir storage on disposition of water increments.
14	Develop inventory information on the types of brush, infestation levels, densities, etc., by region.
15	Develop information on how brush incidence has been changing over time.
16	Develop information on the effects on future water availability of leaving brush infestation alone.
17	Develop estimates of the effect of brush management alternatives on livestock stocking rates.
18	Develop estimates of the effect of brush management alternatives on nongame animal populations.

(continued)

Table C-1. (continued)

Number	Need Description
19	Develop estimates of the effect of brush management alternatives on cropped acreage.
20	Develop estimates of the effect of brush management alternatives on game animal populations.
21	Develop models exploring the interrelationship of game animal abundance and lease income, including other factors such as services provided and location.
22	Predict the consequences of brush management for ranch net income from wildlife leases.
23	Estimate the consequences of brush management as reflected in the sale value of rangeland and associated assets.
24	Given different types of brush complexes and treatment methods, determine the profitability of brush management to the rancher.
25	Develop estimates of the consequences of changes in water quality on fish, wildlife, and watercourse plant populations.
26	Develop estimates of the downstream effect of water increments such as those which could be incurred under brush management on fish, wildlife, and aesthetic characteristics.
27	Develop recommendations pertinent to environmentally sound methods of brush management across large target areas.
28	Develop estimates of the consequences of brushland management for the aesthetic value of land.
29	Develop information on the atmospheric implications of brush management.
30	Develop estimates of the value of additional water to various users in terms of both income and risk as it varies by time and water volume.
31	Develop estimates of the marginal economic consequences in terms of income and risk to various users of possible changes in water quality.
32	Develop information on the value of altered flooding regimes.
33	Develop estimates of the economic consequences of altered nongame populations.
34	Develop estimates of the economic consequences of altered aquatic populations.
35	Develop estimates of the net economic value of the water generated from selected sites.
36	Develop predictive models which, given the characteristics of a site, predict the net economic benefits of brushland management.
37	Develop economic and institutional criteria for site identification.

(continued)

Table C-1. (continued)

Number	Need Description
38	Assess the economic, social, distributional, and other consequences of the potential policies which would foster brush management.
39	Develop information on the economic effects of alternative ways water scarcity can be addressed considering reservoirs, conservation, etc.
40	Assess whether reservoir storage development or investments would improve the economic desirability of brush management.
41	Develop data on the economically rational amount of water that can be developed through brushland management in Texas.
42	Develop estimates of the economic consequences of allowing brush incidence to continue along its current physical trend.
43	Examine the institutional and legal reforms necessary to allow use of each of the potential policy options in Texas.
44	Compare brush management to other water development policies such as alternative water supply possibilities and make recommendations about the most desirable policies to pursue.
45	Develop estimates of the economic benefits, use of water, and rights to water in an area where brush management has been implemented, for example Rocky Creek.
46	Examine the institutional and legal reforms put in place by other states to encourage brush management for water production.
47	Develop recommendations for research which should be done in conjunction with demonstration implementations.

