ASSESSMENT OF BRUSH CONTROL AS A WATER MANAGEMENT STRATEGY

Submitted to:
Texas Water Development Board
Research and Planning Fund Grants Management Division
PO Box 13231
1700 N. Congress Avenue
Austin, Texas 78711-3231

Submitted by:

RESEARCH & PLANNING CONSULTANTS
7600 Chevy Chase Drive, Suite 500
Austin, Texas 78752
(512) 371-8100

In association with:

Espey, Padden Consultants, Inc.
Environmental & Engineering Services
3809 South Second St., Suite B-300
Austin, TX 78704
(512) 326-5659
FAX (512) 326-5723

March 2000

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Research and Planning Consultants, Inc. and Espey, Padden Consultants, Inc. worked cooperatively to conduct this "Assessment of Brush Control as a Water Management Strategy" for the Texas Water Development Board. Individuals contributing to this study report include:

- Mr. John H. Specht, Senior Consultant, Research and Planning Consultants, Inc.
- Mr. Steven Mobley, Principle, Research and Planning Consultants, Inc.
- Mr. Mike Reed, Research Analyst, Research and Planning Consultants, Inc.
- Dr. William H. Espey, Jr., President, Espey, Padden Consultants, Inc.
- Dr. David K. Harkins, Engineering Staff, Espey, Padden Consultants, Inc.

Agency and University personnel contacted were:

- Dr. William A. Dugas, Resident Director, Texas Agricultural Experiment Station, Blackland Research Center
- Dr. Darrel Ueckert, Professor, Rangeland Ecology & Management, Texas Agricultural Experiment Station
- Mr. James E. Moore, Assistant Executive Director, Texas State Soil and Water Conservation Board
- Dr. Robert E. Whitsen, Department Head, Rangeland Ecology & Management Department, Texas A&M University
- Mr. Allan Colwick, Water Resources Specialist, Natural Resources Conservation Service
- Mr. Steven T. Bednarz, Civil Engineer, Water Resources Assessment Team, Natural Resources Conservation Service
- Mr. Dan Beckett, Manager, Texas Water Bank, Texas Water Development Board
- Ms. Carolyn Brittin, Chief, Regional Planning and Projects, Planning Division, Texas Water Development Board
- Mr. E. Charles Baird, Team Leader, Water Resources Assessment Team, Natural Resources Conservation Service
- Dr. Dee Carlson, USDA-ARS-Northwest Watershed Research Center
- Dr. Thurow, Department Head, University of Wyoming
- Mr. Eric Redeker, Caesar Klebery Wildlife Institute
- Mr. Gary Valentine, Wildlife Biologist, Natural Resource Conservation Service.

1 STUDY PURPOSES

This study is described as an "Assessment of Brush Control as a Water Management Strategy" by the Texas Water Development Board in their request for a research proposal. The requirement for the study or assessment arises from two distinct aspects. The first is the increasing demand for high quality sources of fresh water to meet the demands of a growing population centered around the major metropolitan areas of the State. The second is the realization that the State's fresh water supplies originating as rainfall initially falls upon the vast rangelands and forested lands where it is dispersed to evapotranspiration, groundwater and surface runoff.

Since the initial movement of European settlers into the region now defined as the State of Texas, the availability of water has been a critical factor. As the population grew and economic development added to the requirement for fresh water, it became necessary to develop the water resource beyond the initial supplies readily available from streams and springs. At the present time, with a highly developed economy and a population of approximately 16 million in 1990 (Water for Texas Today and Tomorrow, 1997) water supplies from groundwater and surface water become critical during periods of drought in many regions of the State. A planning process has been mandated by the Texas Legislature under Senate Bill 1 with the State divided into specific regions for planning purposes. The question then arises whether significant additional quantities of water can be made available from the watersheds where rain initially becomes available for use or capture. If the water supply can be substantially increased, how can that be accomplished and at what cost?

In Texas the vast majority of the land area is privately held. Historic management of these lands has not always been conducive to the production of high quality fresh water for municipal, industrial and agricultural uses. The problem of changing or modifying land uses or modifying management practices to improve or increase the production of water becomes a question of public participation with the landowner to obtain benefits for both. In this process the public needs to be assured of measurable benefits, as increased water availability, at a cost that is less than or equal to other sources.

A part of the public concern in the evaluation of the benefits from improved land management for the production of water must be its availability to the area of need or use, reliability during periods of drought, the relative cost of the water compared to other sources and the quality of the water produced. It is not enough to know from years of scientific study that some relatively less important species of plants or brush are large water users and in theory would produce additional water through the reduction of evapotranspiration. It is not correct to multiply the theoretical reduction in evapotranspiration test by the area to be treated or modified to arrive at a large assumption of additional water available to the State to meet drought conditions and for future growth. It is for the purpose of addressing these issues and questions that this "Assessment" has been undertaken.

To conduct this "Assessment of Brush Control as a Water Management Strategy" the study addresses the following topics:

1. An evaluation of the vegetative regions of Texas to assess the potential for the production of additional water supplies which can be effectively used for municipal, industrial and agricultural purposes.

2. Consideration of the multiple benefits of brush control and improved management of watersheds where there is a significant potential for increased water production. In the review of the multiple benefits to be gained, seek to gain a perspective between the private benefits and the benefit to the public.

3. Define and evaluate the use of hydrologic models for the selection of watersheds with potential for the production of increased water supplies.

4. Other significant factors necessary to watershed management for increased water production including timing and reliability of increased water production, quantification of anticipated increase of groundwater and surface water, impact of rainfall intensity and drought on watershed productivity, control and storage of increased water availability, and the degree of brush removal from the selected watershed in consideration of other values.

5. Current Federal and State programs applicable to brush control available or being applied in Texas. How effective have these subsidies been in the past to gain landowner participation? Has the structure of the programs worked effectively to reduce brush cover and has long term maintenance and land management been included in the requirements for participation?

6. Recommendations relative to the structuring of programs and subsidies for brush control in selected watersheds in Texas. General guidelines for the identification and selection of watersheds with potential for the production of increased ground and surface water in Texas.

2 EVALUATION OF VEGETATIVE REGIONS OF TEXAS

Texas is highly variable both biologically and geologically. It ranges from piney woods in the east to desert mountains in the Trans-Pecos region in the west. Elevations vary from sea level on the Gulf Coast to 8,000 foot peaks in the Trans-Pecos to High Plains at 4,000 feet in the Panhandle region. Precipitation varies across the State from 54 inches per year in the southeast corner to 8 inches in the Trans-Pecos near El Paso. Approximately 60% of the land area in Texas is classified as rangeland (Texas State Soil and Water Conservation Board 1991), which is managed for the production of livestock, wildlife and more recently for outdoor recreation and aesthetic values. The value of rangelands as watersheds producing water for aquifers and streams has long been recognized, but it is only recently that increasing attention has been given to the potential of watersheds to effect the quality and the quantity of water available to municipal, agricultural and industrial users.

Considering the high degree of variability of the land area of Texas and the vast differences in the vegetation which occurs across the State, significant areas or vegetative regions do not have a potential for the production of additional water. It is doubtful that regions of the State with more than 32 inches of rainfall per year or less that 17 inches of rainfall per year (Figure 2-1) would justify brush control or vegetative manipulation for the purpose of producing significant increases to groundwater or surface water supplies (comment of James Moore, Assistant Executive Director, State Soil and Water Conservation Board).

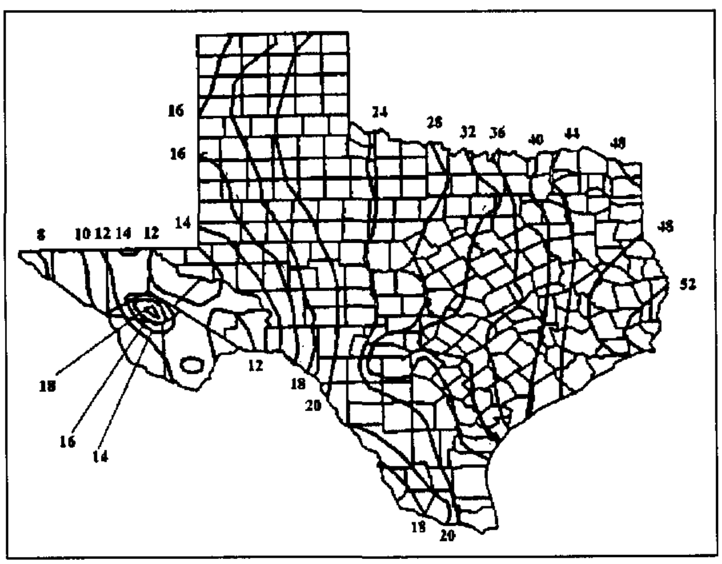

Figure 2-1
Texas precipitation
(Texas State Soil and Water Conservation Board, 1991)

In the drier regions of the State (less than 17 inches of rainfall) there is little surface runoff except during intense storms and the high evaporation rate limits infiltration into aquifers. In east Texas, high rainfall rates tend to saturate the soils producing substantial surface runoff. Timber harvest and other land clearing has apparently increased stream flow temporarily, but the stream flows have tended to recede as new vegetative growth returns (A Comprehensive Study of Texas Watersheds, Texas State Soil and Water Conservation Board, 1991).

Within the central area of Texas, between the 17 to 32 inch rainfall zones, there are vegetative regions (Figure 2-2) with soils and parent materials conducive to the production of increased water flows as a result of brush removal. The region with the greatest potential for increased water production is the Edwards Plateau. This region has approximately 14,315,100 acres of heavy and moderate brush (USDA SCS 1982 Brush Inventory) consisting primarily of oak, juniper or mesquite. It is a region of thin calcareous soils underlain by fractured limestone. Numerous small clear flowing streams transect the region often fed by springs and seeps. The fractured limestone provides the opportunity for rapid movement of percolating groundwater to reach aquifers, many of which feed numerous small springs.

The Balcones Fault Zone marks the southern boundary of the Edwards Plateau. This zone of fractured limestone facilitates the rapid movement of surface water and some groundwater into the Edwards Aquifer providing a major water supply to a corridor extending from Uvalde on the southwest to Round Rock on the northeast. Often where the fault zone is crossed by streams, significant amounts of surface water are lost to the aquifer.

In north central Texas including the High Plains, the Rolling Plains, the Rolling Red Prairie, the North Central Prairie, West Cross Timbers, East Cross Timbers and Grand Prairie (Figure 2-2) there are significant benefits to landowners from brush control including some increase in stream flow and surface runoff. The primary brush species in this large and diverse area include shinnery/sage, juniper, oaks, pricklypear and mesquite. However, from the standpoint of potentially significant increases of water available to local aquifers or for stream flow, brush removal and conversion to grass cover may have little net benefit (Texas State Soil and Water Conservation Board 1991)(Carlson, Thurow, Knight and Heitschmidt 1990).

In south Texas, an area below the Balcones Escarpment extending generally south to the Gulf of Mexico and southwesterly to the Rio Grande Valley, soils and parent materials are not conducive to the rapid movement of rainfall into aquifers. This area includes the Blackland Prairie, the Claypan Area, the North Rio Grande Plain, the West Rio Grande Plain, the Central Rio Grande Plain, the Lower Valley and the Coastal Prairies (Figure 2-2). Primary brush species in this large area of Texas include mesquite, condalias/lotebush, huisache, live oak, yaupon and McCartney rose. While some stream flow increases may be induced from brush removal, generally the conversion from heavy and moderate brush cover to grasses will not produce a significant net increase in flow (Texas State Soil and Water Conservation Board 1991) (Richardson, Burnett and Bovey 1978) (Weltz and Blackburn 1993).

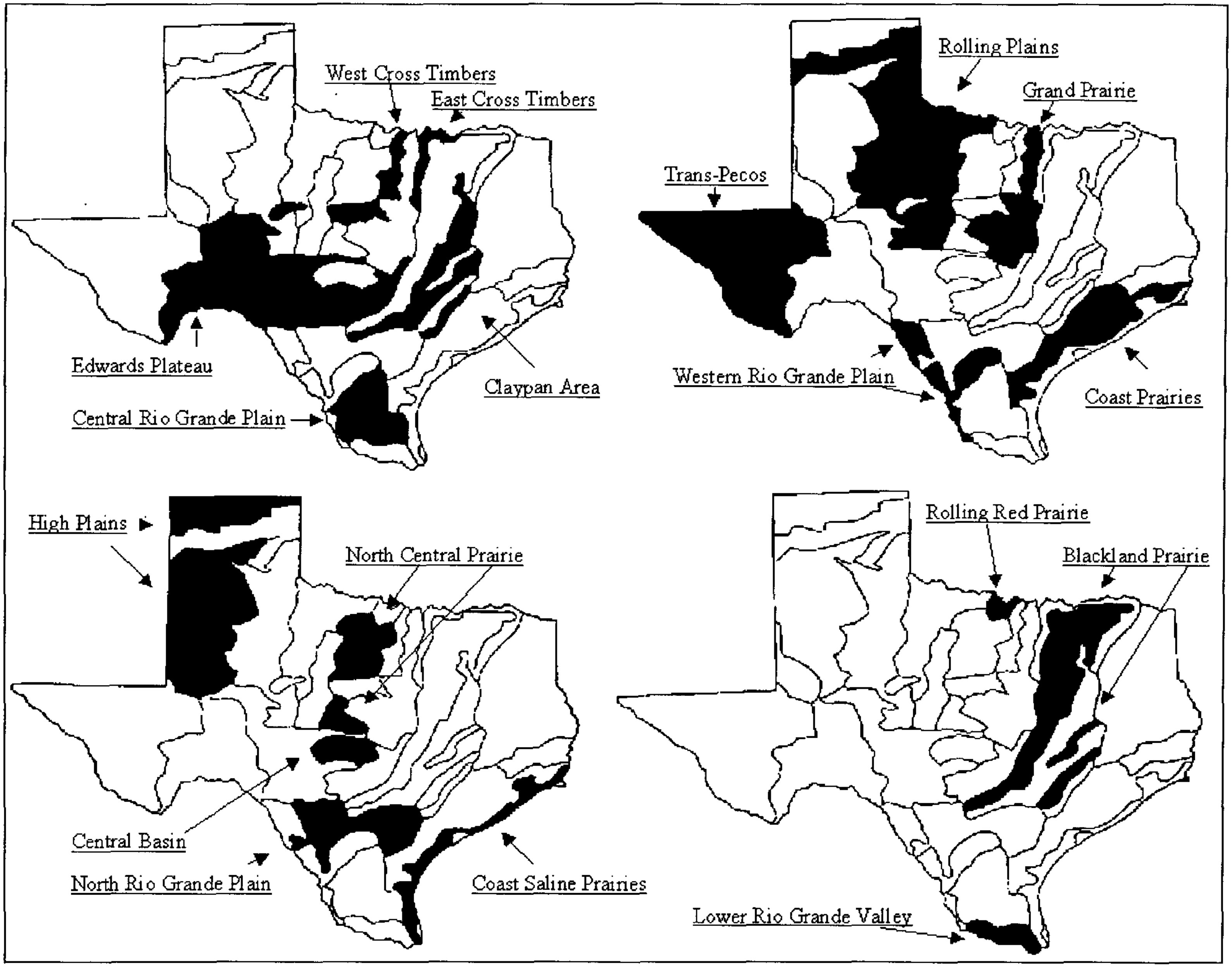

Figure 2-2
Vegetative regions of Texas
(Texas State Soil and Water Conservation Board, 1991)

Another significant brush problem in Texas is the control of phreatophytes primarily along the rivers and streams. Species included in the definition of phreatophytes for purposes of this discussion are Saltcedar or Tamarisk and Mesquite where it is growing in the proximity of streams or areas with a shallow water table. Saltcedar is an introduced species that competes successfully with native vegetation in riparian zones through out the Southwest (Stevens and Walker 1998). In Texas, Saltcedar occupies significant areas in and adjacent to the major river channels resulting in the transpiration of substantial amounts of water (Sosebee, undated)(Texas State Soil and Water Conservation Board 1991). It is also noted that Saltcedar growing along stream channels and on sandbars can cause channel changes, increased flood levels and on occasion, greater siltation downstream (Blackburn, et. al. 1982; Texas State Soil and Water Conservation Board, 1991). Recent studies of methods of treatment to control Saltcedar and restore native vegetation were reported by McDaniel and Taylor (1999). The cost of control for Saltcedar on the Bosque del Apache National Wildlife Refuge was estimated to range from $750 - $1292 per hectare. The cost of site restoration including wetland development was estimated to range from $2000 - $3000 per hectare (1 hectare = 2.471 acres). Additional discussion of removal costs for various vegetation is found in Section 3.1.

The Texas Department of Agriculture and the Agricultural Extension Service are currently conducting a brush control study in the upper Pecos River watershed to determine the benefit of the removal of Saltcedar on the quantity and quality of water in the watershed. Dr. Charlie Hart is leading the project team at the Agricultural Extension Service. In September 1997 the Texas Department of Agriculture applied for a permit 24C from the EPA to allow arsenol to be used as the treating agent for Saltcedar eradication. In September 1999 the permit was granted and spraying of Saltcedar began.

The initial phase of brush control was 658 acres downstream of Red Bluff Reservoir. Approximately 90 feet from the riverbank on both sides of the river were treated for 30 river miles. The arsenol was applied by helicopter and the cost was $190.00/acre (verbal conversation with Dr. Hart, March 2000). Dr. Hart indicated that approximately the same amount of money will be used in 2000 to treat 120 river miles downstream of Red Bluff Reservoir. Results of Saltcedar control will not be fully realized for 2 years. Estimates on water quantity and quality will be made some time next year (verbal conversation with Dr. Hart, March 2000). Water quantity comparisons will be based on known flows in the Pecos River from precipitation and releases from Red Bluff Reservoir with Saltcedar present (current conditions), and flows in the Pecos River after Saltcedar removal from precipitation and Red Bluff releases.

3 BRUSH CONTROL: COST, BENEFITS, AND APPLICATIONS

There is no question as to the multiple benefits of brush management on Texas rangelands, pastures and forests. It is of interest to reflect on the evolution of efforts to improve the production from lands other than croplands driven by the commodity bringing the greatest return to the landowner. In the years following World War II the nations' requirements centered upon food and fiber production. Every effort was made to increase the production of food and fiber from the land and brush was seen as a major impediment. Brush eradication became the byword for ranchers, land managers, foresters and small stockmen. State and Federal Agencies, Universities and scientists concentrated upon the assignment to eradicate brush and replace it with productive herbaceous vegetation and forest production.

As we approached the 1960's it became apparent that brush eradication was not possible even with the introduction of selective herbicides. Further, the landowner was becoming aware that the production of wildlife had a value in addition to the traditional grazing of livestock. Other benefits to management of vegetation were being emphasized such as erosion control, watershed protection and aesthetic values so that thinking and terminology began to shift to the concept of "brush management" in the 1970's. Mechanical methods of brush removal were thoughtfully integrated with the application of new selective herbicides to gain control of brush infested lands relative to the use and production intended.

In the 1980's a new concept was emerging, "Integrated Brush Management" by Charles Scifres and associates at Texas A & M University. This concept recognized the importance of considering all factors related to the land area to arrive at an approach acceptable to the landowners and to the concerned public. Embodied in this concept was recognition that all brush species and their occurrence on the land was not inherently bad. The control or removal of brush should be a site or watershed specific consideration and from an environmental perspective, herbicides must be judiciously applied to minimize the risk of environmental damage while achieving the desired control or reduction of the target vegetation.

Refinements and innovations were added in support of the Integrated Brush Management concept in the 1990's. Ueckert, McGinty and associates developed "Brush Busters", a cooperative program of the Texas Agricultural Experiment Station and the Texas Agricultural Extension Service. Brush Busters advocates the treatment of individual species of brush or noxious vegetation to be removed. It is designed so that a rancher or land manager can successfully remove the offending brush to maintain control of his rangelands, pastures or forested lands for selected purposes at costs which are within the financial capability of all landowners. The program employs many methods of killing or removing selected brush plants ranging from hand grubbing to the application of selective herbicides to stems, leaf surface or soil spot treatment.

Still another concept was introduced by Rollins which has been termed "Brush Sculptors". In a paper published in "Brush Sculptors Symposium Proceedings" in 1997 Rollins added the phrase, "an appreciation for brush". This concept recognizes the value of many species of brush to wildlife, to livestock, and for a number of other beneficial purposes. It suggests that each landowner should consider the relative value of some brush species on a given parcel of land or watershed in the process of managing for his purposes or goals. Considerations should be given to the value of the plants or plant associations for wildlife feed, shelter, protection from predators, and cover. While there is some trade-off with livestock when maintaining brush for wildlife propagation, there are also some benefits to livestock to be considered. Aesthetic values must also be considered while deciding on brush control or removal, and some areas may receive substantial consideration to maintain land values for recreation or development purposes.

Even when considering the economy of the Brush Busters program described above, the issue of cost is ever present for most landowners and ranchers. With the Federal and State programs to assist landowners with the cost of brush control through technical support and direct payments intended to encourage brush control practices in the public interest, the question of private benefit vs. public benefit is difficult to ascertain. The more recent interest in the increased production of ground and surface water for municipal, industrial and agricultural uses, which is the subject of this study, becomes extremely difficult because costs, water production, relative private benefit, public benefit and environmental impacts tend to be site specific even within homogeneous vegetative regions. Additional discussion of brush control to increase available water is found in later sections of this study.

3.1 Cost Associated with Initial Brush Removal

When the principal objective of brush control in a selected watershed is the increased production of groundwater and surface water runoff, 90% to 95% of the brush species would usually need to be removed. Subsequent growth of herbaceous vegetation would have to be managed through the grazing of livestock to avoid evapotranspiration that can equal the level prior to the removal of brush (Dugas, Hicks and Wright 1998)(Carlson, Thurow, Knight and Heitschmidt 1990). The treated watershed would require regular maintenance to prevent the re-infestation by brush species adding a substantial annual cost.