Table C-2. Priorities Assigned to Needs

	Priorities by Reviewer												Commitee Average			
	Short Term						Long Term						Quantitative		Qualitative	
Need	1	2	3	4	5	6	1	2	3	4	5	6	Short Term	Long Term	Short Term	Long Term
1	1	1	1	1	1	1	1	2	3	2	2	3	1.00	2.17	Highest	High
2	2	3	2	3	1	4	1	2	3	2	1	3	2.50	2.00	High	High
3	3	3	3	4	2	5	1	1	2	1	1	2	3.33	1.33	Medium	Highest
4	3	5	3	5	2	5	2	3	3	2	1	3	3.83	2.33	Low	High
5	2	1	3	3	4	3	2	1	3	3	2	3	2.67	2.33	Medium	High
6	3	5	4	2	4	3	2	4	3	2	2	3	3.50	2.67	Low	Medium
7	4	3	4	4	5	3	2	3	4	3	2	3	3.83	2.83	Low	Medium
8	4	4	4	4	5	4	2	4	4	3	4	4	4.17	3.50	Lowest	Low
9	5	4	1	4	1	1	2	2	3	3	1	2	2.67	2.17	Medium	High
10	4	5	4	2	4	5	3	5	4	2	4	5	4.00	3.83	Low	Low
11	1	4	2	2	2	2	1	1	1	1	1	2	2.17	1.17	High	Highest
12	5	5	5	4	5	5	5	3	5	3	5	5	4.83	4.33	Lowest	Lowest
13	3	4	4	3	4	4	2	1	2	3	2	2	3.67	2.00	Low	High
14	5	4	4	3	3	5	3	3	3	3	2	4	4.00	3.00	Low	Medium
15	3	4	5	4	4	4	2	4	5	4	2	3	4.00	3.33	Low	Medium
16	3	4	4	4	1	1	1	1	3	4	1	1	2.83	1.83	Medium	Highest
17	5	5	4	4	5	5	5	5	4	4	5	5	4.67	4.67	Lowest	Lowest
18	4	4	5	2	3	4	4	4	5	2	2	4	3.67	3.50	Low	Low
19	5	5	5	4	5	5	5	5	5	4	5	5	4.83	4.83	Lowest	Lowest
20	3	2	2	1	3	3	2	2	3	2	2	3	2.33	2.33	High	High
21	4	4	3	3	5	5	2	3	3	3	5	5	4.00	3.50	Low	Low
22	4	5	3	3	5	4	2	5	3	3	4	4	4.00	3.50	Low	Low
23	2	4	3	2	5	5	1	3	3	2	5	5	3.50	3.17	Low	Medium
24	4	3	3	3	4	5	2	3	2	3	1	4	3.67	2.50	Low	High
25	5	4	5	2	5	3	4	2	4	2	2	2	4.00	2.67	Low	Medium
26	5	4	4	3	3	3	3	2	4	2	1	2	3.67	2.33	Low	High
27	5	3	4	3	4	5	2	3	4	2	2	4	4.00	2.83	Low	Medium
28	5	4	5	4	5	5	5	2	5	4	4	4	4.67	4.00	Lowest	Low
29	5	5	5	4	5	5	5	5	5	4	5	5	4.83	4.83	Lowest	Lowest
30	1	2	2	2	3	2	1	1	2	1	1	1	2.00	1.17	High	Highest
31	2	3	3	3	3	2	2	1	3	2	1	2	2.67	1.83	Medium	Highest
32	5	4	5	3	5	5	3	2	4	3	4	4	4.50	3.33	Lowest	Medium
33	4	3	5	3	4	4	4	3	4	3	2	4	3.83	3.33	Low	Medium
34	4	3	5	3	5	3	4	3	4	3	5	3	3.83	3.67	Low	Low
35	3	1	2	2	3	2	1	1	2	1	1	1	2.17	1.17	High	Highest
36	3	1	4	4	3	3	1	1	2	2	1	3	3.00	1.67	Medium	Highest
37	3	3	3	2	3	3	2	1	3	2	1	2	2.83	1.83	Medium	Highest
38	4	2	4	3	4	5	1	2	2	1	1	3	3.67	1.67	Low	Highest
39	1	1	4	1	1	1	1	1	4	1	1	1	1.50	1.50	Highest	Highest
40	3	3	4	3	4	3	2	2	3	3	1	3	3.33	2.33	Medium	High
41	4	4	3	2	3	4	2	1	2	1	1	2	3.33	1.50	Medium	Highest
42	3	2	5	4	3	5	1	2	4	3	1	5	3.67	2.67	Low	Medium
43	2	2	3	3	2	2	1	2	2	2	1	1	2.33	1.50	High	Highest
44	3	4	3	4	3	2	1	1	3	3	1	1	3.17	1.67	Medium	Highest
45	1	1	2	2	2	3	1	1	5	2	2	2	1.83	2.17	Highest	High
46	4	2	1	1	3	2	2	4	4	5	2	1	2.17	3.00	High	Medium
47	2	3	3	1	1	1	2	5	4	3	1	3	1.83	3.00	Highest	Medium