The costs associated with initial removal vary significantly with the vegetative type, the density of brush, size of brush, method or methods of brush removal selected, soils, number of acres treated and topography. Teague et. al. reported in an ongoing study on the Waggoner Ranch in the Rolling Plains midway between Dallas and Amarillo that the costs associated with Mesquite control using a number of differing methods were as follows:

Table 3.1-1
Mesquite Control Costs in the Rolling Plains
(Teague, et.al., 1997)

Treatment	Cost per treatment	Treatment interval
Chemical spray	\$15 - 25/acre	Retreat every 10-12 years
Spray & chain (as above)	\$25 - 40/acre	Chain after 2 yrs. then as above
Roller chopping	\$25 - 65/acre	Retreat every 6 - 8 years
Root plowing & reseed	\$80 - 90/acre	Grub every 12 years
Fire	\$2.5 - 5/acre	Burn every 5 - 7 years
Grub	\$10 - 75/acre	Retreat every 10 - 15 years

Ashe juniper initial clearing and control in the Edwards Plateau region for two case studies was reported by Reinke (1997). On the Bolin Ranch in Schleicher County, juniper was initially chained one way and burned approximately one year later. The cost of this approach for clearing and initial control was $15.38/acre. A second study was conducted on the Jo Ella Bolt Ranch in Kimble County. Hand grubbing was initially used to remove the brush, followed by burning after deferment to allow fuel buildup at a cost of $47.75/acre. Reinke also commented that juniper is commonly controlled with grubbing or dozing at a cost of $40 - 50/acre.

The "North Concho River Watershed - Brush Control Planning, Assessment and Feasibility Study" prepared by the Upper Colorado River Authority stated, "Present values of total per acre control costs range from $20.42 for moderate mesquite that can be initially controlled with individual plant herbicide treatments to $75.42 for heavy cedar that must be initially controlled with mechanical tree bulldozing". These estimated costs were predicated upon a 10 year period beginning with initial control. This study went on to determine the relative benefits ascribed to the landowner and to the State for the purpose of assigning the costs to be borne by the landowner and the costs to be contributed by the State. State costs were roughly compared to the costs of other sources of water supply such as O. H. Ivy Reservoir on the Colorado River.

The Brush Busters program can be considered as an approach applicable to initial treatment of light stands of brush or as the method of treatment to be used as maintenance on an area or watershed where initial control of moderate or heavy brush stands required mechanical treatment. Taken from the Brush Busters - Individual Plant Treatment Series prepared by Ueckert and McGinty, estimated costs for control of light density brush species are as follows:

Table 3.1-2
Brush Control Costs – Brush Busters Program
(Ueckert and McGinty, 1999)

Brush Species	Treatment	Cost
Juniper	Leaf spray cost plus labor @ $12/hr.	$20/ac.
Juniper	Soil spot spray plus labor @ $12/hr.	$9/ac.
Juniper	Hand Grubbing @ $12/hr.	$15/ac.
Mesquite	Leaf spray cost plus labor @ $12/hr.	$13/ac.
Mesquite	Stem spray cost plus labor @ $12/hr.	$18/ac.
Pricklypear	Pad or stem spray cost plus labor @ $12/hr.	$11/ac.

3.2 Benefits of Brush Control

The major question facing the rancher or the landowner is whether the investment to control brush is justified by the increased forage production and ultimately, in increased sale of livestock or products. To determine the financial feasibility of brush control, specific information is needed for the ranch or area to be treated including reasonable information on ranching costs, type of livestock, livestock prices, brush treatment methods to be applied, brush treatment costs, and the estimated forage increases. In a paper published in the October 1994 issue of Rangelands titled "Brush Control Considerations: A Financial Perspective" by Holechek and Hess it is generally inferred that brush control practices in the western United States under favorable conditions are often considered to be financially unsound if the primary purpose is to increase grazing capacity. When additional considerations such as wildlife, watershed protection, aesthetics, erosion control and improved land condition are evaluated, the financial picture often will become more favorable. Some of these alternative land use considerations will yield additional income to the rancher or landowner while others are of benefit to the public at large. When there is a public benefit that can be quantified for the purpose of providing payments or subsidies to the landowner, brush control practices can become financially beneficial to both.

In the paper by Holechek and Hess, it is stated, "as a rule it is financially unsound for a rancher to spend more than 10 times the anticipated per acre returns on any range improvement practice. Forage production and financial returns from range types in Texas or adjacent States with application to Texas under good range condition and good management presented by Holechek and Hess are shown in the following table:

Table 3.2-1
Brush Control Financial Returns
(Holechek and Hess, 1994)

RANGE TYPE	TYPE OF OPERATION	STATE	FORAGE PRODUCTION lbs/acre	FINANCIAL RETURNS $/acre
Southern pine forest	Cattle-cow	Louisiana	2500-4000	8-14
Coastal prairie	Cattle-cow	Texas	2500-3500	9-12
Coastal prairie	Wildlife/cattle	Texas	2500-3500	25 - (15 wildlife-10 cattle)
Southern mixed prairie	Cattle-cow	Texas	2000-3000	6-8
Southern mixed prairie	Cattle/wildlife	Texas	2000-3000	17 - (10 wildlife-7 cattle)
High plains-shinnery	Cattle-cow	New Mexico	800-1700	3-4
Oak-savannah	Sheep/goats	Texas	2000-3000	8-14
Oak-savannah	Wildlife/cattle	Texas	2000-3000	28 - (20 wildlife-8 cattle)
Shortgrass prairie	Cattle-cow	New Mexico	800-1400	4.50-5.50
Shortgrass prairie	Cattle-yearling	New Mexico	800-1400	4-10
Desert prairie	Cattle-sheep	New Mexico	500-900	2.50-3.50
Chihuahuan desert	Cattle-cow	New Mexico	300-700	.60-1.00
Pinyon juniper	Cattle-cow	New Mexico	100-500	.25-1.00

It should be noted that the examples in the table above indicate that when adding wildlife to the products to be marketed, the financial picture is significantly more favorable. The important aspect of such multipurpose use of the rangeland implies a very different approach to brush control such as the approach advocated by the Brush Sculpters program. When only a limited amount of brush is removed from the rangeland, the potential for the increased production of water is decreased or in some instances eliminated. There are a number of other land use options considered by today's rancher and landowner many of which would be in direct conflict with the goal of 90-95% brush removal for the purpose of increased water production.

Water management strategies were discussed in a report entitled "Water Management Strategies: Ranking the Options" (Kaiser, Lesikar, Shafer, and Gerston, 1999). The report presented results from a survey of 16 regional water planning groups concerning 20 water management strategies. The survey was sent to officials of the planning groups to determine their opinion on the feasibility and preference of the 20 management strategies. Brush management was one of the 20 water management strategies included in the survey. The report indicated that three of the sixteen SB1 planning regions believe that brush management is a preferred and feasible strategy in those regions. The three regions were F (Upper Colorado), K (Lower Colorado), and O (Llano Estacado). Region E (Far West) indicated a mid-range preference and high feasibility of brush management.

3.3 Financial Criteria Applied to Brush Control

The determination of financial feasibility for brush control cannot be generalized for the State of Texas or for vegetative regions within the State as described in Section 2 of this study. As noted in Section 3.2, a great deal of specific information about the watershed, the ranch and the value of the products is required before a determination of net present value or internal rate of return could be calculated for an investment in a large scale brush control program to increase forage production or to improve land condition. (Hanselka, Hamilton and Conner. 1996)

Holechek and Hess considered 13% return on investment necessary to justify brush control financially. This provides for the recovery of the investment over a 10 year period and adds 3% for illiquidity. In addition, some adjustment to the rate of return is necessary for the biological risk associated with the selected brush control practice. In an example, mesquite control using currently available herbicides would provide no more than 65% mortality on southwestern ranges. To adjust for the risk, 13% rate of return is divided by 0.65 resulting in a 20% rate of return to justify the investment.

In the report "North Concho River Watershed – brush control planning, assessment and feasibility study," section on Economic Analysis a significantly different approach was used with the purpose of dividing the cost of the brush control program between private benefits and State contributions. Revenues and partial variable costs were determined for a hypothetical 1000 acre ranch. It was noted that net revenues could not be calculated from the figures presented since not all revenues and variable costs were included. In the analysis, the net benefits to the ranchers would be determined by using the net present value for the type-density categories applied to the acreage by type on each enrolled ranch. To determine the State contribution, the study multiplied the per acre State cost share (the cost of the brush control by brush type-density category less the net benefit to the rancher) for each brush type-density category by the eligible acreage in each category on the ranch. An example taken from the table for the Southeastern Part – North Concho River shows for control of moderate mesquite the total cost is estimated at $20.42 per acre with the rancher cost share established at $8.35 per acre (38.15%) and the State cost share result set at $12.07 per acre (51.85%).

The North Concho study goes on to estimate the cost to the State for the additional water produced as a result of brush control in the watershed. The average cost of an acre foot of additional water as estimated by the use of the SWAT hydrologic model described in Section 4.3 and Section 4.4 of this report was $49.75. This price was compared with the cost of water from O. H. Ivie Reservoir currently set at $80 per acre foot. It is very important to note that for meaningful economic analysis to take place, accurate resource information and cost data must be obtained. Errors such as the over estimate of additional water production or actual landowner participation can distort results.

3.4 Decision Models for Brush Control

The use of a computer simulation model designed for research has become a popular practice. Unfortunately, very few field problems have ever been solved using a research computer simulation model. (Pierson, Spaeth and Neltz. 1996) It is not the models that present a problem, but the difficulty of accurately defining the problem and designing sound solutions for solving the problem. The use of the computer to operate a decision model based upon economic factors faces a problem similar to the research computer simulation model. If accurate field data reflecting a sound definition of the problem and a technically acceptable solution is not reflected in the economic input, it is not meaningful to produce a number representing the net present value or internal rate of return. (Thurow. 1996)

If brush control in a selected vegetative region can positively demonstrate that there is an increase in yield of groundwater and surface runoff, a determination must be made as to what cost should be borne by the landowner and what costs should be borne by others. While it is relatively easy to determine the costs and benefits of the landowner, the assignment of costs and benefits to others is extremely difficult. Questions of who the actual beneficiaries of additional water supplies will be must be determined, including a technical analysis of the practicality of actual delivery and beneficial use of the water supply increase. Issues of water rights, timely use and storage must be considered and resolved. Finally, after consideration has been given to the aforementioned questions, the resulting cost of additional water supply developed must be competitive with other competing sources of water.

The preparation of a decision support model for the assessment of brush control as a water management strategy was initially considered for inclusion in this study. Such a model would be a useful tool when analyzing the feasibility of brush control in selected watersheds as a part of the regional planning process established in Texas Senate Bill 1. While such a model would require a significant amount of work by multi-disciplinary, technically qualified personnel, the most critical aspect will be an accurate determination of the quantity of water made available in excess of the historically measured and recorded ground and surface water.

Literature search reveals that numerous publications report on the preparation of decision support models. (Yakowitz, Stone, Lane, Heilman, Masterson, Abolt and Imam. 1993) (Yakowitz, Stone, Imam, Heilman, Kramer and Hatfield, 1993) (Yakowitz, 1992) (Stone, Lane and Yakowitz. 1994) (Yakowitz. 1994) (Heilman, Yakowitz, Stone, Kramer, Lane and Imam. 1993) (Knisel and Foster. 1980) (Williams, Renard and Dyke. 1983) (Rebard. 1985) None of these references address the issue of brush control economics or water production directly, rather they address economics and other agricultural resources using computer modeling to determine the best management practices.

The economics and strategies of brush control in Texas has been addressed in a publication by the Texas Agricultural Extension Service titled "Integrated Brush Management Systems (IBMS):

strategies and Economics" by Hanselka, Hamilton and Conner in 1996. This report describes a step by step process for analyzing range improvements and suggests the use of a computer program called ECON to assist in the economic analysis. (Connor, Hamilton, Stuth and Riegal. 1990) Also suggested is the use of a decision model "EXSEL" that is an expert system for selecting brush and weed control methods that includes details on practice selection, specific herbicides and combinations, rates, mixing instructions, application techniques, timing and expected responses, and many other resource related factors. (Hamilton, Welch, Myrick, Lyons, Stuth and Connor. 1993) Water production to aquifers and surface runoff, in addition to historical water production, has not been included in the ECON or EXCEL software.

In a publication titled "Decision Support Software for Estimating the Economic Efficiency of Grazingland Production" by Kreuter, Rowas, Conner, Stuth and Hamilton published in the Journal of Range Management, September 1996, a decision support software program called "Grazingland Alternative Analysis Tool (GAAT) is described and illustrated. GAAT was designed to estimate the economic efficiency of grazing production systems including individually or in combination: livestock, wildlife, leased grazing, grain and forage crops, woods products and other non-forage crop. The user must supply information on the planning horizon, discount rate, available forage, consumption by class of animal, herd management practices, product yields, product and input prices, and improvement investments. As with other decision support models, the removal of brush species for the purpose of water production has not been included. GAAT could be modified and adapted for use in the analysis of water production, but would require a significant amount or work and technical input to identify and program water related factors before the model would be useful in the decision making process.

4 HYDROLOGIC MODELS USED TO PREDICT PRODUCTION OF GROUND AND SURFACE WATER

The following section discusses the various hydrologic modeling tools that have been utilized to evaluate the changes in runoff from watersheds in various brush control programs. Two models that have been utilized in Texas are the Simulation of Production and Utilization of Rangeland (SPUR) model and the Soil and Water Assessment Tool (SWAT) model. In addition, four Texas watershed studies, which evaluated the impact of brush control, with respect to the hydrologic characteristics of the watershed, are reviewed. These watersheds include North Concho River, Seco Creek, Throckmorton, and Cusenbary Draw.

4.1 SPUR Model (Simulation of Production and Utilization of Rangeland)

4.1.1 Introduction

The SPUR model was developed by the USDA Agricultural Research Service (ARS) in December 1987. SPUR is a comprehensive rangeland ecosystem model developed for research and management of rangeland systems (Wight and Skiles, 1987). The model includes two classifications: 1) a pasture or field-scale version that emphasizes the plant and animal processes and interactions, and 2) a basin-scale version that emphasizes the hydrology of small basins. Model components were developed using technology drawn from a variety of hydrologic and rangeland models such as ELM (Grassland Simulation Model), SWRRB (Simulator for Water Resources in Rural Basins), and CREAMS (A field scale Model for Chemicals, Runoff, and Erosion form Agricultural Management Systems – see Figure 4.2-1). No new field research was conducted as a basis for the development of SPUR. SPUR is a physically based model but includes some empirical functions. Data sets containing detailed information relative to total basins were not available at the time of completion of the model. Therefore, only a limited amount of validation has been possible and usually on a component basis (Wight and Skiles, 1987).

The SPUR model is composed of five basic components or sub-modules: climate, hydrology, plant, animal (both domestic and wildlife), and economics. The climate module operates outside the model and provides meteorological data such as rainfall, maximum and minimum air temperatures, solar radiation, and wind run data needed to drive SRUR. The hydrology module calculates upland surface runoff volumes, peak flow, snowmelt, daily soil water balance, upland sediment yield, and channel streamflow and sediment. The plant component predicts forage production based on net photosynthesis. The animal sub-module allows domestic livestock and wildlife to be consumers for the plant-animal interface. Forage consumption is calculated for all classes of animals. The economic package uses animal production or pounds of beef gain to estimate the benefits and costs of alternative grazing practices, range improvements, and animal management options (Wight and Skiles, 1987).

Two versions of SRUR were developed by Wight and Skiles (1987): field-scale and basin-scale. The field-scale version was developed to simulate animal and plant interactions on a pasture-or field-level. The field-scale version can simulate the growth of up to seven plant species in as many as nine range sites within a grazing unit. The basin-scale version is more complex than the field-version. The basin-scale version provides a means of predicting quantities of runoff and sediment yield for basins of up to 2,500 hectares with up to 27 hydrologic units, and it retains the ability to simulate plant growth, grazing, and beef production (Wight and Skiles, 1987). The basin-scale version was designed to simulate small basin watershed processes (Carlson and Thurow, 1992). However, the resolution of the basin-scale model components is diminished relative to the field-scale version. The basin-scale version uses the watershed as a management unit and is designed for the land manager (Wight and Skiles, 1987).

The hydrology component of SPUR was the focus of this review. The upland phases of the hydrology model draw heavily from SWRRB (Williams et al. 1985). The SWRRB model includes the major processes of surface runoff, percolation, return flow, evapotranspiration, pond and reservoir storage, and erosion and sedimentation. Surface runoff in the SPUR model is calculated using the Natural Resource Conservation Service NRCS curve number technique (USDA 1972).

4.1.2 Validation of SPUR

Extensive validation is the only way of verifying a model's predictive capability (D.H. Carlson, T.L. Thurow 1996). The SPUR model was not validated as a whole; however, individual sub-modules were validated by the ARS teams which developed them. Validations of each sub-module are documented in the SPUR Documentation and User's Guide. Validation of the model as a whole requires the use of extensive, long-term data sets with concurrent hydrology, plant, and animal data. The unavailability of large data sets with the detail and broad scope required to assess the accuracy of the predictive capabilities of SPUR limited validation (Carlson and Thurow, 1992).

Stout et al. (1990) indicated that only a limited validation of the plant-animal interface had been conducted. The authors concluded that the model was unable to adequately predict biomass production. SPUR was also evaluated using several extensive data sets from different sites across Texas (Carlson and Thurow, 1992). Several weaknesses were determined by analyzing the consistent deviations between values for predicted and observed plant biomass, species composition, and hydrology output variables. The initial evaluation revealed numerous source code errors and an inability of the model to simulate short-term runoff, growth responses of individual perennial species through time, shrub/tree growth dynamics, evapotranspiration and soil water content under very low cover conditions, and long-term stability of plant species composition where annuals and perennials co-occur (Carlson and Thurow, 1992).

Validation of the hydrology component of the SPUR model was documented in "SPUR – Simulation of Production and Utilization of Rangelands, Documentation and User Guide". The validation was attempted on a small watershed on Walnut Gulch follow. Walnut Gulch is an ephemeral tributary of the San Pedro River in southeastern Arizona. The watershed has a total drainage area of 108 acres and is an intermountain alluvial basin typical of mixed grass-brush. A return-flow travel time of 100 days was used to ensure that there was no baseflow included in the model. A 17-year simulation with the SPUR hydrology component was compared with actual data from the watershed for 1965-1981 (Wight and Skiles, 1987). Agreement between the predicted and observed runoff for the entire watershed area is shown in Figure 4.1-1. The agreement between the two values is relatively poor as evident by the regression statistics (Wight and Skiles, 1987). Cumulative predicted and observed runoff for the entire watershed with a curve number of 86 and 87 is shown in Figures 4.1-2 and 4.1-3, respectively. The runoff predicted by SPUR is driven by the curve number (CN), as illustrated in Figures 2 and 3. The cumulative predicted runoff is closer to observed with the CN of 86, there was a substantial difference when the CN increases to 87. Results from the model will depend greatly on the selection of the CN. D.H. Carlson and T.L. Thurow (1996) indicated that one "specific area of substantial error in the hydrology portion of SPUR was consistent underprediction of evapotranspiration and overprediction of deep drainage on sites with low vegetation cover".

Evaluation of the SPUR model conducted by Texas A&M University verified the initial conclusion developed by the ARS modelers: the hydrology–plant interface was inadequate (MacNeil et al., 1987). Carlson and Thurow (1996) also wrote, "the analysis of SPUR revealed that the hydrology input parameters had little influence over plant outputs and vice versa", again indicating the problems associated with the link between the hydrology and plant sub-modules in SPUR.

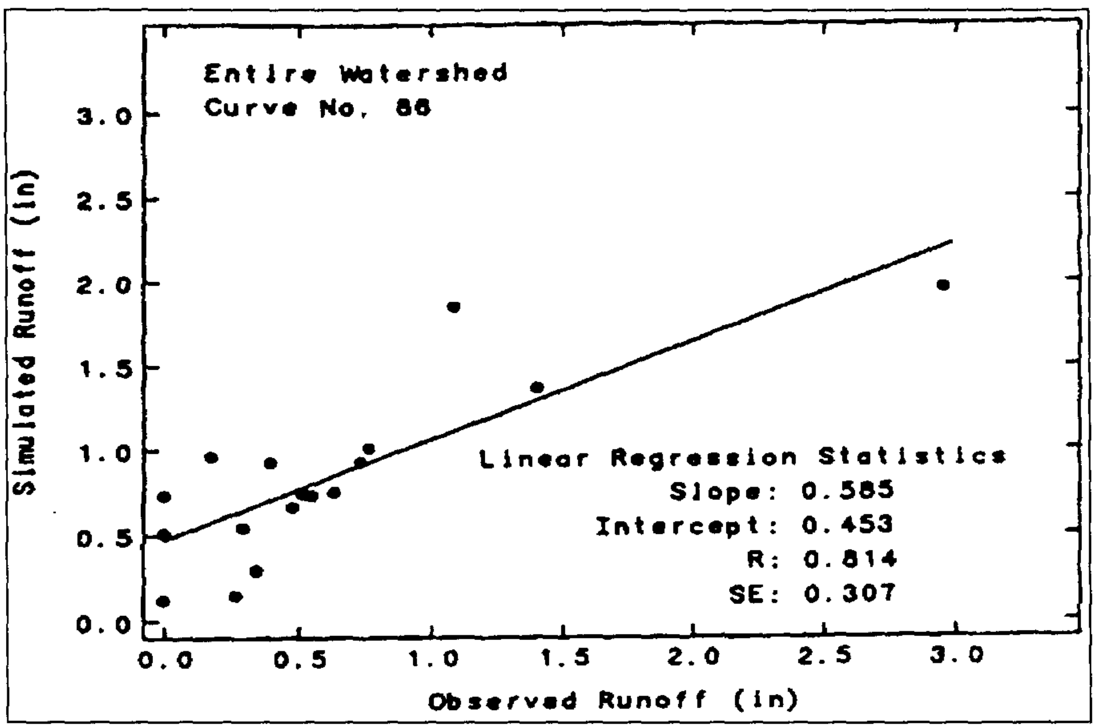

Figure 4.1-1
Comparison of predicted and observed runoff values for entire watershed
(Wight and Skiles, 1987)

When SPUR was released the predictive capabilities and documentation was inadequate for wide-spread practical use (Carlson and Thurow 1992). Problems discovered in the evaluation of the model, as well as limited validation prompted the upgrade of SPUR performed by cooperation between the USDA-SCS and Texas A&M University. The upgrade of SPUR resulted in a new model called SRUP-91. The model upgrade and subsequent validation is described in the next section.

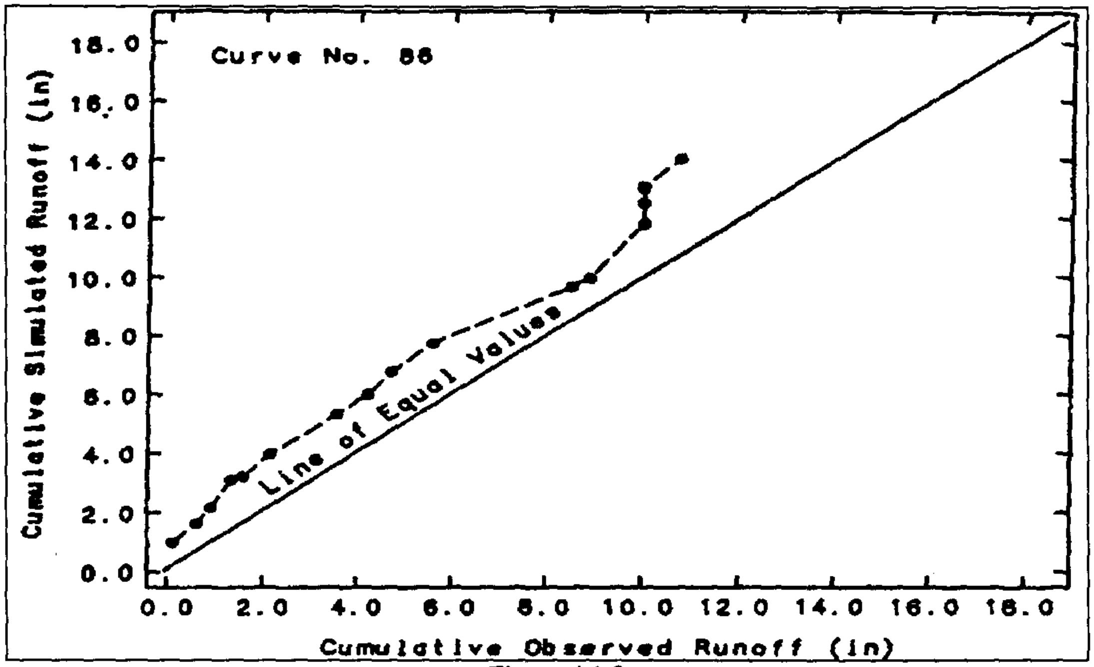

Figure 4.1-2
Comparison of cumulative predicted and observed runoff values for entire watershed using a curve number of 86
(Wight and Skiles, 1987)

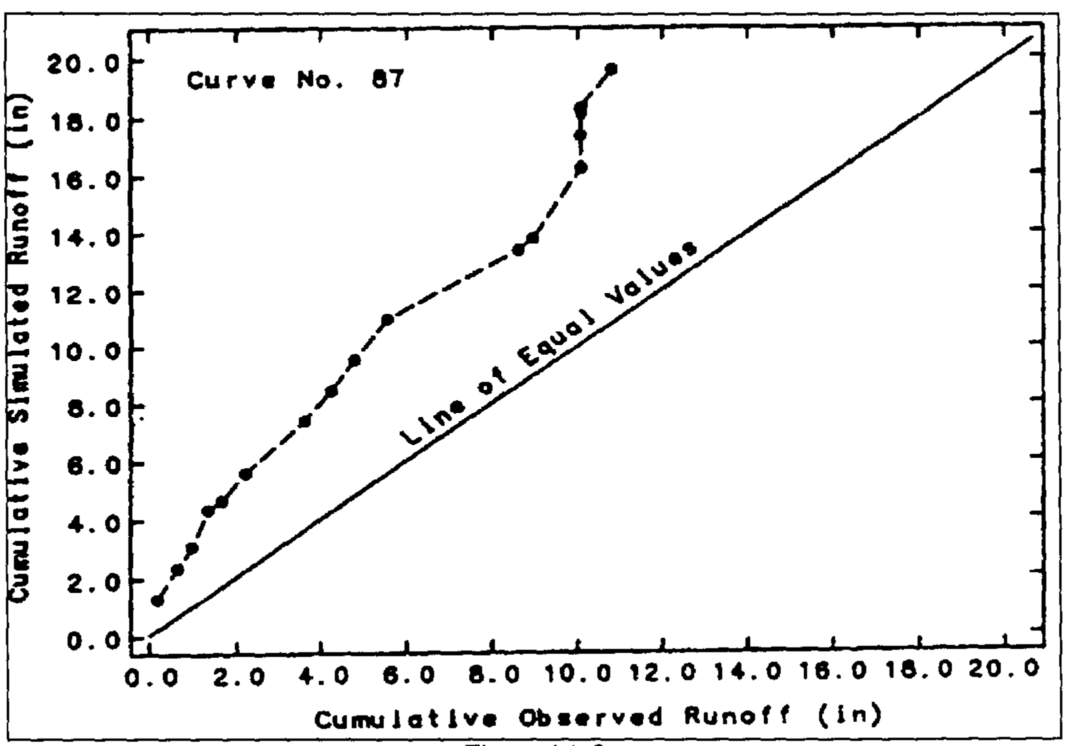

Figure 4.1–3:
Comparison of cumulative predicted and observed runoff values for entire watershed using a curve number of 87
(Wight and Skiles, 1987)

4.2 SPUR-91 Model (Simulation of Production and Utilization of Rangeland)

4.2.1 Introduction

SPUR-91 began with an effort to correct various problems encountered in the evaluation of SPUR. A flowchart for the hydrology module of SPUR-91 is shown in Figure 4.2-1. Many improvements were made to the SPUR model; however, for this review, these changes will only be listed. Major improvements, as described in "Comprehensive evaluation of the improved SPUR model (SPUR-91)", include the following:

1. soil moisture conditions were initialized by soil layer rather than for a soil profile as a whole;
2. alteration of subroutine to permit more than one soil layer below the root zone in the field-scale model;
3. incorporation of option to over-ride subroutine that reduced late-season photosynthesis according to age;
4. coding error corrections for "critical" plant parameters;
5. addition of new plant parameter to partition rooting depth of individual species;
6. creation of controlling variable (mean soil water potential rather than soil water potential of wettest layer) for root mortality and shoot death;
7. evaporation parameter for soil and evaporation depth tied to amount of standing cover,
8. upland sediment production algorithms added to field-version.
9. improvements to increase the flexibility of the plant growth model and to improve intercommunication between the hydrology and plant components (Carlson and Thurow 1996).

Additional changes can be found in (Carlson and Thurow, 1992).

4.2.2 Validation of SPUR-91

The SPUR-91 model evolved from the above improvements/changes to SPUR and associated validation process. Validation of SPUR-91 began with a 5-year data set of hydrology, vegetation, and livestock parameters collected on the Rolling Plains rangelands of North Texas near Throckmorton. Weaknesses of the model determined during this validation period were corrected and validated using a 6-year watershed/plant/livestock data set from West-Central Texas near Sonora. Again, weaknesses of the model were determined and revised. The revised model was then validated using a 2-year soil/water/plant data set from South Texas near Alice. Again, the model was revised and validated using a 2-year data set from the Rolling Plains near Vernon. Personnel of the USDA-SCS then tested all the above data sets again using SPUR-91 and indicated that the results were "very good".

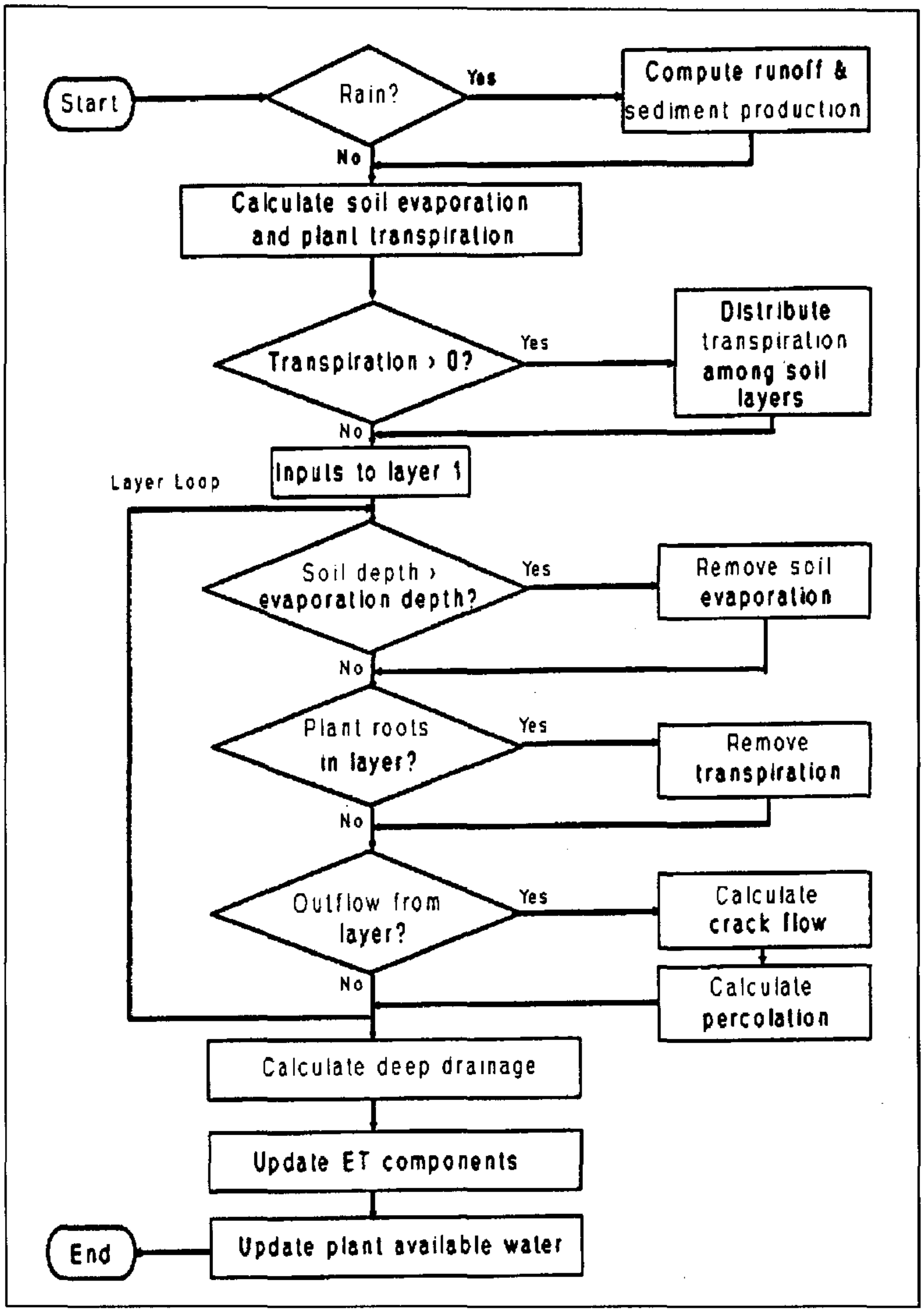

Figure 4.2–1
Flowchart for the upland hydrology submodel of SPUR-91.
(Carlson and Thurow, 1992)

The validation work described above concentrated on the field-scale version of SPUR-91. From a hydrology standpoint the basin-scale version of SPUR-91 has more emphasis on the hydrology of the watershed (See Table 4.2-1). Carlson and Thurow (1996) write that "predicted monthly runoff did not adequately reflect observed monthly runoff (R = 0.37 to 0.58) for any cover type", an inherent problem of the curve number technique (USDA, 1972) used. The authors state that the model closely predicted the proportion of runoff in the total water budget for all cover types for a four-year period from 1986 to 1989, (Table 4.2-2). Analysis of Table 4.2-2 illustrates that individual runoff categories in the three cases (bareground, herbaceous, herbaceous + mesquite) indicated a difference in runoff of 30%, 56%, and 8%, respectively, between the observed 4-year water balance and the SPUR-91 output (Carlson and Thurow, 1996). Based strictly on a hydrology standpoint, the SPUR-91 model did not predict monthly or yearly runoff numbers accurately. SPUR-91 is an upland hydrology program and although it has some routing capabilities, it generally does not predict streamflow accurately (Per. Comm. Carlson, 1999).

Carlson and Thurow (1996) indicate that the modifications incorporated into SPUR-91 have improved the intercommunication between the hydrology and plant interface. However, they also realize that "SPUR-91 appears to have the potential for aiding in the assessment of various management practices on rangelands; however, currently the model is more reliable when used to predict general trends of management responses rather that absolute values". The authors also verify that "a modified version of the model which replaces the curve number technique with an infiltration-based model would have the potential to strengthen the hydrology-plant interface in SPUR-91".

Additional improvements to SPUR-91 are currently underway at ARS. SPUR 2000 (field-scale version) is an upland hydrology model with a smaller scale of resolution than other models such as SWAT. SPUR 2000 addresses run-in/runoff issues over the landscape and soil detachment that occurs along the landscape. The model treats each "subwatershed" as hydrologically independent. The "landscape" version of SPUR 2000 utilizes WEPP (ARS-Water Erosion Prediction Project) basin-scale model, which is another routing model similar to SWAT. Both models were, in general, developed by the same key individuals and are derived from SWRRB, and CREAMS. A flowchart for the development of SPUR and SWAT is shown in Figure 4.3-2. SPUR 2000 now has the ability to predict hydrology components such as runoff without relying on the curve number method. Dr. Carlson states (Per. Comm.) that "SPUR 2000 has the ability to give more realistic estimates of rangeland responses to management, such as brush control, at the subwatershed scale." SPUR 2000 is currently undergoing testing and validation and could be ready for use next year.

Table 4.2–1
SPUR-91: field scale vs. basin scale
(Carlson and Thurow, 1992)

Field-Scale Version			Basin-Scale Version	
		4.2.2.1.1 Emphasis		
Plant-animal processes and interactions.			Hydrology of small watersheds.	
		4.2.2.1.2 Intended Use		
Simulate effects of field management.			Simulate effects of landscape management.	
		4.2.2.1.3 Scope		
1	field		27	fields
9	sites		0	sites
8	soil layer per site		8	soil layer per site
7	plant species		7	plant species
1	steer variety		1	steer variety
10	wildlife species		10	wildlife species
			9	channel
			1	pond
		4.2.2.1.4 Input Required		
Minimum	Maximum		Minimum	Maximum
48	491	<< HYDROLOGY >>	81	2154
54	556	<< PLANT >>	54	1132
24	436	<< ANIMAL >>	24	562
8	8	<< ECONOMICS >>	8	8

Table 4.2–2
Simulated and observed runoff values
(Carlson and Thurow, 1995)

Simulated and observed 4-year water balance in mm (and as a percent of precipitation received) for bareground, herbaceous, and herbaceous + mesquite cover types for three replicates of each treatment.

	Observed		**SPUR-91**	
Precipitation	2682		2658	
Bareground				
Runoff	665a	(24.8)	467b	(17.6)
Evapotranspiration	2057a	(76.7)	2066a	(77.7)
Deep percolation	36a	(1.3)	112b	(4.5)
Herbaceous				
Runoff	44a	(1.6)	101b	(3.8)
Evapotranspiration	2710a	(101.0)	2539b	(95.5)
Deep percolation	27a	(1.0)	21a	(0.8)
Herbaceous + mesquite				
Runoff	182a	(6.8)	168b	(6.3)
Evapotranspiration	2550a	(95.1)	2544a	(95.7)
Deep percolation	17a	(0.6)	0b	(0.0)

*Means in a row followed by the same letter are not significantly different ($P > 0.05$).

4.3 SWAT Model (Soil and Water Assessment Tool)

4.3.1 Introduction

The following discussion of SWAT is based on review of the literature and information on the SWAT website, supported by the U.S. Department of Agriculture, (USDA) Agricultural Research Service (ARS) at the Grassland, Soil and Water Research Laboratory in Temple, TX. A flowchart for the SWAT model is presented in Figure 4.3-1. The SWAT model was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The SWAT model consists of the following characteristics:

- is physically based.
- uses readily available inputs
- is computationally efficient
- enables users to study long-term impacts

SWAT encompasses aspects of various ARS models and is a direct descend of the SWRRB model (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990). Specific models that contributed significantly to the development of SWAT were CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems)

(Leonard et al., 1987), and EPIC (Erosion-Productivity Impact Calculator) (Williams et al., 1984).

The Simulator of Water Resources in Rural Basins (SWRRB) was developed in the early 1980's (Figure 4.3-2) for application to runoff and sedimentation loadings from rural watershed (Williams and Arnold, 1993). The model has been extensively documented (e.g., Arnold et al., 1990, Arnold et al., 1995) and widely applied (e.g., McIntosh et al., 1993, Srinivasan and Arnold, 1994). In its original form, SWRRB was designed for application to a small watershed. SWAT, developed from the application ROTO (Routing Outputs to the Outlet) – to SWRRB. SWRRB is a "continuous" simulation model, designed to perform long-term simulations in order to determine statistics of runoff and loadings. Thus it includes storm events as well as the intervening nonstorm conditions in the watershed of plant growth, evapotranspiration, and desiccation. The timestep is 1 day. The basis model components (Arnold and Williams, 1995) and (Ward and Benaman, 1999) are summarized in Table 4.3-1. Ward and Benaman (1999) are evaluating the application of SWAT for TMDL (Total Maximum Daily Loading) application in Texas watercourses for the Texas Natural Resource Conservation Commission. Input hydrological data for each subbasin includes area (as proportion of basin), the average interior main channel width, slope, length, Meaning's n, and effective hydraulic conductivity (for transmission loss), runoff curve number, and fraction of each subbasin that flows into ponds or reservoirs, with specific volume and spillway data for each. Data on soils for each subbasin are also required, including number of layers, erosion factor, depth, density, water capacity, conductivity, clay content, maximum rooting depth, and particle size distribution. Most of the soil data for SWRRBWQ can be taken from the Soil Conservation Service (SCS) Soils-5 database. To specify crops and agricultural practices requires vegetation types, tillage operations, number of crops in rotation, planting and harvesting dates, curve numbers biomass conversion factor, water stress yield factor harvest index, and if irrigation is an option, the date and the amount of irrigation, or the water stress and irrigation runoff ratio. The plant growth submodel follows the same philosophy as EPIC, but with considerable simplification, especially in the input data required. The pesticide chemistry is the same as used in GLEAMS.

SWAT was developed to apply to "ungaged rural basins" (Williams and Arnold, 1993). It is applicable to a range of catchments and evidences good comparison to data (e.g., Arnold and Allen, 1996, Bingner et al., 1997).

Table 4.3-1: SWAT Model Components
(Arnold and Williams, 1995) and (Ward and Benaman, 1999)

WEATHER	
Precipitation	User option of input of measured daily values or simulation based upon monthly probability distributions
Air Temperature	User option of input of measured daily values or simulation based upon monthly probability distributions
Solar Radiation	Based upon statistics of radiation and correlation with precipitation and temperature
HYDROLOGY	
Surface Runoff	Determined by SCS Curve Number method
Irrigation	Specified by a water-stress trigger and required input of ratio of volume assumed to run off the field
Percolation	Based upon a soil-layer water budget, vertical transport of water governed by hydraulic conductivity, field capacity and water in storage in each layer
Lateral Flow	Downslope movement of water in soil layer
Transmission Losses	Applied to channel routing, based upon effective hydraulic conductivity of channel sediments
Potential Evaporation	Based upon air temperature and radiative budget, using user's choice of Preistly-Taylor or Hargreaves-Samani formulae (see Arnold and Williams, 1995)
Soil Water Evaporation	Computed from soil water content profile, and value of potential evaporation
Pond and Reservoir Storage	A rudimentary water budget on a simple reservoir of fixed volume, to include cumulative effect of farm ponds or Section 566 reservoirs on water yield from a subbasin
SEDIMENTATION	
Sediment Yield	Determined from Universal Soil Loss Equation (USLE), whose parameters must be specified for each subbasin
Channel Sedimentation	A gross sediment budget for the channel length with deposition based on Stokes settling and erosion based upon an adaptation of Bagnolds' power theory (see Williams, 1980)
CROP GROWTH	
Soil Temperature	Function of soil layer depth, computed from air temperature, thermal conductivity governed by soil density and water content, and lagging factor for thermal inertia
Leaf Area Index	Computed from accumulated heat and plant biomass, and species-specific parameters
Potential Growth	Estimated from incoming radiation and leaf area index
Actual Plant Growth	Based upon potential growth reduced by a factor determined ;by water and/or temperature stress for given species
NUTRIENTS	
Crop Uptake of N & P	Based on optimal (species-dependent) N & P concentration and fraction of total growth expressed in terms of heat accumulation
Leaching	Computed transport of N and soluble P out of soil layer by percolation and lateral flow
Runoff	Loss of nitrate and soluble P from uppermost soil layer based on concentration and runoff flow
Sediment Loss of P	Computed from partitioning coefficient, concentration of P in top soil layer and sediment yield
PESTICIDES	
Interception by Plants	Based upon loading rate and plant leaf area index
Delivered to Ground	Surplus of pesticide application after loss to atmosphere and interception by plants
Pesticide Decay	First-order loss based upon input of half-live for plant and soil
Leaching	Cascade calculation from top layer down, based on percolation and initial pesticide concentrations in each layer
Yield	Computing from partitioning coefficient, sediment concentration and runoff and lateral flow volumes

Bingner et al. (1989) carried out a comparison of SWRRB, EPIC, CREAMS, ANSWERS and AGNPS using data from Mississippi research watersheds. They found SWRRB and CREAMS to produce results "close to" measured values more than the other models, and noted that SWRRB requires simpler inputs than CREAMS. McIntosh et al., (1993) employed SWRRB-WQ as well as EPIC and AGNPS to comparatively evaluate the effect of tillage and nutrient-management strategies on runoff. Srinivasan and Arnold (1994) described integration of SWAT into a GIS system for model output visualization, and reporting on the application to a 114 sq. km. watershed in the Seco Creek Basin. Srinivasan and Arnold, (1994) reports that the predicted average monthly streamflow to be in good agreement with measured values. Bingner et al. (1997) made a study of subwatershed size dependency of SWAT, finding that runoff volume is not appreciably effected by the number and size of subwatersheds, but there is a definite "upper" limit to subwatershed size, required to adequately simulate fine sediment yield produced from upland sources.