Table C-3. Prioritization Summary

Class	Range of Scores	Number and Percentage of Needs Falling into Class	
		Short Term	Long Term
Highest	1–1.9	4 (9%)	13 (28%)
High	1.9–2.63	7 (15%)	11 (23%)
Medium	2.63–3.37	10 (21%)	12 (26%)
Low	3.37–4.1	19 (40%)	7 (15%)
Lowest	4.1–5	7 (15%)	4 (9%)

Table C-4. Needs Sorted by Short Term Priority

Need	Description	Short Term	Long Term
1	Develop a database on water yield across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic, and soils characteristics.	1.00 Highest	2.17 High
39	Develop information on the economic effects of alternative ways water scarcity can be addressed considering reservoirs, conservation, etc.	1.50 Highest	1.50 Highest
45	Develop estimates of the economic benefits, use of water, and rights to water in an area where brush management has been implemented, for example Rocky Creek.	1.83 Highest	2.17 High
47	Develop recommendations for research which should be done in conjunction with demonstration implementations.	1.83 Highest	3.00 Medium
30	Develop estimates of the value of additional water to various users in terms of both income and risk as it varies by time and water volume.	2.00 High	1.17 Highest
11	Develop data on and a model for predicting the disposition of a given quantity of additional surface water and groundwater in terms of use, groundwater recharge, return flow reuse, flow to estuaries, evaporation, etc.	2.17 High	1.17 Highest
35	Develop estimates of the net economic value of the water generated from selected sites.	2.17 High	1.17 Highest
46	Examine the institutional and legal reforms put in place by other states to encourage brush management for water production.	2.17 High	3.00 Medium
43	Examine the institutional and legal reforms necessary to allow use of each of the potential policy options in Texas.	2.33 High	1.50 Highest
20	Develop estimates of the effect of brush management alternatives on game animal populations.	2.33 High	2.33 High
2	Add data to the database in #1 pertaining to brush management methods, treatment patterns, and maintenance.	2.50 High	2.00 High

(continued)

Table C-4. (continued)

Need	Description	Short Term	Long Term
31	Develop estimates of the marginal economic consequences in terms of income and risk to various users of possible changes in water quality.	2.67 Medium	1.83 Highest
9	Assess and develop procedures for monitoring the water yield from a brush management application over time.	2.67 Medium	2.17 High
5	Develop a database on water quality effects of brush management across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic and soils characteristics.	2.67 Medium	2.33 High
16	Develop information on the effects on future water availability of leaving brush infestation alone.	2.83 Medium	1.83 Highest
37	Develop economic and institutional criteria for site identification.	2.83 Medium	1.83 Highest
36	Develop predictive models which, given the characteristics of a site, predict the net economic benefits of brushland management.	3.00 Medium	1.67 Highest
44	Compare brush management to other water development policies such as alternative water supply possibilities and make recommendations about the most desirable policies to pursue.	3.17 Medium	1.67 Highest
3	Develop models which, given the physical characteristics of a parcel, predict water yield.	3.33 Medium	1.33 Highest
41	Develop data on the economically rational amount of water that can be developed through brushland management in Texas.	3.33 Medium	1.50 Highest
40	Assess whether reservoir storage development or investments would improve the economic desirability of brush management.	3.33 Medium	2.33 High
6	Add data to the database in #5 pertaining to brush management methods, removal patterns and maintenance.	3.50 Low	2.67 Medium

(continued)

Table C-4. (continued)

Need	Description	Short Term	Long Term
23	Estimate the consequences of brush management as reflected in the sale value of rangeland and associated assets.	3.50 Low	3.17 Medium
38	Assess the economic, social, distributional, and other consequences of the potential policies which would foster brush management.	3.67 Low	1.67 Highest
13	Develop estimates of the effects of increased reservoir storage on disposition of water increments.	3.67 Low	2.00 High
26	Develop estimates of the downstream effect of water increments such as those which could be incurred under brush management on fish, wildlife, and aesthetic characteristics.	3.67 Low	2.33 High
24	Given different types of brush complexes and treatment methods, determine the profitability of brush management to the rancher.	3.67 Low	2.50 High
42	Develop estimates of the economic consequences of allowing brush incidence to continue along its current physical trend.	3.67 Low	2.67 Medium
18	Develop estimates of the effect of brush management alternatives on nongame animal populations.	3.67 Low	3.50 Low
4	Expand models in #3 to predict water yield under alternative brush management methods, patterns and maintenance schemes.	3.83 Low	2.33 High
7	Develop models which, given the physical characteristics of a parcel, predict water quality effects of brush management.	3.83 Low	2.83 Medium
33	Develop estimates of the economic consequences of altered nongame populations.	3.83 Low	3.33 Medium
34	Develop estimates of the economic consequences of altered aquatic populations.	3.83 Low	3.67 Low
25	Develop estimates of the consequences of changes in water quality on fish, wildlife, and watercourse plant populations.	4.00 Low	2.67 Medium

(continued)

Table C-4. (continued)

Need	Description	Short Term	Long Term
27	Develop recommendations pertinent to environmentally sound methods of brush management across large target areas.	4.00 Low	2.83 Medium
14	Develop inventory information on the types of brush, infestation levels, densities, etc. by region.	4.00 Low	3.00 Medium
15	Develop information on how brush incidence has been changing over time.	4.00 Low	3.33 Medium
21	Develop models exploring the interrelationship of game animal abundance and lease income, including other factors such as services provided, and location.	4.00 Low	3.50 Low
22	Predict the consequences of brush management for ranch net income from wildlife leases.	4.00 Low	3.50 Low
10	Develop criteria for the physical treatability of a piece of land, i.e., criteria which identify untreatable acreage.	4.00 Low	3.83 Low
8	Expand models in #7 to predict water quality under alternative brush management methods, patterns, and maintenance schemes.	4.17 Lowest	3.50 Low
32	Develop information on the value of altered flooding regimes.	4.50 Lowest	3.33 Medium
28	Develop estimates of the consequences of brush-land management for the aesthetic value of land.	4.67 Lowest	4.00 Low
17	Develop estimates of the effect of brush management alternatives on livestock stocking rates.	4.67 Lowest	4.67 Lowest
12	Develop information on the effect of increased water on watercourse channel dynamics.	4.83 Lowest	4.33 Lowest
19	Develop estimates of the effect of brush management alternatives on cropped acreage.	4.83 Lowest	4.83 Lowest
29	Develop information on the atmospheric implications of brush management.	4.83 Lowest	4.83 Lowest

Table C-5. Needs Sorted by Long Term Priority

Need	Description	Short Term	Long Term
30	Develop estimates of the value of additional water to various users in terms of both income and risk as it varies by time and water volume.	2.00 High	1.17 Highest
11	Develop data on and a model for predicting the disposition of a given quantity of additional surface water and groundwater in terms of use, groundwater recharge, return flow reuse, flow to estuaries, evaporation, etc.	2.17 High	1.17 Highest
35	Develop estimates of the net economic value of the water generated from selected sites.	2.17 High	1.17 Highest
3	Develop models which, given the physical characteristics of a parcel, predict water yield.	3.33 Medium	1.33 Highest
39	Develop information on the economic effects of alternative ways water scarcity can be addressed considering reservoirs, conservation, etc.	1.50 Highest	1.50 Highest
43	Examine the institutional and legal reforms necessary to allow use of each of the available policy options in Texas.	2.33 High	1.50 Highest
41	Develop data on the economically rational amount of water that can be developed through brushland management in Texas.	3.33 Medium	1.50 Highest
36	Develop predictive models which, given the characteristics of a site, predict the net economic benefits of brushland management.	3.00 Medium	1.67 Highest
44	Compare brush management to other water development policies such as alternative water supply possibilities and make recommendations about the most desirable policies to pursue.	3.17 Medium	1.67 Highest
38	Assess the economic, social, distributional, and other consequences of the potential policies which would foster brush management.	3.67 Low	1.67 Highest
31	Develop estimates of the marginal economic consequences in terms of income and risk to various users of possible changes in water quality.	2.67 Medium	1.83 Highest

(continued)

Table C-5. (continued)