SWAT is documented by detailed users manuals (Arnold et al., 1996; Srinivasan et al., 1996). The software, manuals, and additional information are available through the SWAT internet site maintained by the TAES/ARS Research Center in Temple (http://brcsun0.tamu.edu/swat/index.html). SWAT computes sequences of daily streamflows to result from specified precipitation input by simulating the hydrologic processes that occur in the watershed and subsurface. A detailed daily water balance accounts for subsurface/surface water interactions as well as surface runoff. SWAT is a comprehensive hydrologic and water quality simulation model. However, the level of sophistication and effort required can be controlled to significant degree by the optional features selected by the model user. SWAT includes extensive optional water quality modeling capabilities. SWAT interacts with GIS databases that facilitate estimation of values for the model parameters. A modification of the NRCS curve number method is incorporated in SWAT for determining the runoff volume that results from a given precipitation amount. The curve number is allowed to vary during a simulation with changes in soil moisture. The percolation components of the model uses a storage routing technique to predict flow through specified soil layers in the root zone. The downward flow rate is governed by the hydraulic conductivity of the soil. Upward flow may occur when a lower layer exceeds field capacity. Lateral flow in each soil slope, and soil water content. Several optional methods are provided for computing evapotranspiration. Evaporation from soils and plants are treated separately. Stream channel losses are determined as a function of channel length and width and flow duration. The groundwater flow contribution to streamflow may be simulated by creating shallow aquifer storage. The aquifer is recharged by percolation from the soil layers in the root zone. A recession constant may be used to lag flow from the aquifer to the system. Other flow components reflected in the aquifer storage computations include evaporation, pumping withdrawals, and seepage to a deep aquifer. The weather variables driving SWAT are precipitation, air temperature, solar radiation, wind speed, and relative humidity. If available, daily precipitation and maximum/minimum temperature data can be input directly to SWAT. If not, the simulator within the model can synthesize daily rainfall and temperature. Solar radiation, wind speed, and relative humidity are always simulated within the model. One set of weather variables may be simulated for the entire basin, or different weather may be simulated for each subbasin.

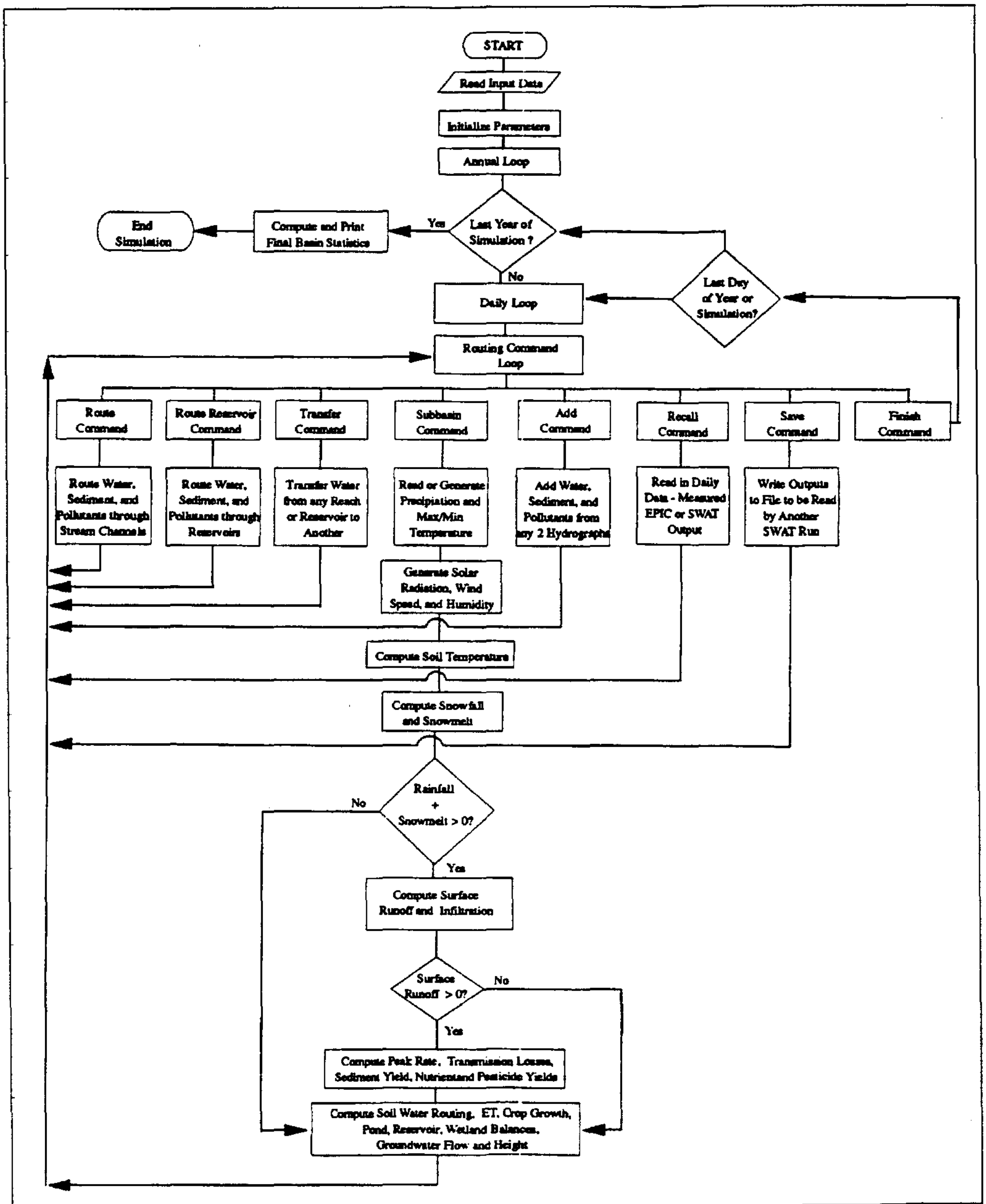

Figure 4.3–1
Hydrologic flow chart of SWAT subbasin model.
(Arnold, et. al., 1998)

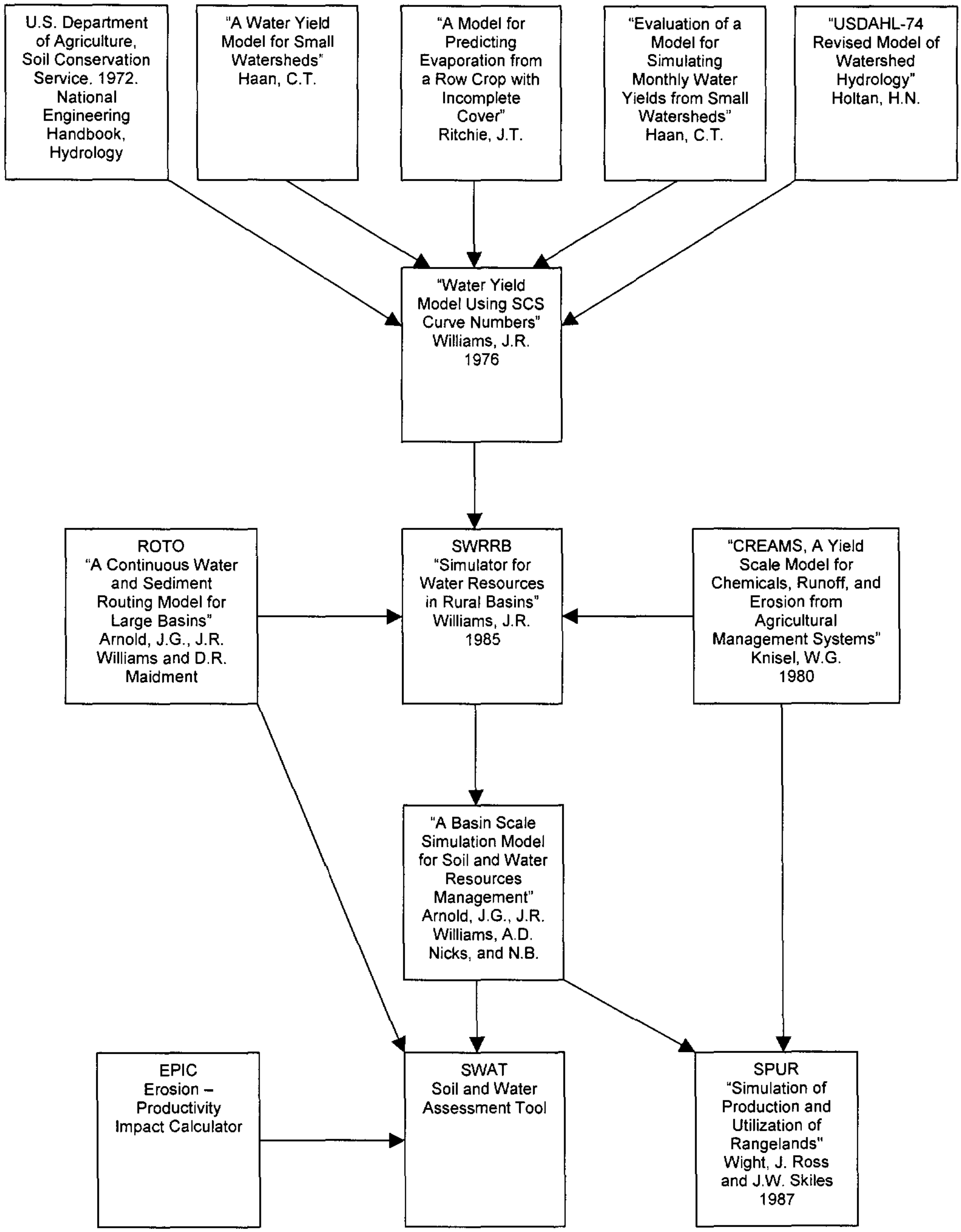

Figure 4.3–2
Model development

4.3.2 SWAT Model Validation

Summarized in Table 4.3-2 are SWAT model validation studies compiled by Arnold, Srinivasan, Muttiah and Allen (1999). The early development of SWAT was based on Simulator for Water Resources in Rural Basins (SWRRB) by Williams et. al. (1985). SWRRB model results were compared to measured date for Chickasha, Oklahoma and Riesel, Texas (Table 4.3-3, 4.3-4). Rosenthal, et. al., (1995) used SWAT in the Lower Colorado River Basin. Streamflow was simulated from 1980 to 1989 for four streamgage locations on the lower Colorado River. Shown in Figure 4.3-4 is a plot of observed and simulated streamflow. Without the two extreme flow events at the Bay City gage, correlation coefficient (R^2 = 0.66). In 1996, Arnold and Allen, evaluated three Illinois watersheds using SWAT. The three Illinois watersheds consisted of Hadley Creek (17.12 km^2), Goose Creek (20.2 km^2), and Panther Creek (27.84 km^2). Results are presented for Hadley Creek for the period of record from 1954 to 1996 (Figure 4.3-5 and 4.3-6). Summarized in Table 4.3-4 is comparison of hydrologic budgets for each of the three Illinois basins. Arnold, Williams, and Maidment (1996) evaluated three watersheds in Texas utilizing the SWAT model. The three watersheds were White Rock (257 km^2), Riesel (17.7 km^2), and the Colorado River (8,927 km^2). Runoff predictions for the White Rock watershed in the lower Colorado River and associated statistical characteristics are summarized in Tables 4.3-6 and 4.3-7. Bingner, et. al, (1996), evaluated a watershed in northern Mississippi, Goodwin Creek Watershed (21.3 km^2) in terms of runoff and sediment using the SWAT Model (Figure 4.3-7). Results were similar to Bingner (1996) with regard to runoff. Total annual runoff trends corresponding closely to the observed trends. However, comparison of annual values indicated comparison of +30%-40%. Srinivasan, et. al, (1998) applied SWAT to two gauged watersheds in the Richland-Chambers Basin, located on the Upper Trinity Basin. Presented in Figure 4.3-8 for the calibration period 1965 to 1969 is the simulated and observed flows at the two gages. Figure 4.3-9 shows the same comparison for each gage for the validation period 1970 through 1984. Statistical comparison of the calibration and validation period for each station is summarized in terms of statistical results in Table 4.3-8.

Table 4.3–2
Model Validation Studies
(Arnold, Srinivasan, Mettiah and Allen, 1999)

Location	Reference	Drainage Area (km^2)	Water Yield/ Streamflow	Soil Water	Surface Runoff	Base Flow	Soil ET	GW ET	GW Recharge	Plant Biomass
Middle Bosque River, Texas	Arnold *et al.* (1993)	471	■		■	■			■	
Coshocton, Ohio	Arnold and Williams (1985)	Lysimeter					■			
Bushland, Texas	Arnold and Williams (1985)	Field plot					■			■
Riesel, Texas Sonora, Texas	Savabi *et al.* (1989) Savabi *et al.* (1989)	1.3 4.1	■	■			■			
Seco Creek, Texas	Srinivasan and Arnold (1994)	114	■							
Neches River Basin, Texas	King *et al.* (1999)	25,032	■							
Colorado River Basin, Texas	King *et al.* (1999)	40,407	■							
Lower Colorado, Texas	Rosenthal *et al.* (1999)	8,927	■							
White Rock Lake, Texas	Arnold and Williams (1987)	257	■							
North Carolina	Jacobson *et al.* (1995)	4.6	■		■					
Goose Creek, Illinois	Arnold and Allen (1996)	246	■	■	■	■	■	■	■	
Hadley Creek, Illinois	Arnold and Allen (1996)	122	■	■	■	■	■	■	■	
Panther Creek, Illinois	Arnold and Allen (1996)	188	■	■	■	■	■	■	■	
Goodwin Creek Watershed, Mississippi	Binger *et al.* (1996)	21.3	■							
Watersheds in: Oklahoma, Ohio, Georgia, Idaho, Mississippi, Vermont, Arizona	Arnold and Williams (1987)	9.0-538	■							
Bushland, Texas Logan, Utah Temple, Texas	Arnold and Stockle (1991)	Field plot								■
Richland and* Chambers Creek, Trinity River Basin, Texas	Srinivasan, Ramanarayanan, Arnold, and Bednarz	282	■		■					
Riesel, Texas*	Arnold, *et.al.* (1995)	17.7	■		■					
Lower Colorado* River	Arnold, *et.al.* (1995)	8,927	■		■					
White Rock*	Arnold, *et.al.* (1995)	257	■		■					

* Added

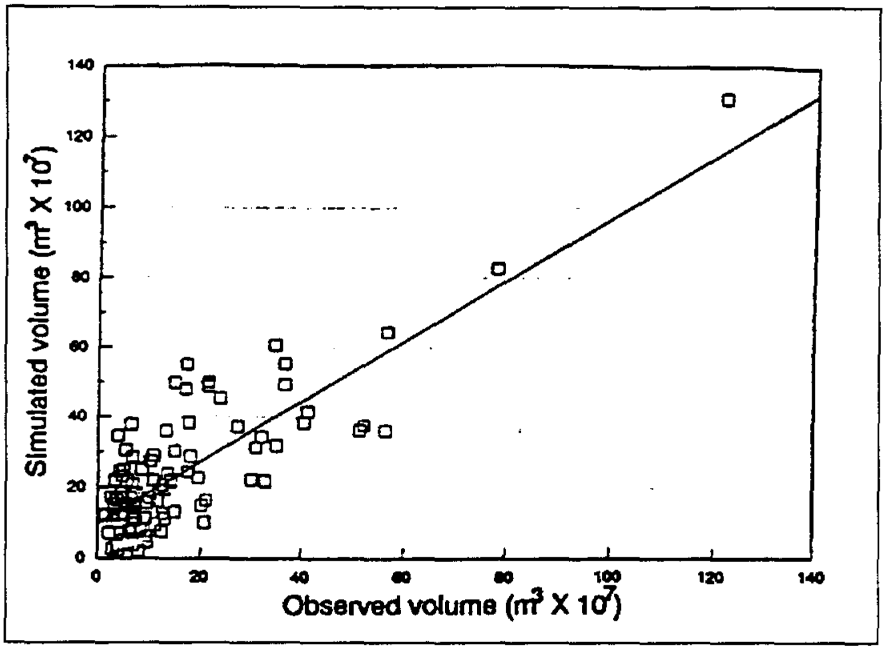

Figure 4.3-3
Observed and simulated monthly streamflows at Bay City from 1980 to 1989
(Rosenthal, Srinivasan, and Arnold - August 1995)

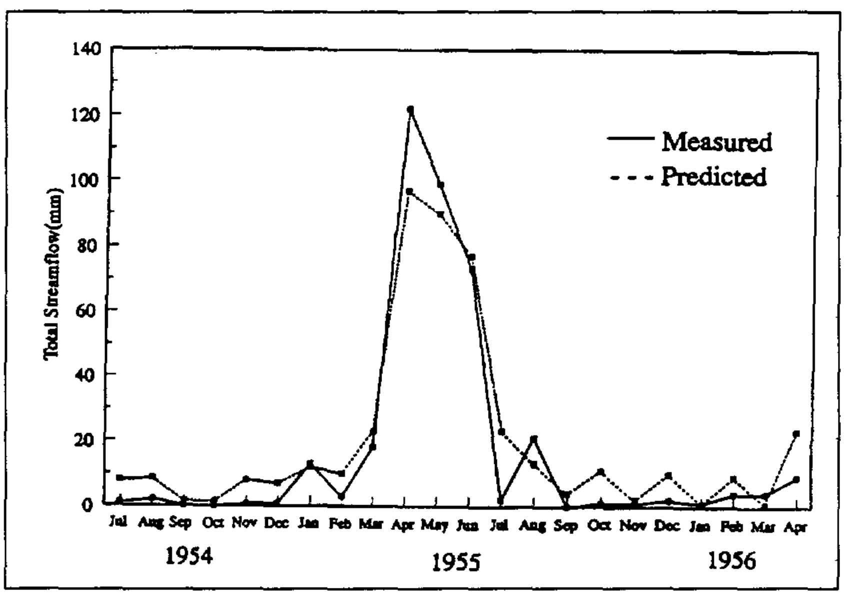

Figure 4.3-4
Measured and predicted total flow by month for Hadley Creek
(Arnold and Allen, 1996)

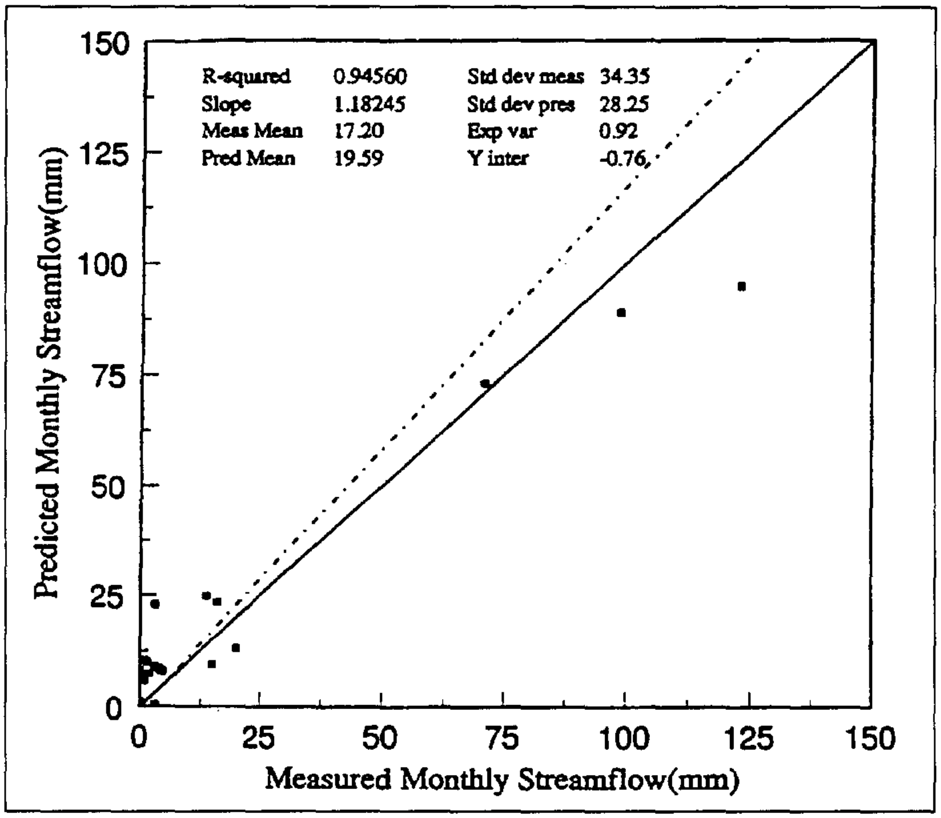

Figure 4.3-5
Measured vs. predicted monthly total streamflow for Hadley Creek
(Arnold and Allen, 1996)

Table 4.3–5
Comparison of hydrologic budgets for the Illinois basins
(Arnold and Allen, 1996)

	Measured (mm)	Predicted (mm)
Goose Creek, 1957		
Precipitation	944.4	
Stream flow	240.8	253.5
Surface runoff	1443.	145.1
Groundwater flow	96.5	121.2
Evapotranspiration	617.2	603.0
Surface and soil ET	535.9	521.6
Groundwater ET	81.3	81.4
Groundwater recharge	264.2	210.0
Change in groundwater storage	+86.4	+85.0
Underflow	Neg.	Not simulated
Hadley Creek, 1957		
Precipitation	1009.1	
Stream flow	353.8	366.4
Surface runoff	305.8	300.5
Groundwater flow	48.0	65.9
Evapotranspiration	626.9	634.6
Surface and soil ET	604.5	612.9
Groundwater ET	22.4	21.7
Groundwater recharge	98.8	88.8
Change in groundwater storage	+26.7	+38.9
Underflow	1.8	Not simulated
Panther Creek, 1952		
Precipitation	822.4	
Stream flow	249.4	239.0
Surface runoff	67.6	85.6
Groundwater flow	181.9	153.4
Evapotranspiration	608.1	594.9
Surface and soil ET	557.0	556.1
Groundwater ET	51.1	38.8
Groundwater recharge	204.0	191.1
Change in groundwater storage	-28.9	-9.7
Underflow	Neg.	Not simulated

Table 4.3-6
Comparison of measured and predicted streamflow in White Rock Lake watershed from 1964-1972
(Arnold et. al. 1995)

Stream gauge	08057100 measured (mm)	Predicted (mm)	08057200 measured (mm)	Predicted (mm)
Annual rainfall	1054	-	1033	-
Annual runoff				
Mean	226	245	313	345
Standard deviation	119	126	124	117
Monthly runoff				
Standard deviation	44	39	49	48
R^2	-	0.89	-	0.90
Slope	-	1.04	-	0.96
Nash-Sutcliffe	-	0.88	-	0.89

Table 4.3-7
Comparison of measured and predicted streamflow at Bay City, Texas, in Lower Colorado River Basin
(Arnold et. al. 1995)

Stream gauge	Annual measured	Predicted	Monthly measured	Predicted
Mean flow ($m^3s^{-1}d$)	726.4	693.8	60.5	57.8
Standard deviation ($m^3s^{-1}d$)	542.0	317.9	97.6	74.3
R^2	-	0.72	-	0.60
Slope	-	1.44	-	1.01
Nash-Sutcliffe	-	0.65	-	0.60

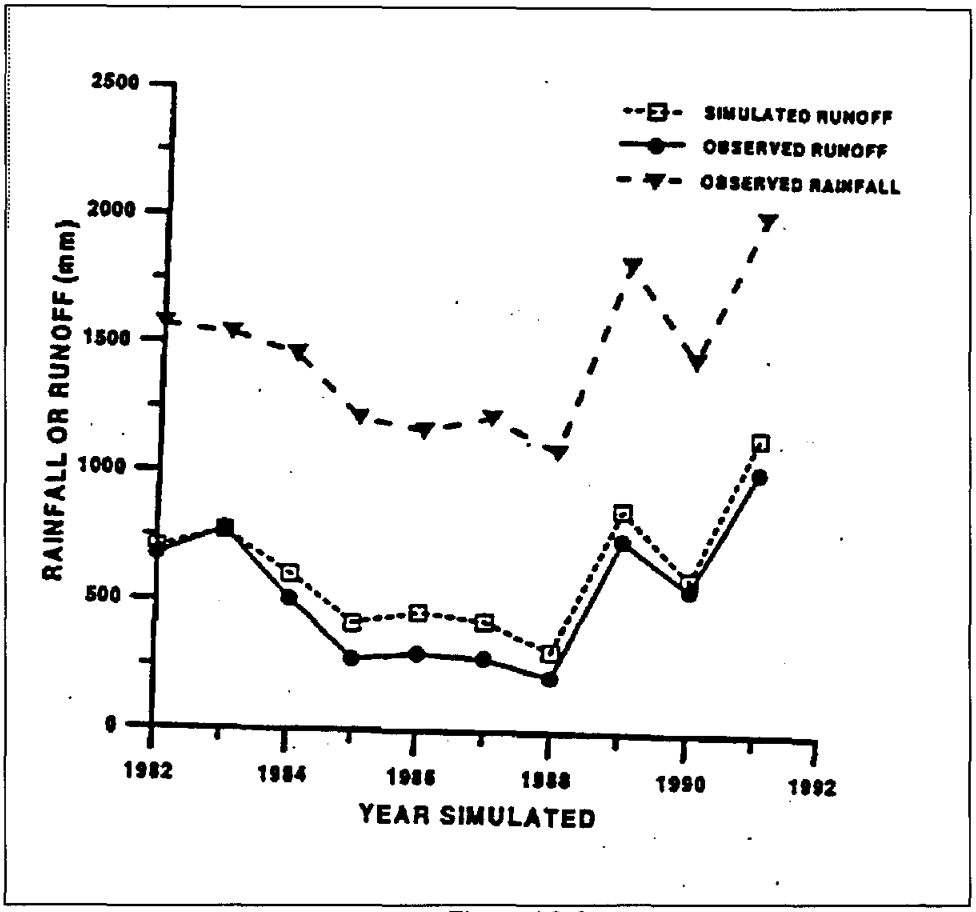

Figure 4.3-6
Simulated annual runoff volume (Case 1) and observed annual rainfall and runoff from Goodwin Creek, Mississippi
(Bingner, Garbrecht, Arnold, and Srinivasan, 1996)

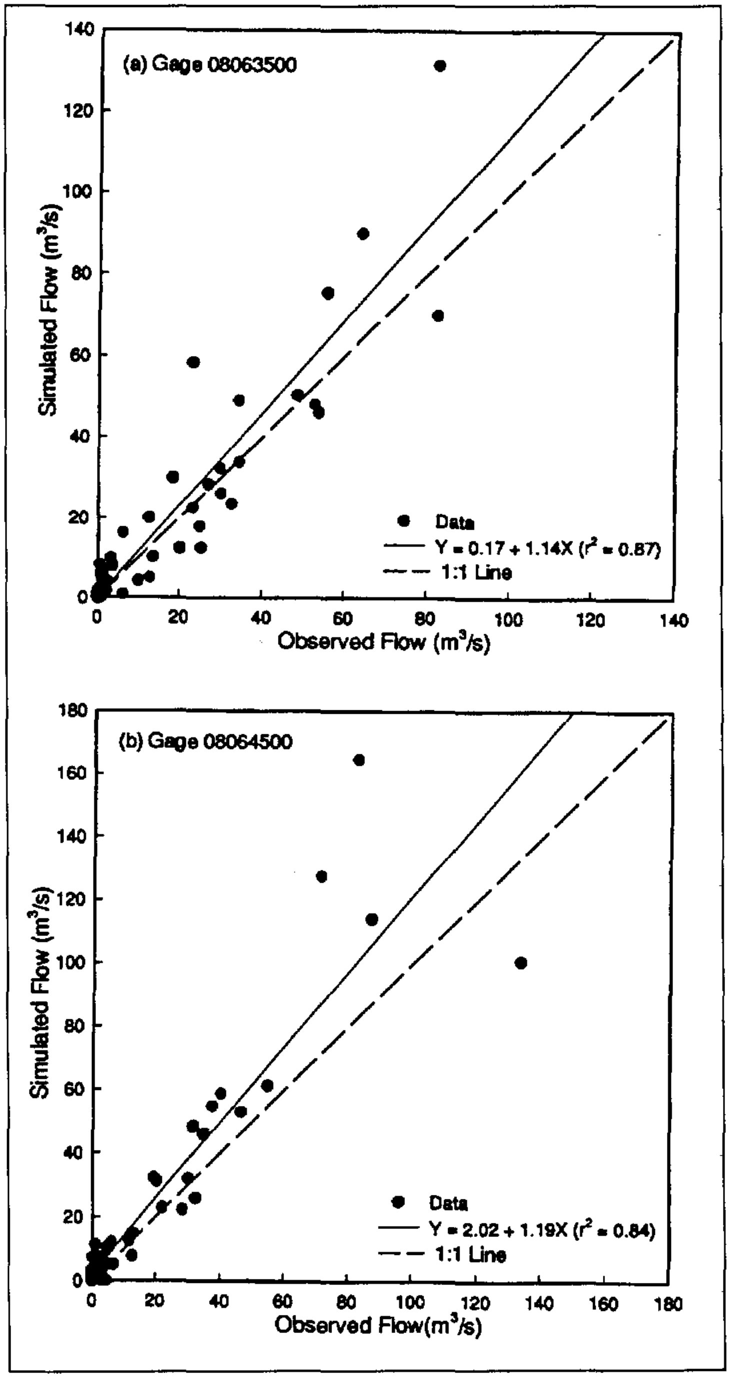

Figure 4.3-7
Scattergram of observed and simulated monthly streamflow data during the calibration period (1965-1969) :
(a) Gage 08063500 and (b) Gage 08064500
(Srinivasan, *et.al.*, 1998)

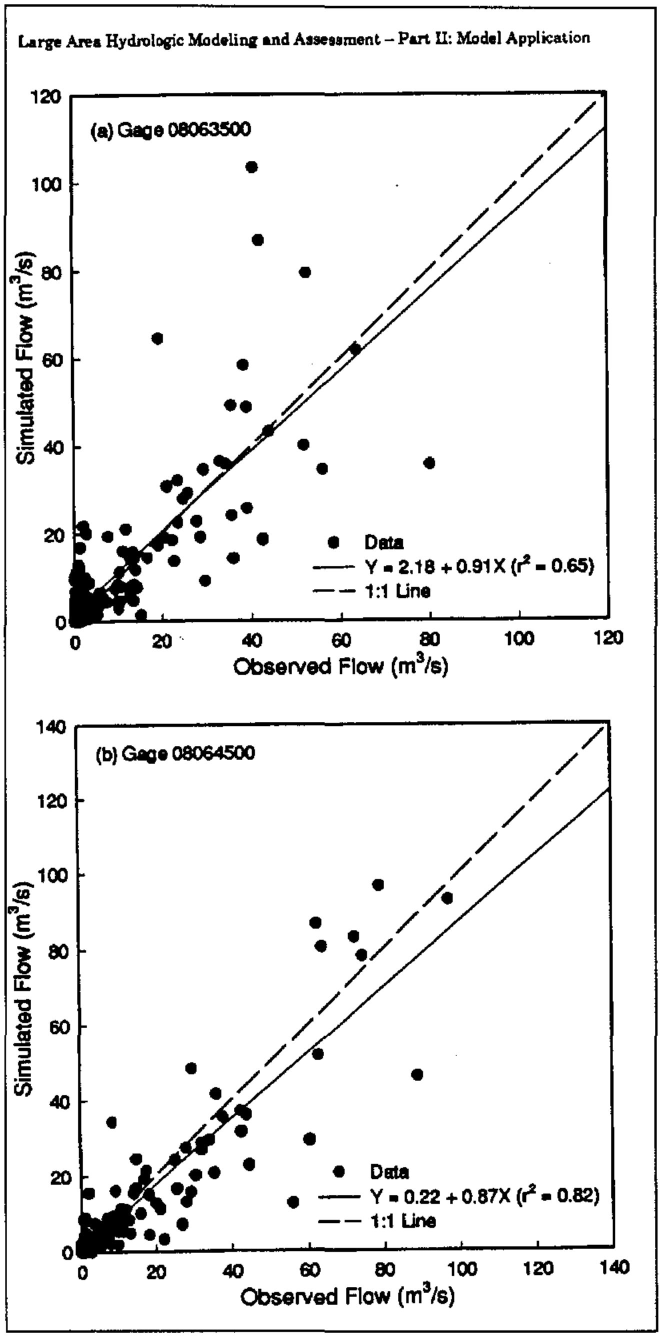

Figure 4.3-8
Scattergram of observed and simulated monthly streamflow data during the validation period (1970-1984):
(a) Gage 08063500 and (b) Gage 08064500
(Srinivasan, *et.al.*, 1998)

Table 4.3-8
Statistical results from comparison of observed and simulated streamflows
(Srinivasan, *et.al.*, 1998)

Stream Gages	No. of Samples	R^2	a	b	t_a	t_b	COE
				Calibration Period			
08063500 (Station 1)	60	0.87	0.2	1.1	0.11	2.3	0.77
08064500 (Station 2)	60	0.84	2.0	1.2	1.00	2.7	0.84
				Validation Period			
08063500 (Station 1)	180	0.65	2.2	0.9	2.60	-1.8	0.52
08064500 (Station 2)	180	0.82	0.2	0.9	0.34	-4.3	0.82

4.3.3 SWAT Model Application

When evaluating the impacts of Brush Control on a watershed, it is important to determine what level of resolution or order of magnitude is important. Is the objective to determine basin-level general trends of a watershed, or a scaled-down resolution to individual subwatersheds, or runoff changes caused by brush control? In all of these cases, there are many factors that must be evaluated, including: range area, watershed characteristics, type of brush control, range land management, and maintenance of brush control. The type of model to be used will also depend on the answers to these questions.

The SWAT model, in general, is a basin level model that routes water through the basin's stream network. SWAT is a sophisticated routing routine that utilizes EPIC to estimate individual responses of subwatersheds in the basin. EPIC was primarily developed as a cropland model, in that the plant growth, hydrology, erosion and management components are based on crop data. Therefore, the watershed responses to management practices can be estimated reasonably well for cropland use (per com., Carlson, 1999).

SPUR 2000 is setup to run within the WEPP basin-scale model, which is a routing model similar to SWAT. SPUR 2000 is specific to rangelands and can simulate various grazing systems and the response to hydrology and vegetation to rangeland management practices, where as EPIC/SWAT cannot (per com., Carlson, 1999). The SWAT model performs streamrouting on perennial streams while WEPP is restricted to a smaller watershed scale routing that occurs from ephemeral and permanent channels, but not perennial streams. Hydrology methods can be used as a tool to evaluate the magnitude or trends associated with brush control management practices.

4.4 North Concho River

4.4.1 Introduction

The North Concho River Watershed Brush Control Study Report (1998) was a year-long study of the watershed, detailing its history, hydrology, geology, and land use. The land in different vegetation types was determined utilizing satellite imagery combined with ground truth. The vegetation types and amounts of acreage within the watershed were determined to be heavy cedar – 110,508 acres, heavy mesquite – 155,896 acres, moderate mesquite – 92,735 acres, and light bush – 83,346 acres. A total of 432,485 acres or 45% of the watershed could be considered for brush control.

4.4.2 Runoff

An important element of this project was the hydrologic interpretation and corresponding hydrologic modeling of the historical runoff characteristics of the Concho River Basin. The amount of additional water expected as a result of controlling brush in the North Concho River Watershed was estimated using the Soil and Water Assessment Tool (SWAT). The model was calibrated to predict historical runoff from the watershed using precipitation records from 11 weather stations located in or near the watershed. Runoff patterns changed during the "1960's". The model was calibrated for two periods, 1949-61 and 1962-96. Land vegetation types and stream channel transmission efficiencies were altered between the two periods so that simulated flows matched published USGS records. Because quantitative information was not available during the pre-1962 period, brush cover was reduced by categorizing the heavy mesquite areas (from the satellite imagery), as moderate mesquite and all other areas were classified as open rangelands in poor conditions. The differences in the vegetation cover, the condition of the stream channel of the river and its major tributaries was parameterized to reflect the loss of their perennial flow after 1961. Prior to 1962 groundwater levels in the Quaternary Alluvium deposits (shallow aquifers) that surround the stream bed were assumed to be sufficiently recharged so that they contribute to perennial flow of the river. Thus stream channel transmission losses were minimized for calibration during this period. However, after 1961 it was assumed that the water table dropped and no longer contributed to stream flow and direct irrigation withdrawals from the river were set at 10 cubic feet per second. Prior to that time irrigation withdrawals were zero. The different model assumption concerning changing conditions in the watershed over time were based on historical and irrigation records combined with interviews of residents. Based on these assumptions the simulated flow accounted for 46% of the variation in the measured discharge rate at the USGS gage during the pre-1962 period and 76% of the variation at that location in the post 1962 period. The agreement between actual and simulated flow was considered accurate enough to use the model to estimate the effect of various brush management scenarios on water yield. The simulation of different brush management scenarios, was based on the assumptions that the underground aquifer was replenished to pre-1962 levels. Thus the simulated increases would not be expected to occur until some future time when the underground aquifers would be replenished. Greatest reduction in evapotranspiration resulted from the removal of heavy cedar. However, this did not yield the greatest increase in flow to the river because cedar is located further from the stream bed. Following recharge of the shallow aquifer, reduction of brush cover on all eligible lands to a 5% canopy which would increase the North Concho River flow at Carlsbad by 33,515 acre feet above the current discharge rate. This represents over a five-fold increase in streamflow.

4.4.3 Comments

The USGS (Sauer, 1972) evaluated the unusually low runoff in the Concho River basin for the period 1962-68. The physical developments and climatic changes in the basin were identified and related to changes in the regimen of streamflow. Sauer (1972) analyzed long-term rainfall records for the period 1943-68 which exhibited statistical characteristics different from those prior to that time. Annual rainfall averaged 10-30% less during this period, and the frequency distribution of monthly rainfall indicates a significant decrease in monthly rainfall above 2.0 inches, especially during the period 1962-68 (Figure 4.1-1). The analysis of runoff data indicates that runoff has responded directly to the deviations in rainfall. Statistical analysis of adjusted annual runoff data shows the runoff to be highly variable, with coefficients of variation ranging from 0.8 to 1.4. Drought frequency analysis indicates a drought of severity equal to the 1962-68 period may be expected on the average once every 200 years. An analysis of rainfall intensity and runoff indicate the basic cause of the unusually low runoff during the period 1962-68 has been a lack of long-duration, high-intensity rainfall.

The North Concho River Watershed Study (1998) utilized the SWAT model to evaluate the hydrologic impact of brush control. In general, model calibration combined with various assumptions regarding groundwater interaction/replenishment and rangeland management lead to various questions regarding the effectiveness of brush control to produce increased runoff and dependable water yield. Removal of woody plants can result in replacement by herbaceous growth (bunch grasses, etc.) resulting in no net increase in runoff (Dugas, 1991; Dugas, 1995; and Dugas 1998). The resulting increase in herbaceous biomass as replacement to the "treated" brush control areas combined with rangeland management practices can result in changes in the water balance between evapotranspiration infiltration and runoff. Livestock grazing can have a significant impact on the runoff. Livestock impacts are an important aspect of rangeland hydrology because livestock can alter the hydrology of a site by their consumption of ground cover and by trampling of the soil and standing vegetation. Heavy year-long grazing can increase runoff from grasslands because the species composition shifts from bunchgrass-dominated to shortgrass-dominated communities and because total cover and litter can be significantly reduced. The degree to which grazing changes species composition and reduces standing vegetation and litter is dependent on grazing frequency and intensity (Wood and Blackburn, 1981; Thurow et al., 1988a; Thurow, 1991). Because livestock are selective eaters, they remove the desirable plants first. These desirable species are often bunch grasses which provide the best vegetative cover. Therefore, less desirable species, which may be woody vegetation, shortgrasses or annuals, are likely to increase under heavy grazing (Archer and Smeins, 1991; Briske, 1991). In this way, long-term grazing can shift the vegetation on a site.

Based on discussions with U.S. Army Corps of Engineers (USACE) personnel at the Fort Worth District, O.C. Fisher Reservoir (constructed in 1957, with a drainage area of 1,488 mi^2, 105 mi^2 is probably non-contributing) located on the North Concho River has only reached the conservation storage (119,200 ac-ft) once (1957). The USACE (Fort Worth District) has not performed any additional studies of the apparent change in hydrology of the North Concho River basin since construction of O.C. Fisher Reservoir. In addition, discussion with Bureau of Reclamation personnel indicated no detailed hydrology studies (since construction) have been performed on the South Concho River/Spring Creek and Middle Concho basins, where the Twin Butte (constructed in 1963) reservoir (drainage area of 3,868 mi^2, 1,055 mi^2 is probably non-contributing) is located.