Need	Description	Short Term	Long Term
16	Develop information on the effects on future water availability of leaving brush infestation alone.	2.83 Medium	1.83 Highest
37	Develop economic and institutional criteria for site identification.	2.83 Medium	1.83 Highest
2	Add data to the database in #1 pertaining to brush management methods, treatment patterns, and maintenance.	2.50 High	2.00 High
13	Develop estimates of the effects of increased reservoir storage on disposition of water increments.	3.67 Low	2.00 High
1	Develop a database on water yield across a number of watershed sites exhibiting varying brush species, precipitation regimes, and geologic and soils characteristics.	1.00 Highest	2.17 High
45	Develop estimates of the economic benefits, use of water, and rights to water in an area where brush management has been implemented; for example, Rocky Creek.	1.83 Highest	2.17 High
9	Assess and develop procedures for monitoring the water yield from a brush management application over time.	2.67 Medium	2.17 High
20	Develop estimates of the effect of brush management alternatives on game animal populations.	2.33 High	2.33 High
5	Develop a database on water quality effects of brush management across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic and soils characteristics.	2.67 Medium	2.33 High
40	Assess whether reservoir storage development or investments would improve the economic desirability of brush management.	3.33 Medium	2.33 High
26	Develop estimates of the downstream effect of water increments such as those which could be incurred under brush management on fish, wildlife, and aesthetic characteristics.	3.67 Low	2.33 High

(continued)

Table C-5. (continued)

Need	Description	Short Term	Long Term
4	Expand models in #3 to predict water yield under alternative brush management methods, patterns and maintenance schemes.	3.83 Low	2.33 High
24	Given different types of brush complexes and treatment methods, determine the profitability of brush management to the rancher.	3.67 Low	2.50 High
6	Add data to the database in #5 pertaining to brush management methods, removal patterns and maintenance.	3.50 Low	2.67 Medium
42	Develop estimates of the economic consequences of allowing brush incidence to continue along its current physical trend.	3.67 Low	2.67 Medium
25	Develop estimates of the consequences of changes in water quality on fish, wildlife, and watercourse plant populations.	4.00 Low	2.67 Medium
7	Develop models which, given the physical characteristics of a parcel, predict water quality affects of brush management.	3.83 Low	2.83 Medium
27	Develop recommendations pertinent to environmentally sound methods of brush management across large target areas.	4.00	2.83 Medium
47	Develop recommendations for research which should be done in conjunction with SCS demonstration implementations.	1.83 Highest	3.00 Medium
46	Examine the institutional and legal reforms put in place by other states to encourage brush management for water production.	2.17 High	3.00 Medium
14	Develop inventory information on the types of brush, infestation levels, densities, etc., by region.	4.00 Low	3.00 Medium
23	Estimate the consequences of brush management as reflected in the sale value of rangeland and associated assets.	3.50 Low	3.17 Medium
33	Develop estimates of the economic consequences of altered nongame populations.	3.83 Low	3.33 Medium

(continued)

Table C-5. (continued)

Need	Description	Short Term	Long Term
15	Develop information on how brush incidence has been changing over time.	4.00 Low	3.33 Medium
32	Develop information on the value of altered flooding regimes.	4.50 Lowest	3.33 Medium
18	Develop estimates of the effect of brush management alternatives on nongame animal populations.	3.67 Low	3.50 Low
21	Develop models exploring the interrelationship of game animal abundance and lease income, including factors such as services provided and location.	4.00 Low	3.50 Low
22	Predict the consequences of brush management for ranch net income from wildlife leases.	4.00 Low	3.50 Low
8	Expand models in #7 to predict water quality under alternative brush management methods, patterns and maintenance schemes.	4.17 Low	3.50 Low
34	Develop estimates of the economic consequences of altered aquatic populations.	3.83 Low	3.67 Low
10	Develop criteria for the physical treatability of a piece of land, i.e., criteria which identify untreatable acreage.	4.00 Low	3.83 Low
28	Develop estimates of the consequences of brushland management for the aesthetic value of land.	4.67 Lowest	4.00 Low
12	Develop information on the effect of increased water on watercourse channel dynamics.	4.83 Lowest	4.33 Lowest
17	Develop estimates of the effect of brush management alternatives on livestock stocking rates.	4.67 Lowest	4.67 Lowest
19	Develop estimates of the effect of brush management alternatives on cropped acreage.	4.83 Lowest	4.83 Lowest
29	Develop information on the atmospheric implications of brush management.	4.83 Lowest	4.83 Lowest