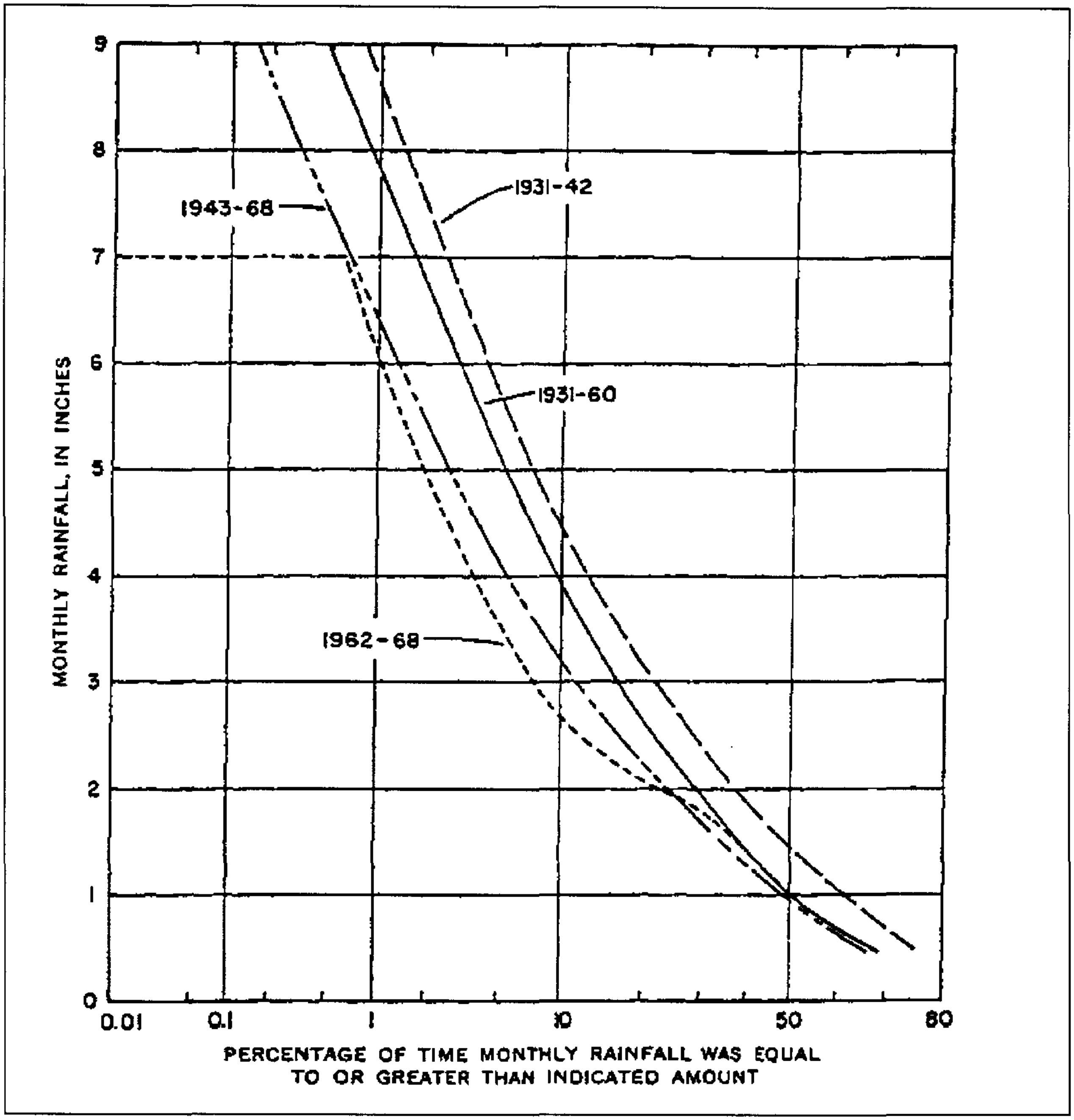

Figure 4.4–1
Frequency distribution of monthly rainfall at San Angelo.
(Sauer, 1972)

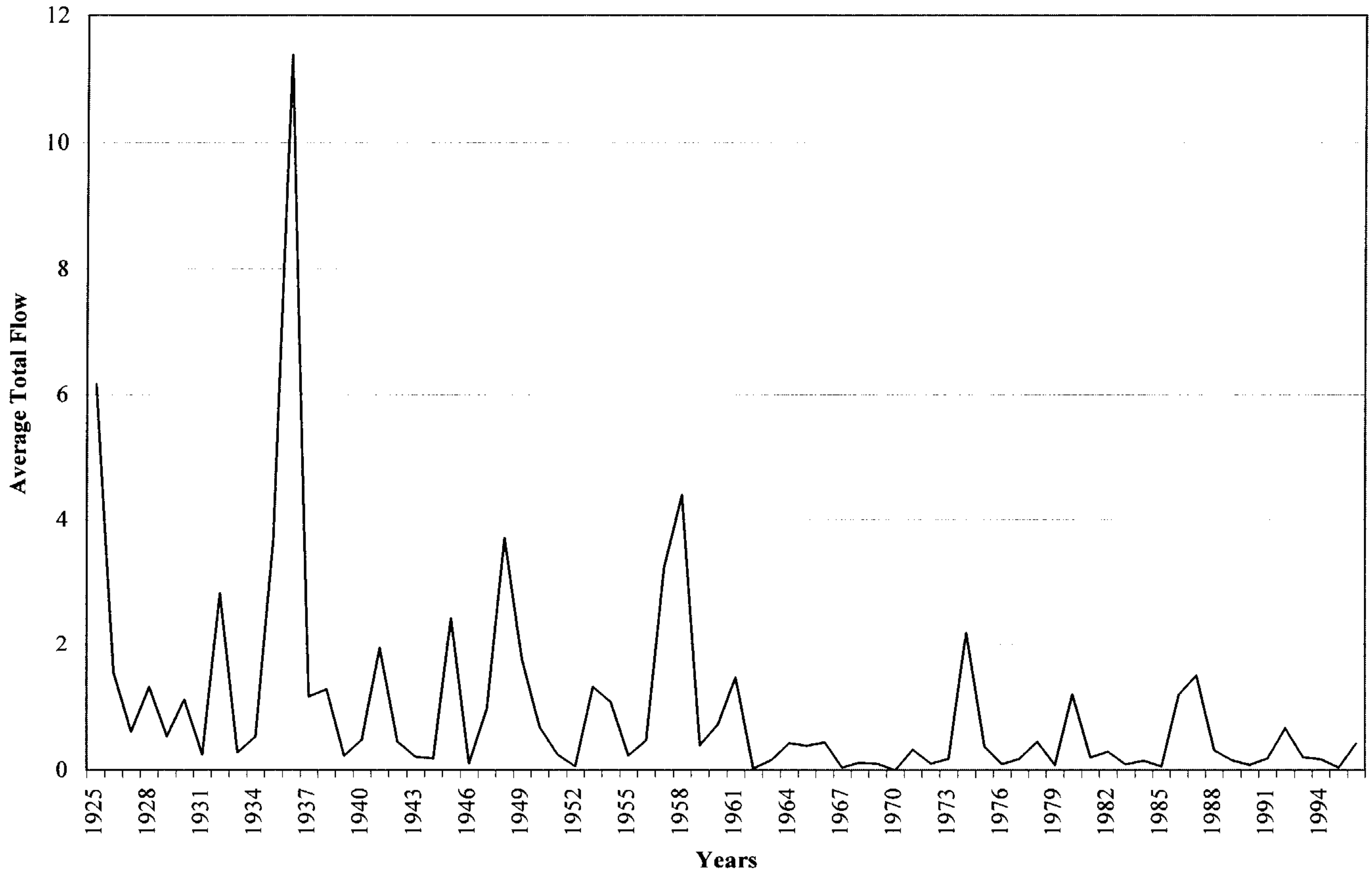

Figure 4.4-2
Average total flow
(Upper Colorado River Authority, 1998)

4.5 Seco Creek Watershed

4.5.1 Introduction

This project (Dugas, Hicks and Wright, 1998) was conducted on a area above the Edwards aquifer recharge zone in the Seco Creek watershed (Figure 4.5-1) and concerns the effect a land management practice (removal of *Juniperus ashei*) has on watershed hydrology. The objectives of this project was to quantify differences in evapotranspiration (ET) and runoff (RO) from watersheds with different land management practices (brush control). Differences of evapotranspiration and runoff were used to interpret the effect of brush removal on watershed hydrology. The project was located on the Hillis Ranch, in northeastern Uvalde County, Texas (Figure 4.4-1). Two, 40 acre adjacent areas, were mapped, and instrumented with meteorological instrumentation in late-1990. In September 1992, all *J. ashei* taller than 1.6 feet were hand cut on the western 40 acres area (treated). No treatment was imposed on the eastern 40 acre area (untreated). The period before September 1992 was defined as the pre-treatment period, and after was the post-treatment period.

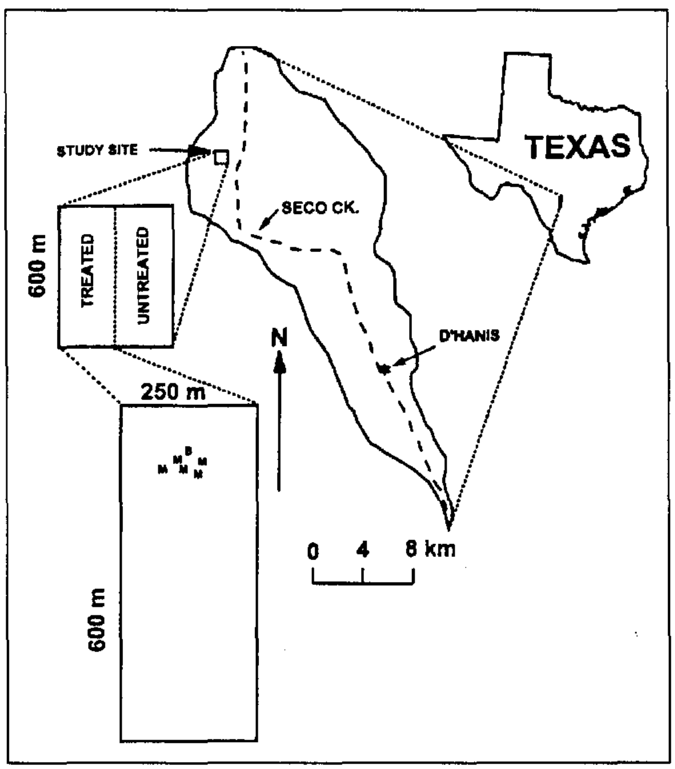

Figure 4.5–1
Map of study site.
(Dugas, et. al., 1998)
"B" and "M" symbols in treated area represent locations of base and mobile stations. Base and mobile stations in the untreated areas were in similar relative locations. Scale applies to map of Seco Creek Watershed.

4.5.2 Runoff

Precipitation events during the 1991-1992 winter demonstrated a linear relationship between the total volume of runoff from each watershed during the pre-treatment period (Figure 4.5-2). Therefore, the two watersheds were considered hydrologically similar before the *J. ashei* was removed from the treated area. The total runoff volume for each storm from the two test watersheds was not equal due to differences in area of the two watersheds. There were only two substantial runoff events in the three years subsequent to removal of *J. ashei* (Figure 4.5-2). The first of these events was in May 1993 and showed a 26% increase in runoff from the treated watershed relative to the untreated watershed. However, a large runoff event in 1995 showed a substantial decrease in runoff from the treated area, compared to the untreated area. Measurement of the runoff for the 1995 storm from the untreated area may not be accurate. The 1993 runoff result was likely atypical because at this time the treated area did not have a good cover of bunch grasses due to the short time since removal of *J. ashei.* The 1995 event, the authors believed, reflected the long-term pattern and is consistent with previous research in the area showing that runoff is decreased from lands having bunch grasses vs. those with a heavy cover of *J. ashei.* For these test watersheds, runoff is only about 5% of seasonal precipitation and occurs only when rainfall intensity is high. Runoff before and after imposition of brush control management in these two areas produced inconclusive results. Potential water yields were increased associated with vegetation management due to reduction of ET only during the first 2 years following treatment. After 3 years, water yield increases decreased.

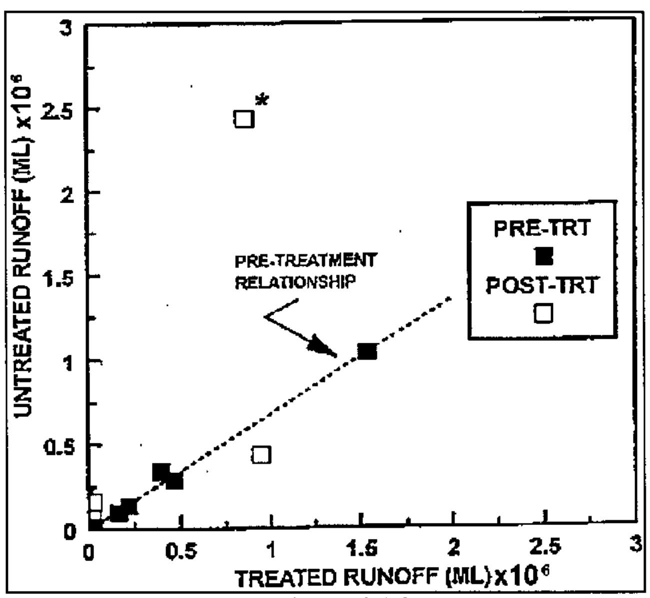

Figure 4.5-2
Total runoff from watersheds in untreated and treated areas during pre-treatment and post-treatment periods.
(Dugas, et. al., 1998)

Each point is the total volume of a runoff event (1×10^6). The dashed line shows the relationship for the pre-treatment period. Runoff volume from the untreated area for the post-treatment data point with an asterisk was estimated using precipitation totals and watershed area because of sensor malfunction and because water heights that were likely greater than H-flume height.

4.5.3 Comments

In general, the period of record and associated storm date runoff data is very limited and does not reflect sufficient variation in rainfall and watershed conditions. The linear relationship between the untreated test site is based on one storm above 0.5 x 10^6 (ml)(Figure 4.5-2). The authors, concluded that "*using differences in runoff before and after imposition of a treatment to examine effects of vegetation management in these two areas produced inconclusive results*". Additional data need to be collected to evaluate changes in runoff between the treated and untreated test areas.

4.6 Throckmorton, Texas

4.6.1 Introduction

This project was conducted during 1988 and 1989 at the Texas Experimental Ranch, 16 km north of Throckmorton (Dugas and Mayeaux, 1991). The slope of this upland site was < 1%. The predominant soil at the site was a Nuvalde clay loam (fine silty, mixed, thermic Typic Calciustolls). Honey mesquite trees at the site had been chemically treated in 1979 and were characterized by multi-stemmed regrowth pattern. Evaporation measurements were made in two adjacent areas. One, (untreated), had a mix of herbaceous vegetation and honey mesquite. The other, (treated), had only herbaceous vegetation after the diesel application which defoliated all of the honey mesquite. The untreated area was immediately to the south of the treated site.

4.6.2 Runoff

While honey mesquite used substantial amounts of water and increased evapotranspiration, the evapotranspiration from the untreated rangeland without the honey mesquite was just slightly lower than evapotranspiration from the untreated rangeland. This is due to an increase in herbaceous evapotranspiration associated with increased standing crop following mesquite control. In this environment, which had a low potential for runoff and deep percolation, removal of honey mesquite would not be expected to increase availability of water for off-site uses because water not transpired by mesquite in subsequent years would be utilized by increase in herbaceous vegetation. If so, brush control for purely hydrological purposes would not be justified. Increases in forage production following mesquite control equaling or exceeding those measured in this study have been reported at several locations in the same geographic area (Dahl et al. 1978, Jacoby et al. 1982, McDaniel et al. 1982, Bedunah and Sosebee 1984). However, differences in evapotranspiration or increases in off-site water availability as a result of honey mesquite control may occur under a grazing regime which precludes accumulation of additional herbaceous standing crop or for different soils.

4.6.3 Comments

Results were limited to the period 1988-1989. The brush control in terms of honey mesquite at the site indicated that for "purely hydrological purpose brush control could not be justified".

4.7 Cusenbary Draw Watershed

4.7.1 Introduction

Cusenbary Draw (Redeker, et. al., 1998), an 80 square mile watershed on the Edwards Plateau, is representative of much of the region in terms of soil (shallow silty clay), vegetation, and land management. Nineteen different ranches are partly or wholly located within the watershed. The predominant bunchgrasses are sideoats grama and Texas wintergrass. The dominant shortgrass is curly mesquite. Juniperus ashei, redberry juniper, and live oak are the dominant woody species on the shallow soils of the upland (e.g., Deep Divide, Shallow and Low Stony Hill range sites), while honey mesquite and live oak dominate the lowlands with deeper soils (e.g., Valley and Bottomland range sites). Aerial photographs were used to develop a composite photograph of the watershed for 1955 and 1990. The amount of woody cover in 1955 and 1990 and the rate of change between these dates was calculated using image analysis technologies on each of the five range sites delineated within the watershed (Redeker, et. al., 1998). From this information the water yield was estimated using the Simulation of Production and Utilization of Rangelands model (SPUR-91). Brush in the Cusenbary Draw watershed increased from an average of 22% cover in 1955 to 24% in 1990. The slight increase during this 35 year period is attributable to brush control efforts (fire, herbicides, chaining, grubbing and/or manual cutting) which kept the potential for brush increase in check. In contrast, on the scattered locales within the watershed where no brush control was applied the brush increased from 22% cover in 1955 to 37% in 1990.

4.7.2 Runoff

Four scenarios of brush management were tested using the SPUR-91 model. Scenarios 1 and 2 estimate the average water yield and livestock carrying capacity associated with the 1955 and 1990 vegetation cover. Scenario 3 estimated the average water yield and livestock carrying capacity associated with the likely woody cover increase in the watershed if there had been no brush control. Scenarios 4 examined the estimated water yield and livestock carrying capacity increase that would be likely to occur based on a response to a mail survey regarding a hypothetical publicly funded brush control cost-share program designed to increase water yield (see Table 4.7-1). All water remaining after evapotranspiration was assumed to be available water yield (Runoff or Groundwater recharge)(per. com., Redeker, 1999).

4.7.3 Comments

Runoff analysis for this project was based on application of SPUR-91. No hydrologic data for the Cusenbary Draw watershed was collected for verification of the SPUR-91 model. Water yield could have been overestimated based on assumption of all remaining water after evapotranspiration is available for yield from watershed.

Table 4.7–1
Water balance and stock carrying capacity
Water balance and stock carrying capacity of the Cusenbary Draw watershed derived from the Simulation of Production and Utilizations of Rangelands (SPUR-91) model.

	1995[1]	1990[2]	No Brush Control[3]	Publicly Funded Brush Control[4]
Precipitation (inches/year)	19.7	19.7	19.7	19.7
Evapotranspiration (inches/year)	18.7	18.9	19.3	18.1
Water Yield	27,150	21,720	10,860	43,440
Moderate Stocked Carrying Capacity (acres/animal unit/year)	25	24	20	28

[1] shrub cover = 3% juniper, 17% oak, 2% mesquite
[2] shrub cover = 12% juniper, 10% oak, 2% mesquite
[3] shrub cover = 18% juniper, 15% oak, 4% mesquite
[4] 40% of the land cleared to 3% shrub cover, 60% of the land at the 1990 shrub cover. The relative composition of both the cleared and uncleared portions of land is the same as the 1990[2] values. The hypothetical publicly funded brush control program was based on cost-share offers which vary according to the current ranch brush cover and were designed to enable ranchers to control brush for 10 years at no net cost.

Table 4.3-3
Comparison of measured and SWRRB simulated water sediment.
(Williams, et.al., 1985)

Location	Chickasha, Oklahoma		Riesel, Texas
	1962-1970	1971-1981	1961-1982
Rainfall (mm*a^{-1})	649	779	890
Runoff (mm)			
Annual			
Mean	35/36*	59/59	169/149
Standard dev.	19/23	28/25	129/88
Monthly			
Standard dev.	3.1/3.3	5.6/6.4	27/20
R^2	0.59	0.60	0.78
Sediment (t*ha^{-1})			
Annual			
Mean	2.8/2.3	4.5/4.1	1.5/1.8
Standard dev.	2.4/1.9	2.6/2.9	1.4/1.1
Monthly			
Standard dev.	0.71/0.44	0.81/0.96	0.32/0.30
R^2	0.60	0.78	0.75

* *Measured predicted.*

Table 4.3-4
Comparison of observed and SWRRB simulated rainfall, runoff, and sediment yield for Oklahoma Basin (1971-1981)
(Williams, et.al., 1985)

Run	Rainfall[a]	Runoff[a]	Sediment[b]
1	677.7	52.27	4.547
2	736.8	72.88	5.485
3	676.2	53.93	3.301
4	702.4	46.76	3.469
5	615.1	27.92	2.093
6	670.7	44.84	3.707
7	687.9	51.33	3.349
8	643.8	49.42	4.163
9	736.9	68.48	5.964
10	674.7	48.90	4.148
Simulated mean	682.22	51.67	4.023
Observed mean	778.63	59.62	4.481
Difference	96.41	7.95	0.458
Critical Difference	232.43	32.13	2.620

[a]In mm*a^{-1}
[b]In t*ha^{-1}*a^{-1}

5 MULTIPLE CONSIDERATIONS IMPACTING WATER PRODUCTION

Since the end of World War II as greater recognition was given to the importance of rangelands and forests to the well being of the Nations production of agricultural products a tremendous amount of research and scientific study has been done on the indigenous plants, wildlife and livestock practices. An important aspect of these studies and research activities has been the relative use of water by plants and the effect such water use has on the environment, soils, streams and the propagation of other ostensibly more beneficial plant species. Today with the increased concern over water supplies to meet growing requirements for municipal, industrial and agricultural uses, production of increased ground and surface water is receiving greater emphasis. Irrespective of the fact that rangelands and forests are the initial recipients of rainfall in the hydrologic cycle sending the waters to aquifers and streams, the concept of increasing the water production from a selected watershed is a complex issue.

5.1 Potential Water Production Increase from Brush Control

Research on the water use of selected brush species that have invaded Texas rangelands generally reveal that plant use, evaporation and losses from interception of rainfall by leaf surfaces accounts for the major portion of rainfall except during high intensity storms (Schuster, 1996)(Hester, et. al., 1997). Studies have found that removal of brush species would reduce evapotranspiration and potentially increase percolation into the soil and surface runoff (Schuster, 1996)(Hester, et. al., 1997). However when brush removal is followed by a significant increase in herbaceous vegetation, there may be little change in evapotranspiration, deep soil percolation or surface runoff in most of the vegetative regions with rainfall between 17 and 32 inches per year(Carlson, Thurow, et. al., 1990) (Blackburn 1983) (Weltz and Blackburn 1993).

The Edwards Plateau appears to have some potential for increased ground and surface water production attributable to a number of unique characteristics. The primary brush species rapidly invading the region are ashe juniper, red berry juniper and in some areas, mesquite. The Edwards Plateau is characterized by shallow calcareous soils, fractured limestone parent materials, rapid runoff caused by rocky surface characteristics, variable steep slopes and periodic high intensity rainfall events. While some studies intended to measure actual changes in water production when significant amounts of brush are removed (Effect of Removal of Juniperus ashei on Evapotranspiration and Runoff in the Seco Creek Watershed, Brush Management on the Cusenbary Draw Watershed: History and Ramifications, and Preliminary Results of Juniper Control Effects on Water Yield at the Sonora Agricultural Experiment Station) have shown positive results, additional study over longer periods of time are necessary. It is noteworthy however when reviewing the Seco Creek study that the growth of herbaceous vegetation significantly reduced the increased water production within 2 years after brush removal, (Dugas, et. a., 1996).