APPENDIX D: PRIORITIZED NEEDS CONTAINED IN RESEARCH ELEMENTS

Element A: Enhance Ability to Predict Water Yield Changes Induced by Brush Management

Priority	Short Term	Long Term
Highest	1	3
High	2	2, 1, 9, 4, 5
Medium	5, 9, 3	6
Low	6, 4	–
Lowest	–	–

Need	Description
1	Develop a database on water yield across a number of watershed sites exhibiting varying brush species, precipitation regimes, and geologic and soils characteristics.
2	Add data to the database in #1 pertaining to brush management methods, treatment patterns, and maintenance.
3	Develop models which, given the physical characteristics of a parcel, predict water yield.
4	Expand models in #3 to predict water yield under alternative brush management methods, patterns, and maintenance schemes.
5	Develop a database on water quality effects of brush management across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic and soils characteristics.
6	Add data to the database in #5 pertaining to brush management methods, removal patterns, and maintenance.
9	Assess and develop procedures for monitoring the water yield from a brush management application over time.

Element B: Develop Economic and Social Implications of Alternative Policies and Actions for Relieving Water Scarcity

Priority	Short Term	Long Term
Highest	39	39, 41, 38, 44, 16
High	41	40
Medium	16, 44, 40	42
Low	38, 42	–
Lowest	–	–

Need	Description
16	Develop information on the effects on future water availability of leaving brush infestation alone.
38	Assess the economic, social, distributional, and other consequences of the potential policies which would foster brush management.

39 Develop information on the economic effects of alternative ways water scarcity can be addressed considering reservoirs, conservation, etc.

40 Assess whether reservoir storage development or investments would improve the economic desirability of brush management.

41 Develop data on the economically rational amount of water that can be developed through brushland management in Texas.

42 Develop estimates of the economic consequences of allowing brush incidence to continue along its current physical trend.

44 Compare brush management to other water development policies such as alternative water supply possibilities and make recommendations about the most desirable policies to pursue.

Element C: Enhance the Ability to Predict How the Water Originating From Rangeland Sites Will Be Used

Priority	Short Term	Long Term
Highest	–	11
High	11	13, 9, 40
Medium	9, 40	32
Low	13	–
Lowest	32	–

Need	Description
9	Assess and develop procedures for monitoring the water yield from a brush management application over time.
11	Develop data on and a model for predicting the disposition of a given quantity of additional surface water and groundwater in terms of use, groundwater recharge, return flow reuse, flow to estuaries, evaporation, etc.
13	Develop estimates of the effects of increased reservoir storage on disposition of water increments.
32	Develop information on the value of altered flooding regimes.
40	Assess whether reservoir storage development or investments would improve the economic desirability of brush management.

Element D: Estimate the Economic and Risk Benefits of Additional Water Changes in Water Quality

Priority	Short Term	Long Term
Highest	–	30, 31
High	30	–
Medium	31	–
Low	–	–
Lowest	–	–

Need	Description
30	Develop estimates of the value of additional water to various users in terms of both income and risk as it varies by time and water volume.
31	Develop estimates of the marginal economic consequences in terms of income and risk to various users of possible changes in water quality.

Element E: Determine What Legal Reforms are Needed to Implement Brush Management Policy

Priority	Short Term	Long Term
Highest	–	43, 38, 44, 16
High	43, 46	–
Medium	16, 44	42, 46
Low	38, 42	–
Lowest	–	–

Need	Description
16	Develop information on the effects on future water availability of leaving brush infestation alone.
38	Assess the economic, social, distributional, and other consequences of the potential policies which would foster brush management.
42	Develop estimates of the economic consequences of allowing brush incidence to continue along its current physical trend.
43	Examine the institutional and legal reforms necessary to allow use of each of the available policy options in Texas.
44	Compare brush management to other water development policies such as alternative water supply possibilities and make recommendations about the most desirable policies to pursue.
46	Examine the institutional and legal reforms put in place by other states to encourage brush management for water production.

Element F: Predict the Water Quality Effects of Brush Management

Priority	Short Term	Long Term
Highest	–	–
High	–	5
Medium	5	–
Low	6, 7	6, 7, 8
Lowest	8	–

Need	Description
5	Develop a database on water quality effects of brush management across a number of watershed sites exhibiting varying brush species, precipitation regimes, geologic and soils characteristics.
6	Add data to the database in #5 pertaining to brush management methods, removal patterns, and maintenance.
7	Develop models which, given the physical characteristics of a parcel, predict water quality effects of brush management.
8	Expand models in #7 to predict water quality under alternative brush management methods, patterns, and maintenance schemes.

Element G: Develop Physical and Economic Criteria for Site Selection

Priority	Short Term	Long Term
Highest	–	37
High	–	–
Medium	37	–
Low	–	–
Lowest	–	–

Need	Description
37	Develop economic and institutional criteria for site identification.

Element H: Determine the Relationship Between Brush Management and Wildlife Income

Priority	Short Term	Long Term
Highest	–	–
High	20	20, 24
Medium	–	–
Low	21, 22, 24	21, 22
Lowest	–	–

Need	Description
20	Develop estimates of the effect of brush management alternatives on game animal populations.
21	Develop models exploring the interrelationship of game animal abundance and lease income, including other factors such as services provided and location.
22	Predict the consequences of brush management for ranch net income from wildlife leases.
24	Given different types of brush complexes and treatment methods, determine the profitability of brush management to the rancher.

Element I: Develop the Economic Implications of Brush Management On and Off the Site Managed

Priority	Short Term	Long Term
Highest	–	35, 36, 37, 41
High	35	24
Medium	36, 37, 41	23
Low	22, 23, 24	22
Lowest	–	–

Need	Description
22	Predict the consequences of brush management for ranch net income from wildlife leases.
23	Estimate the consequences of brush management as reflected in the sale value of rangeland and associated assets.
24	Given different types of brush complexes and treatment methods, determine the profitability of brush management to the rancher.

35	Develop estimates of the net economic value of the water generated from selected sites.
36	Develop predictive models which, given the characteristics of a site, predict the net economic benefits of brushland management.
37	Develop economic and institutional criteria for site identification.
41	Develop data on the economically rational amount of water that can be developed through brushland management in Texas.

Element J: Study the Costs, Benefits, and Consequences of Alternative Policies Encouraging Brush Management

Priority	Short Term	Long Term
Highest	–	16, 38, 41, 43, 44
High	43, 46	–
Medium	16, 41, 44	27, 42, 46
Low	27, 38, 42	–
Lowest	–	–

Need	Description
16	Develop information on the effects on future water availability of leaving brush infestation alone.
27	Develop recommendations pertinent to environmentally sound methods of brush management across large target areas.
38	Assess the economic, social, distributional, and other consequences of the potential policies which would foster brush management.
41	Develop data on the economically rational amount of water that can be developed through brushland management in Texas.
42	Develop estimates of the economic consequences of allowing brush incidence to continue along its current physical trend.
43	Examine the institutional and legal reforms necessary to allow use of each of the available policy options in Texas.
44	Compare brush management to other water development policies such as alternative water supply possibilities and make recommendations about the most desirable policies to pursue.
46	Examine the institutional and legal reforms put in place by other states to encourage brush management for water production.

Element K: Document the Benefits of Currently Existing Brush Management Programs

Priority	Short Term	Long Term
Highest	45, 47	35, 37
High	35	45
Medium	37	47
Low	–	–
Lowest	–	–

Need	Description
35	Develop estimates of the net economic value of the water generated from selected sites.
37	Develop economic and institutional criteria for site identification.
45	Develop estimates of the economic benefits, use of water, and rights to water in an area where brush management has been implemented, for example Rocky Creek.
47	Develop recommendations for research which should be done in conjunction with Soil Conservation Service demonstration implementations.

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