Another study, "North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study" predicts a substantial increase in groundwater levels and in surface water runoff following 95% removal of red berry juniper and mesquite brush. This project has been funded by the Texas Legislature for the 1999 biennium. Measured results may began to be observed within 3 to 5 years depending upon the extent of landowner participation and climatic conditions. Because of the high degree of variability in rainfall intensity, statistically valid results may require 10 or more years. The prior establishment of USGS gauging stations, studies of watershed hydrology by the USGS and the US Army Corps of Engineers and the existing O. C. Fisher Reservoir should be highly beneficial to the determination of the effect of brush control on the hydrology of the watershed.

Eight additional watersheds are to be selected for brush control programs similar to the North Concho Project by the Texas Soil and Water Conservation Board. This selection process was also funded for the 1999 biennium by the Texas Legislature. The work of identifying watersheds with a high potential for the production of increased groundwater and surface water runoff will be conducted by the Texas Agricultural Experiment Station, Blackland Research Center under the Direction of Dr. W. A. Dugas. The selection process is to be completed by the fall of the year 2000.

A new study is intended in the Edwards Plateau region in Bexar County. The paired watersheds of Government Canyon and Honey Creek will be studied to determine the effect of brush removal. This study will be conducted by the Natural Resource Conservation Service and the US Geological Survey.

5.2 Estimates of Ground and Surface Water Increases

Many studies and research projects as noted in this report have submitted data demonstrating the use of large amounts of water through the evapotranspiration of plants and the apparent greater use by invasive brush species. A number of studies have produced data demonstrating an increase in water production (Seco Creek, Texas Agricultural Experiment Station at Sonora, Cusenbary Draw) where brush species such as ashe juniper, mesquite and others have been killed or removed. To gain perspective on the potential increase in water supply availability as a result of brush control practices in selected regions of the State, the additional water was projected as "Savings" in "A Comprehensive Study of Texas Watersheds and Their Impacts on Water Quality and Water Quantity" by the Texas State Soil and Water Conservation Board. The study projected that, initially, up to 6,914,177 acre feet per year might be saved, just slightly less than the water stored in all of the State's water supply reservoirs combined (TWDB 1997. Water for Texas Today and Tomorrow). The report strongly qualifies the savings figure as "guesses at best" and "represent solely acreage with moderate and heavy brush canopy".

Such estimates of water savings appear to be over optimistic and likely to be misunderstood by the public. Much of the projected water savings would be used on the land and would not be available to accumulate for municipal, industrial and agricultural uses. In many of the vegetative regions, savings resulting from the removal of brush species would be used within a few years by the increased growth of beneficial herbaceous species. Often the movement of saved water into aquifers is inhibited by impervious layers of clay or rock. Surface water flows often are little different before and after brush removal because of liter accumulation under tree and brush canopy and herbaceous vegetation initially present.

The use of computer simulation models described in Section 4 of this report constitutes a possible approach for predicting the effect of brush control on groundwater infiltration and surface water runoff. The predicted changes in water yields simulated for the selected watershed may also be used to estimate water yields from larger areas with comparable vegetative, geological and meteorological characteristics. Such applications of computer simulation models are not considered to be a useful approach to solving field problems. (Pierson, Spaeth and Weltz. 1996) The problem is not with the models, but rather lies with the adequate identification and definition of the real world problems found in the subject watershed. (reference Section 4.4.3 of this report) It is imperative that greater emphasis should be placed upon the definition of the problems associated with the resources within the selected watershed and the design of workable solutions using experienced personnel with varying areas of expertise as necessary. (Thurow. 1996)

Experimental sites cited in this report yield valuable data and can be used for the purpose of identifying other vegetative regions or other watersheds within the region of the experimental site with a potential for increased water yield through brush control. Such extrapolation however, can only provide a rough estimate of water yield because of significant variations of watershed characteristics even within the same vegetative region or an adjacent watershed.

The best approach to determine the effect of brush control upon groundwater and surface water runoff in a selected area found in the course of this study is the application of brush removal on a selected watershed with careful monitoring of landowner participation, vegetative changes, meteorology, changes in groundwater levels and surface water runoff over a period of ten years or longer. Such a program has been initiated on the North Concho watershed, described in Section 4.4 of this report. As noted with the use of computer simulation models, it is important to develop an in-depth definition of the existing resources to form the basis for the determination of changes resulting from the removal of brush. The information and experience gained from the North Concho brush control project will serve to refine the use of computer simulation models to predict water yields, provide guidance in the selection of other watersheds with a potential for increased water yields and serve to define the real world problems related to brush control as a water management strategy. (Thurow. 1996)

5.3 Timing and Reliability of Increased Water Supplies

The production of increased water resulting from brush control activities occurs primarily as a result of relatively high intensity rainfall. Where storms produce rainfall of less than approximately 2 inches, it is most often held on the site and ultimately lost to evapotranspiration. Records of rainfall, some dating back to the early 1900's, often reflect heaviest accumulations in the spring and fall with summer and winter months tending to be drier. Logically it follows that the potential for increased availability of water from watersheds subjected to brush control would be most likely to occur when most juxtaposed areas of use would also have received substantial rainfall.

Prolonged drought periods are a common occurrence in Texas and are the reason for the current concern over the future availability of water supplies. When drought occurs, raising the regions demands for water, the same drought conditions are also effecting the watersheds where brush control has been applied. Without rainfall or more specifically without high intensity rainfall events, the treated watershed can not produce increased water supplies for downstream users.

There are ways to mitigate these problems of timing and availability, including purposeful movement of saved or increased water into nearby aquifers. Aside from the natural recharge of aquifers through percolation or direct flow through fissures and cracks in the underlying rock formations, forced recharge can be employed. Forced recharge has the disadvantage of added costs which must be compared to alternative sources of water, if available. Another way of accumulating and holding the increased water supplies produced by brush control would be the use of existing reservoirs or the construction of new reservoirs. Either way the additional cost of storage must be considered as a part of overall cost of any increased water made available. Surface reservoirs have the disadvantage of surface evaporation and the use of large land areas causing conflicts with landowners and environmental concerns.

To insure the availability of additional water supplies developed through brush control programs during periods of drought, reservoirs or aquifer storage will be required. These facilities will add significantly to the cost of these additional water supplies. The actual cost of these water supplies will vary with the increased yield of the watershed, the cost of brush control, the benefit to the ranchers or landowners, the storage facilities to be used, the location or locations of the water users, and the cost of water treatment to standards necessary to the intended use. It is not possible in the context of this study to estimate the cost/unit of added water supply nor to estimate private benefits. However, when specific areas or watersheds are identified as having a potential for an increased water supply through a brush control program, careful technical studies can provide preliminary cost/unit estimates.

5.4 Texas Water Rights

The added purpose for the expenditure of public funds for brush control is the production of an increased water supply to be applied to a specific use. Initially there needs to be a quantification of the amount of new or additional water that is produced from the treated watershed. The question then is who is entitled to use the new water under Texas system of water rights? Technically, the State has title to any new surface water, and groundwater is, in all probability, controlled by a Groundwater District created under statutes passed by the Texas Legislature and subject to review by the State's regulatory agency, the Texas Natural Resource Conservation Commission. The issuance of a permit or permits for use of the new water should be addressed concurrently with the development of the new water source. This process whether with the TNRCC or the local Groundwater District may be contested and could in some circumstances be quite costly, adding significantly to the cost of the newly created water supply. TNRCC by letter (December 21, 1999, see Appendix) to Regional Water Planning Group Members stated:

> *"Any increase in naturalized flows that were brought about via a brush control project would first be considered available to existing water rights of record that were not otherwise satisfied."*

5.5 Brush Management – A Consideration by Each Landowner

The removal of 90 - 95% of the brush within a selected watershed to maximize the production of increased groundwater and surface water supplies is probably not possible nor is it desirable. Several factors previously identified have modified the thinking of both landowners and scientists. Ranchers find it difficult to justify brush eradication on their rangelands because the cost associated with removal or killing of the brush will not increase the production of livestock sufficiently to pay for itself. However with the increased value associated with wildlife production, brush management becomes a viable option. Brush management infers selective control of brush species as advocated in "Brush Sculptors" to gain the advantages of specific brush species which are beneficial to the wildlife species to be propagated. When significant amounts of brush are retained and managed on a selected watershed the previously identified potential for increased water production may be substantially reduced or eliminated.

Still other factors may influence the decision of a rancher or landowner in regard to the removal or management of brush. The purpose of ownership may be for outdoor recreation or simply a personal long term investment, as is common especially in the southern portion of the Edwards Plateau (Redeker, et. al., 1998). Under these circumstances, the landowner may elect to do nothing or he may ascribe to a form of vegetation management more for aesthetic purposes. In other instances, the rancher or a land developer may prefer to do little if anything to the vegetation pending sale of the land for development purposes.

5.6 Landowner Participation

The brush control project on the North Concho River watershed is predicated upon the removal of 90 - 95% of the brush canopy to produce a substantial amount of water to be stored in the O. C. Fisher Reservoir. To achieve that level of brush removal, a program has been funded by the State which would offer landowners a subsidy up to 77% of the cost of brush removal. In addition the landowner must agree to maintenance of the cleared areas for a 10 year period. Early indications are that landowners are responding with a sign-up of 154,000 acres out of the total 450,000 acres eligible within 15 days of initial availability (personal communication with James Moore, Assistant Executive Director, Texas State Soil and Water Conservation Board). Full participation will be extremely important to success of the program as will the actual measured production of increased water supply.

Selection of the North Concho River watershed for this initial test of the effectiveness of brush control for water production was well conceived. The lack of stream flow in the River to maintain the conservation pool in O. C. Fisher Reservoir, the rapid infestation of the watershed by red berry juniper and mesquite, and the need for additional water supplies to meet the demands of the growing San Angelo area all bode well for the participation of ranchers and landowners.

Rancher and landowner participation with brush control programs for the increased production of water in other areas and particularly in the Edwards Plateau region is a major question. Considering the factors discussed previously in this report, participation may be somewhat less than that necessary for an effective program on any given watershed. Similarly, when considering the limited potential for significant water production coupled with the costs associated with a brush control program, the public may not be willing to subsidize a brush management program to the extent necessary to encourage landowner participation. Public willingness to establish a long term brush control program for added water production will also hinge upon the availability of other sources of water and on the cost of those other sources compared to the total cost of water from participating watersheds. Decisions to support a brush control program for water production must necessarily be made on a watershed by watershed basis by the State Planning Region effected. It is imperative that the State, working through State Agencies and the Universities, provide the Regional Planning Groups with the best information and planning tools possible to facilitate local decision making.

6 SUBSIDY PROGRAMS FOR BRUSH CONTROL

6.1 Federal Programs

The multiple benefits of brush management have long bee3n recognized and Federal Agricultural Acts for many years have provided for payments to ranchers and landowners to encourage approved practices. Most often the payment to the landowner were based upon a 50% cost share, with the approved practice inspected by a representative from the USDA Farm Service Agency prior to payment. Federal funds were also made available for research and extension activities through the Agricultural Research Service or the Natural Resources Conservation Service (formerly the Soil Conservation Service). Brush control subsidies and technical assistance were directed primarily at increasing the production of forage for livestock, the prevention of soil erosion and watershed protection. These programs have been only partially successful because of the marginal profitability of the livestock industry utilizing rangelands and forests.

Federal programs that may be applicable to brush control as a water management strategy include:

<u>Conservation Reserve Program</u> (USDA – Natural Resources Conservation Service)
In 1985 Congress passed the Food Security Act of 1985 to address the issues of widespread conversion of fallow land to production. Title XII of the Act established the Conservation Reserve Program, or CRP. A voluntary long-term cropland retirement program, the CRP provides participants with an annual per-acre rent plus half the cost of establishing a permanent land cover (usually grass of trees). In exchange, the participant retires highly erodible or environmentally sensitive cropland from production for 10 to 15 years.

<u>Environmental Quality Incentives Program</u> (EQIP) (USDA – Natural Resources Conservation Service)
The EQIP provides technical, educational, and financial assistance to eligible farmers and ranchers to address soil, water and related natural resource concerns on their lands in an environmentally beneficial and cost effective manner. The program provides assistance to farmers and ranchers in compliance with Federal, State, and tribal environmental laws, and encourages environmental enhancement. The program is funded through the Commodity Credit Corporation. The purposes of the program are achieved through the implementation of a conservation plan that includes structural, vegetative, and land management practices on eligible land. Five to ten year contracts are made with eligible producers. Cost share payments may be made to implement one or more eligible structural or vegetative practices, such as animal waste management facilities, terraces, filter strips, tree planting, and permanent wildlife habitat. Incentive payments can be made to implement one or more land management practices, such as nutrient management, pest management, and grazing land management.

Brush removal is included under EQIP on a priority system established by the Natural Resources Conservation Service. The program is based upon a cost share up to 70% from Federal funds, but not more than $50,000 per cooperator. This and the existing PL 83-566 program described below can be dove-tailed with the State programs, provided that Federal funds cannot be used in place of private funds to match State funds nor can State funds be used as matching funds for the Federal program.

Forestry Incentives Program (FIP) (USDA – Forest Service)
The FIP supports good forest management practices on privately owned, non-industrial forest lands nationwide. FIP is designed to benefit the environment while meeting future demands for wood products. Eligible practices are tree planting, timber stand improvement, site preparation for natural regeneration, and other related activities. FIB is available in counties designated by a Forest Service survey of eligible private timber acreage.

Watershed and River Basin Planning and Installation (PL 83-566) (USDA – Natural Resources Conservation Service)
Technical and financial assistance is provided in cooperation with local sponsoring organizations, state and other public agencies to voluntarily plan and install watershed- based projects on private lands. The purposes of watershed projects include watershed protection, flood prevention, water quality improvements, soil erosion reduction, rural, municipal and industrial water supply, irrigation water management, sedimentation control, fish and wildlife habitat enhancement and create and restore wetlands and wetland functions.

Project sponsors are provided assistance in installing planned treatment measures when plans are approved. Surveys and investigations are made and detailed designs, specifications, and engineering cost estimates are prepared for construction of structural measures. Areas where sponsors need to obtain land rights, easements, and rights-or-way are delineated. Technical assistance is also furnished to landowners and operators to accelerate planning and application of needed conservation on their individual units.

In Texas a number of the small reservoirs have been utilized for the purpose of providing a water supply for rural communities and small cities. In the recharge area of the Edwards Aquifer that lies along the southern boundary of the Edwards Plateau, the small flood control structures were located so as to allow the floodwaters to recharge the aquifer. To a limited extent, this program allows the removal of brush where it is beneficial to the purposes of the flood control structures. This program has also been the primary responsibility of the Natural Resource Conservation Service working with the local soil and water conservation districts.

Resource Conservation and Development Program (RC&D) (USDA – Natural Resources Conservation Service)
The purpose of the RC&D program is to accelerate the conservation, development and utilization of natural resources, improve the general level of economic activity, and to enhance the environment and standard of living in authorized RC&D areas. It improves the capability of state, tribal and local units of government and local non-profit organizations in rural areas to plan, develop and carry out programs for resource conservation and development. Current program objectives focus on improvement of quality of life achieved through natural resource conservation and community development that leads to sustainable communities, prudent use (development), and the management and conservation of natural resources. The Natural Resources Conservation Service can provide grants for land conservation, water management, community development, and environmental needs in authorized RC&D areas.

Flood Prevention Program (PL 78-534)
The Flood Control Act of Dec. 22, 1944 authorized the Secretary of Agriculture to install watershed improvement measures to reduce flood, sedimentation, and erosion damages; further the conservation, development, utilization, and disposal of water, and the conservation and proper utilization of land.

Wetlands Reserve Program (USDA-Natural Resources Conservation Service)
The Wetlands Reserve Program is a voluntary program offering landowners the opportunity to protect, restore, and enhance wetlands on their property. The NRCS provides technical and financial support to help landowners with their wetland restoration efforts. The goal is to achieve the greatest wetland functions and values, along with optimum wildlife habitat, on every acre enrolled in the program. This program offers landowners an opportunity to establish long-term conservation and wildlife practices and protection beyond that which can be obtained through any other USDA program.

Wildlife Habitat Incentives Program (WHIP) (USDA – Natural Resources Conservation Service)
The WHIP is a voluntary program for people who want to develop and improve wildlife habitat primarily on private land. Through WHIP the NRCS provides both technical assistance and up to 75% cost-share assistance to establish and improve fish and wildlife habitat. Agreements between NRCS and the participant generally last from 5 to 10 years from the date the agreement is signed.

Federal programs that may be applied to brush control are not predicated on water production or broad landowner participation in a specified area or watershed. The Federal programs are for the traditional purposes of increasing forage production, erosion control, watershed protection and other environmental purposes.

6.2 Texas Programs

Brush management programs in Texas have consisted primarily of extension services and research activities. The Texas Agricultural Extension Service, the Texas A&M University Agricultural Experiment Stations and the research work at Texas Tech University have made significant contributions to the knowledge and application of technical information related to range management and the control of brush on Texas rangelands and forests.

With the increased concern over the availability of water supplies to meet the growing needs of the State a number of political leaders such as State Senator Bill Sims began to urge the Texas Legislature to authorize studies to determine the potential for the increase of water availability when brush was removed from the rangelands especially in the western portions of the State. State Representative Rob Junnel was successful in the appropriation of funds for the study of the North Concho River watershed that was completed in 1998. In the Seventy-sixth Legislature, appropriations were made for the implementation of the brush control program developed in the North Concho study. The Texas State Soil and Water Conservation Board was given responsibility for implementation of the program working through the local Soil and Water Conservation Districts. Funding for the biennium is approximately & $7 million for brush control cost share with ranchers and landowners, $1 million for administration including

$300,000 to be used by the Upper Colorado River Authority for program evaluation and $1 million for studies to identify 8 additional watersheds in specified areas for future brush control activities.

The brush control program on the North Concho River watershed is just beginning. The basic guidelines for participation by landowners are: (personal communication with James Moore, Assistant Executive Director, Texas State Soil and Water Conservation Board)

- Cost share with landowners
- Maximum State cost share – 77%, minimum 30.6% (based upon calculated benefit to landowner)
- Contracts for 10 year term (includes brush control maintenance)
- Upon initial treatment landowner is paid full contractual amount

It is anticipated that a request will be made to the next session of the Legislature for additional funds to complete the North Concho program.

It is important to recognize that State funds have been appropriated for specific brush control areas and purposes. Two critical conditions must be considered for the State program to continue in the future – first the brush control applied to the selected watershed must prove the production of an increased supply for ground and surface water at a competitive cost with alternative sources of water, and second, landowner cooperation must be responsive (Thurow, Thurow and Garriga. 1999) in the selected watershed to effect sufficient brush removal and management to produce the projected increased water flows. Without positive findings to both conditions, public participation in the form of future funding could be doubtful.

7 RECOMMENDATIONS FOR BRUSH CONTROL PROGRAMS IN TEXAS

The multiple use management of Texas rangelands and forests are very critical to the future of the State and its citizens. The control of invasive brush species in all regions of the State brings with it to varying degrees increased forage production, watershed protection, erosion control, wildlife and endangered species propagation and protection of aesthetic values. Whether the increased production of ground and surface water will justify the expenditure of public funds is a serious question which will require further study and demonstration projects on selected sites. Review and interpretation of various project reports and scientific literature suggests that brush control does result in some short term increases in the hydrologic balance in some localized areas. However, the importance of brush control with respect to producing significant increases in long term dependable water supply has not been demonstrated.

A number of demonstration projects have been established as referenced in this report in various areas of the Edwards Plateau. These study areas have been on relatively small watersheds involving primarily the removal of Juniperus ashei (ash juniper). A major study area in the northwestern portion of the Edwards Plateau, the North Concho River watershed, has been selected and funded initially for implementation beginning in the summer of 1999. The selection of the North Concho River watershed was based upon circumstances highly favorable to the determination of the effects of brush removal on the production of groundwater and surface water runoff. Funding of the project by the Texas Legislature was based upon a detailed study, the "North Concho River Watershed - Brush Control Planning, Assessment and Feasibility Study", by the Upper Colorado River Authority with the participation of many scientists and engineers with applicable expertise.

Still other studies and demonstration projects are planned by the State and Federal Agencies as noted in Section 6 of this report. While these studies and projects would have merit absent the prior studies, it would seem prudent from the standpoint of technical feasibility and the expenditure of public funds to gain the benefit of the technical data and measured results from the studies and projects currently underway, before initiation of new brush control demonstration projects.

Section 4 of this report addresses the use of hydrologic models to assess the production of ground and surface water from a selected watershed resulting from the removal or the modification of brush canopy. Such a model can be of great value in the selection of a watershed or river basin where brush control and the eradication of phreatophytes would produce an increase in water availability. Review of the SWAT model and its application on the North Concho River watershed would indicate the need for additional refinement and verification of the model for use in the evaluation of rangeland hydrology. Work to refine the SWAT model is currently underway under the leadership of Dr. W. A. Dugas at the Blackland Experiment Station. As is always the case, care needs be taken when making assumptions to be used in conjunction with a hydrologic model and in the interpretation and extrapolation of hydrologic results. A hydrologic model is a tool to be used in the selection of watersheds with water supply potential. Actual measured results over a period of time sufficient to yield valid scientific data must be viewed as the determinant factors when judging the ultimate benefit of brush control for water yield.

Based upon the review of reports by State and Federal Agencies and numerous technical papers as noted in the various sections of this report, the Edwards Plateau is the region with the greatest potential for the increase of water availability as a result of brush management. This potential is significantly limited by the participation of ranchers and landowners. Elimination of brush is no longer a practical concept, rather the selective management of woody vegetation will be the applied method of treatment. This may limit the potential for significant water availability increases in some watersheds.

To gain rancher and landowner cooperation for brush control in selected watersheds will require the application of public funds as is being done in the North Concho River project from local or State sources. In addition, the Federal EQUIP program as applied to brush control can be extremely helpful especially for long term maintenance of project watersheds. The North Concho River project sought to determine the relative benefits accruing to private and public interests. This is a valid concept which will have to be negotiated with each landowner within a project watershed.

Phreatophyte eradication has significant potential benefits in the reduction of water use by plants that have little benefit for any purpose. These plants, some of which are introduced species, are primarily located along stream banks. There is little if any direct benefit to adjacent landowners from phreatophyte removal and in fact these plants often occur on stream banks and sand bars that are technically the property of the State. While phreatophyte eradication is an extremely expensive and long term undertaking, it should become a program of the State working in cooperation with local water districts, river authorities, cities and other political subdivisions.

The selection of watersheds for brush management projects to produce additional water for specific water supply purposes should be considered and funded locally. This is a specific potential source of water which should be considered by the SB 1 Planning Groups or in the alternative by a specific water user. Payment for this source of water supply should be assumed by the end user and the necessary water right permit must be acquired from the Texas Natural Resources Conservation Commission by the end user or their representative district or river authority. Direct responsibility for development and cost of brush control water supply projects by the user promotes technically sound and practical decisions. Application of large Federal or State subsidies to water supply projects such as brush management on selected local watersheds can result in impractical and wasteful decisions. Limited assistance from Federal and State Agencies can be very beneficial to initiate consideration of the potential offered by a local watershed project or to provide the needed technical assistance to fully understand the potential benefits.

REFERENCES

Alexander. 1993. Controlling Juniper: Fire and Goats, a Combination.

Ansley, Pinchak, and Ueckert. 1995. Changes in Redberry Juniper Distribution in Northwest Texas (1948-1982)

Ansley, Trevino, and Jacoby. 1998. Intraspecific Competition in Honey Mesquite: leaf and whole plant responses.

Arnold, J.G., R. Srinivasan, K.S. Muttiah, and J.R. Williams., 1998. Case and Hydrologic Modeling and Assessment Part I: Model Development. Journal of the American Resumes Research, vol. 34 (1): pp. 73-81.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and P.M. Allen. 1999. Continental Scale simulation of the Hydrologic Balance. Journal of the American Water Resources Association. Vol. 35 (5):1037-1051.

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management. Texas A&M University. Press, College Station.

Arnold, J.G., J.R. Williams, D.R. Madmen. 1995. A Continuous Water and Sediment Routing Model for Large Basins. Journal of Hydraulic Engineering. 121(2):171-183.

Arnold, J.G., P.M. Allen. 1996. Estimating Hydrologic budgets for Three Illinois Watersheds. Journal of Hydrology. 176:57-77.

Bingner, R.L. et al. 1997. Effect of Watershed Subdivision on Simulation of Runoff and fine Sediment Yield. ASAE, Phoenix Arizona.

Blackburn. 1982. Influence of Brush Control on Hydrologic Characteristics of Range Watersheds.

Bovey. 1998. Herbicide Absorption and Transport in Honey Mesquite and Associated Woody Plants in Texas.

Bovey __. A Fifty-Year History of the Weed and Brush Program in Texas and Suggested Future Direction.

Branson, Gifford, Renard, and Hadley. 1972. Rangeland Hydrology.

Budunah, D.J., and R.E. Sosebee, 1984. Forage response of a mesquite-buffalowgrass community following range rehabilitation. J. Range Manage., 37:483-487

Carlson, D.H., Personal Communications., 1999.

Carlson, D.H., T.L. Thurow, Knight, and Heitschmidt. 1990. Effect of Honey Mesquite on the Water Balance of Texas Rolling Plains Rangeland.

Carlson, D.H., T.L., Thurow. 1992. SPUR-91: Workbook and User Guide. Texas Agricultural Experiment Station, MP-1743.

Carlson, D.H., T.L. Thurow, and J.R. Wight. 1995. SPUR-91: simulation of production and Utilization of Rangelands. P. 1021-1068. In: V.P. Singh (ed.), computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Co.

Carlson, D.H., and T.L., Thurow. 1996. Comprehensive evaluation of the Improved SPUR Model (SPUR-91). Ecological Modeling. 85:229-240.

Connor, J.R., W.T. Hamilton and J.R. Connor. 1996. "ECON: An investment analysis procedure for range improvement practices". Texas Agricultural Extension Service, B-6041

Department of Rangeland Ecology and Management, Texas A&M University ___. Watershed Management.

Dugas, Hicks, and Wright. 1998. Effect of Removal of Junipereus ashei on Evapotranspiration and Runoff in the Seco Creek Watershed.

Dugas, Hicks, Wright and Lindemann. 1995. Effect of Removal of Junipereus ashei on Evapotranspiration and Runoff in the Seco Creek Watershed.

Dugas, W. A., H. S. Mayeux. 1991. Evaporation From Rangeland with and without Honey Mesquite. Journal of Range Management. 44:161-170.

Dye, Ueckert and Whisenant. 1995. Redberry Juniper-Herbaceous Understory Interactions.

Fulbright. 1999. Mesquite: Ecosystem Bandit or Benefactor.

Hamilton, W.T., B.R. Welch, B.G. Myrick, J.W. Lyons and J.R. Connor. 1993. "EXSEL: Export system for brush and weed control technology selection". In Proceedings of the American Society of Agricultural Engineers Annual Meeting. Spokane, Washington, 1993.

Hanselka and Falconer. 1994. Pricklypear Management in South Texas.

Hanselka, C.W., W.T. Hamilton and J.R. Connor. 1996. "Integrated Brush Management Systems (IBMS): Strategies and Economics". Texas Agricultural Extension Service, B-6041

Hanselka, Hamilton, and Conner. 1996. Integrated Brush Management Systems.(IBMS): Strategies and Economics.

Hanselka, Hamilton, and Rector. 1996. Integrated Brush Management Systems for Texas.

Heilman, P., D.S. Yakowitz, J.J. Stone, L.A. Kramer, L.J. Lane and B. Iman. 1993. An exploration of the economics of farm management alternatives to improve water quality.

Hester, Thurow, and Taylor. 1996. Hydrologic Characteristics of Vegetation Types as Affected by Prescribed Burning.

Hibbert. 1979. Managing Vegetation to Increase Flow in the Colorado River Basin.

Hicks and Dugas. 1998. Estimating Ashe Juniper Leaf Area From Tree and Stem Characteristics.

Holechek and Hess. 1994. Brush Control Considerations: A Financial Perspective.

Kaiser, Lesikar, Shafer, and Gerston. 1999. Water Management Strategies: Ranking the Options.

Knisel, W.G. 1980. CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S. Department of Agriculture Conservation Res. Report No. 26.

Knisel, W.G. and G.R. Foster. 1980. CREAMS, A System for Evaluating Best-Management Practices.

Kreuter, U.P., R.C. Rowan, J.P. Connor, J.W. Stuth and W.T. Hamilton. 1995. "Decision Support Software for Estimating the Economic Efficiency of Grazingland Production". Journal of Range Management. 1996.

Leonard, R.A., W.G. Knisel, and D.A. Still. 1987. GLEAMS: Groundwater Loading Effects on Agricultural management Systems. Trans. ASAE 30(5):1403-1428.

Lyons, Owens, and Machen __. Juniper Biology and Management in Texas.

McDaniel and Taylor. 1999. Steps for Restoring Bosque Vegetation Along the Middle Rio Grande of New Mexico.

McGinty, Cadenhead, Hamilton, Hanselka, Ueckert, and Whisenant ___. Chemical Weed and Brush Control Suggestions for Rangeland.

McGinty, Thurow, and Taylor. 1995. Improving Rainfall Effectiveness on Rangeland.

McIntosh, T.H., H. Qui, and H. Harris. 1993. Use of Agricultural computer Simulation Models for Water Quality-Land Management Decisions in N.E. Wisconsin. 36th Conf. Intnl. Assn. For Great Lakes Res., Program & Abstracts, 118.

Pierson, F.B., K.E. Spaeth, and M.A. Weltz. 1996. The Use of Models as Rangeland Management Decision Aids. Grazingland Hydrology Issues: Perspectives for the 21st Century.

Ranch, Ruschhaupt, Janak, and Davis. 1996-1997. Mechanical Brush Control.

Redeker, E., Personal Communications., 1999.

Redeker, Thurow, and Wu. 1998. Brush Management on Cusenbary Draw Watershed: History and Ramifications.

Renard, K.G. 1985. Artificial Intelligence and Natural Resource Modeling.

Richardson, Burnett, and Bovey. 1978. Hydrologic Effects of Brush Control on Texas Rangelands.

Ritchie, J.T. 1972. A Model for Predicting Evaporation from a Row Crop with Incomplete Cover. Water Resources Research, 8: 1204-1213.

Rosenthal, W.D., R. Srinivasan, and J.G. Arnold. 1995. Alternative River Management Using a Linked GIS-Hydrology Model. ASAE. Vol. 38(3):783-790.

Sauer, S. P. 1972. Factors contributing to Unusually Low Runoff During the Period 1962-68 in the Concho River Basin, Texas. Geological Survey Water-Supply Paper 1999-L. United Sates Government Printing Office, Washington.

Schuster. 1996. Soil and Vegetation Management: Keys to Water Conservation on Rangeland.

Scifres. 1980. Brush Management - Principles and Practices for Texas and the Southwest.

Society for Range Management. 1996. Grazingland Hydrology Issues: Perspectives for the 21st Century.

Srinivasan, R. and J.G. Arnold. 1994. Integration of a Basin-Scale Water Quality Model with GIS. Water Resources Bulletin. Vol. 30 (3):453-462.

Srinivasan, R., J.G. Arnold, R.S. Muttiah, and P.T. DYKE. 1995. Plant and Hydrologic Simulation for the Conterminous U.S.

Srinivasan, R., T.S. Ramanarayanan, J.G. Arnold, and S.T. Bednarz. 1998. Large Area Hydrologic Modeling and assessment Part II: Model Application. Journal of the American Water Resources Association. Vol. 35 (5):1037-1051.

Stephens and Walker. 1998. Saltcedar Control.

Stone, J.J., L.J. Lane, D.S. Yakowitz. 1994. Decision support system for natural resource and environmental protection.

Taylor. 1999. Summer Bruning in the Edwards Plateau: Is this a Scorched Earth Practice?

Teague, Borchardt, Ansley, Pinchak, Cox, Foy, and McGrann. 1997. Sustainable Management Strategies for Mesquite Rangeland: The Waggoner Kite Project.

Reinke, 1997. Two Least-Cost and Effective Juniper Control Case Studies. Texas A&M University Research Station at Sonora. Juniper Symposium 1994.

Texas Agricultural Experiment Station, Texas A&M University System. Juniper Symposium 1997.

Texas Agricultural Extension Service, Texas Agricultural Experiment Station. Brush Sculptors Symposium Proceedings 1997.

Texas Agricultural Extension Service. 1997. Selected Rangeland Weed and Brush Control Demonstrations.

Texas Agricultural Extension Service. 1998. Selected Rangeland Weed and Brush Control Demonstrations.

Texas State Soil and Water Conservation Board. 1991. A Comprehensive Study of Texas Watersheds and Their Impacts on Water Quality and Water Quantity.

Texas Water Development Board. 1997. Water for Texas Today and Tomorrow.

Thurow, T.L. 1996. Rangeland Watershed Research and Technological Needs for the Future. Grazingland Hydrology Issues: Perspectives for the 21st Century.

Thurow, T.L., A.P. Thurow and M.D. Garriga. 1999. Policy prospects for brush control to increase off-site water yield.

Upper Colorado River Authority. 1998. North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study.

U.S. Department of Agriculture, Soil Conservation Service. 1972. National Engineering Handbook, Hydrology Section 4, Chapters 4-10.

US Geological Survey Water-Supply Paper 1999-L. 1972. Factors Contributing to Unusually Low Runoff During the Period 1962-68 in the Concho River Basin, Texas.

Ward, George and Jennifer Benaman, 1999: MODEL FOR TMDL APPLICATION IN TEXAS WATERCOURSES: SCREENING AND MODEL REVIEW. Draft report to Texas Natural Resource Conservation Commission, Center for Research in Water Resources, University of Texas at Austin.

Welch. 1991. Brush Management Methods.

Weltz and Blackburn. 1993. Water Budget for South Texas Rangelands.

White and Hanselka 1994. Prescribed Range Burning in Texas.

Wight, J.R., and J.W. Skiles. 1987. Simulation of Production and Utilization of Rangelands. Documentation and User Guide. United Stat4es Department of Agricultural Research Service, ARS-63.

Williams, J.R., J.G. Arnold. 1993. A System of Hydrologic Models. Proceedings of the Federal Interagency Workshop on Hydrologic Modeling Demands for the 90's. USGS Water-Resources Investigations Report 93-4018:4-8.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A Modeling Approach to Determining the Relationship Between Erosion and Soil Productivity. Trans. ASAE 27(1):129-144.

Williams, J.R. and W.V. LaSeur. 1976. Water Yield Model Using SCS Curve Numbers. Journal of the Hydraulic Division, American Society of Civil Engineers, 102(HY9): 1241-1253.

Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. Simulator of Water Resources in Rural Basins. Journal of Hydraulic Engineering, American Society of Civil Engineers 111:970-986.

Yakowitz, D.S., J.J. Stone, L.J. Lane, P. Heilman, J. Masterson, J. Abolt and B.A. Iman. 1993. Decision support system for evaluating the effects of alternative farm management systems on water quality and economics.

Yakowitz, D.S., J.J. Stone, B. Iman, P. Heilman, L.A. Kramer and J.L. Hatfield. 1993. Evaluating management practices with a decision support system: An application to the MESA site near Treynor, Iowa.

Yakowitz, D.S. 1994. A regularized algorithm for solving two-stage stochastic linear programming problems: A water resource example.

APPENDIX

TEXAS WATER DEVELOPMENT BOARD

William B. Madden, *Chairman*
Elaine M. Barrón, M.D., *Member*
Charles L. Geren, *Member*

Craig D. Pedersen
Executive Administrator

Noé Fernández, *Vice-Chairman*
Jack Hunt, *Member*
Wales H. Madden, Jr., *Member*

February 2, 2000

Mr. Ron Luke
President
Research and Planning Consultants
7600 Chevy Chase Drive, Suite 500
Austin, Texas 78752

Re: Research Grant Contract Between the Research and Planning Consultants (RPC) and the Texas Water Development Board (Board), Contract No. 99-483-312, Draft Final Review Comments: "Assessment of Brush Control as a Water Management Strategy"

Dear Mr. Luke:

Staff members of the Texas Water Development Board have completed a review of the draft report under TWDB Contract No. 99-483-312 and offer comments shown in Attachment 1.

However, Item 5 in Attachment 1was not included or addressed in the Draft Final Report and as submitted does not meet contractual requirements. Therefore, please submit this item for review prior to delivery of the Final Report.

After review comments have been transmitted to RPC regarding the above referenced item, RPC will consider incorporating all comments from the EXECUTIVE ADMINISTRATOR and other commentors on the draft final report into the Final Report.

Please contact Mr. Mike Smith, the Board's designated Contract Manager, at (512) 936-6090, if you have any questions about the Board's comments.

Sincerely,

Tommy Knowles, Ph.D., P.E.
Deputy Executive Administrator
Office of Planning

Cc: Steve Mobley
Mike Smith

ATTACHMENT 1
TEXAS WATER DEVELOPMENT BOARD

Review Comments: "Assessment of Brush Control as a Water Management Strategy"
Contract No. 99-483-312

1. Please explain how hydrological extrapolation from test sites to larger areas (watersheds) for different vegetative regions was evaluated.

2. Page 3, first sentence; replace "geological" with "geologically."

3. Modify both the title and contents of Section 3, "The Benefits of Brush Control" to reflect both costs and benefits. Currently the subsections do not correlate to the Section title.

4. The cost of brush control is included but not the private benefits (states they are hard to ascertain). Please include a review of the net present value of internal rate of return and quantify any private benefits.

5. The report does not review available literature on decision models that rely on net present value or internal rate of return estimates as required in Task 1 of the Scope of Work (SOW). Please include a discussion on this section.

6. Page 12, paragraph 3, first sentence; change "verify" to "verifying"

7. Page 12, paragraph 4, fifth sentence; change "simulated" to "simulate"

8. Page 12, paragraph 5, first sentence; insert the word "the" between "of" and "hydrology"

9. Page 12, paragraph 5, fourth sentence; change "include" to "included"

10. Page 36, third paragraph, fifth sentence; insert "on" between "impact" and "the"

11. Page 46, fourth paragraph, fourth sentence; change wording of fourth sentence as follows; "The study projected that, initially, up to 6,914,177 acre feet per year might be saved, just slightly less..." Leave fifth sentence as it is written.

12. The value of brush control for public water supply during drought and an estimated cost/unit of water supply while identifying private benefits should be included.

13. The following locations need to be proof read as it appears that one or more words are missing from the intended text:
    Page 1; last paragraph, next to last sentence

Page 3, last paragraph, last sentence
Page 35, first paragraph, last sentence
Page 53, last paragraph, last two sentences

14. Page 51, second paragraph; page 53, second paragraph, the correct term is EQIP not EQUIP

General Comments

15. The report was in compliance with all aspects of the Scope of Work from an environmental perspective with one notable exception. The recent treatment of salt cedar in the upper Pecos River watershed with Arsenol by the Texas Department of Agriculture (Mr. Mike McMurry, Project Manager) was not cited. That is an important project in the control of phreatophytes in Texas and should be referred to in the final report.

16. Please give a detailed description of currently available state and federal programs for brush control and the direct benefits to the landowners. On the environmental side of the issue, there could have been discussion about the tax incentives for conservation easements for the improvement of critical habitat for any threatened or endangered species.

17. A letter to Regional Water Planning Group Members dated December 21,1999 regarding "State Agency Technical Assistance Related to Water Management Strategies" more specifically addresses the issue of water rights as discussed on page 47 of the report. The letter includes a Texas Natural Resource Conservation Commission Water Management Strategies Matrix. For the Proposed Water Strategy "Brush Control", the following potential water rights impacts are noted: "TNRCC does not regulate. Any increase in naturalized flows that were brought about via a brush control project would first be considered available to existing water rights of record that were not otherwise satisfied."

18. An additional suggested reference is a recent report entitled Water Management Strategies" Ranking the Options by Kaiser, Lesikar, Shafer, and Gerston. This report indicates in three of sixteen SB1 planning regions that brush management is both strongly preferred and believed to be feasible as a water management strategy.

Craig D. Pedersen
Executive Administrator

TWDB Board
William B. Madden, *Chairman*
Noé Fernández, *Vice-Chairman*
Elaine M. Barron, M.D., *Member*
Charles L. Geren, *Member*
Jack Hunt, *Member*
Wales H. Madden, Jr., *Member*

TEXAS PARKS & WILDLIFE

Andrew Sansom
Executive Director

TPWD Commission
Lee M. Bass, *Chairman*
Carol E. Dinkins, *Vice-Chair*
Ernest Angelo, Jr., *Member*
John Avila, Jr., *Member*
Richard (Dick) Heath, *Member*
Alvin L. Henry, *Member*
Katharine Armstrong Idsal, *Member*
Nolan Ryan, *Member*
Mark E. Watson, Jr., *Member*
Perry R. Bass, *Chairman-Emeritus*

TNRCC

Jeffrey A. Saitas
Executive Director

TNRCC Commissioners
Robert J. Huston, *Chairman*
Ralph Marquez, *Commissioner*
John Baker, Jr., *Commissioner*

December 21, 1999

Regional Water Planning Group Members

Re: State Agency Technical Assistance Related to Water Management Strategies

Texas Parks and Wildlife Department (TPWD), Texas Natural Resource Conservation Commission (TNRCC), and Texas Water Development Board (TWDB) are committed to assisting each planning region to assess environmental and permitting aspects of water development strategies they may contemplate as part of their planning responsibilities. We urge you to take advantage of these resources though the decision to do so or not is entirely up to the individual Regional Water Planning Groups. Towards that end our agencies have taken, or will commit to taking, the following specific actions.

1. TPWD and TWDB staff are non-voting members of all planning committees and routinely attend regional meetings. The staff are an important source of information and insight and they may be called upon at any time for assistance. If they do not know the answer, they can quickly find it. Some regions have made extensive use of this resource, others have not.

2. TPWD staff has assembled considerable information about Texas aquatic environments. An assessment of Texas rivers and streams that meet the criteria for designation as ecologically unique and an assessment of terrestrial impacts of many proposed reservoirs are two examples. All of this information has been assembled on the TPWD Internet site for ease of access.

3. TPWD and TNRCC staff have prepared initial evaluation matrixes for use by planning regions to assist members in review of water development strategies that may be considered in the regional water plan. Use of the matrixes should help prioritize those strategies as to potential environmental issues that will have to be addressed should that strategy be pursued.

4. TPWD and TNRCC will participate, along with other state and federal resource agencies, in a series of meetings (identified as "Clearinghouses") in the winter and early spring of 2000, to provide additional input relating to environmental and other permitting aspects of water management strategies.

While these actions will be helpful in environmental and other permitting assessments of water development strategies, it is important that regional planning committees do not wait on the clearinghouse meeting to consider environmental or other permitting issues associated with specific strategies. Due to the potentially large number of water management strategies that will be evaluated by regional water planning groups, use of the evaluation matrixes supplied by TNRCC, and TPWD may help prioritize strategies to maximize input from federal agencies. We suggest that Regional Water Planning Groups should take the time to prioritize strategies in this manner to maximize input from federal resource agencies.

In addition, TPWD and TNRCC staff are ready to provide that evaluation assistance right now, within available agency resources and regulatory constraints. While each region may certainly proceed as they feel best meets their needs, taking advantage of state agencies resources and expertise could provide the Regional Water Planning Groups with important information through which to advance planning efforts. Water development strategies will have to pass muster of both state and federal permitting processes. The state agencies have extensive experience in these matters and are ready to share that with the planning committees. Should regional committees wait until the clearinghouse process, state agencies will have the same constraints as federal agencies and the results will not be satisfactory for anyone. Please take advantage of state resources now.

To request technical assistance relating to water management strategies, please contact your TPWD or TWDB non-voting member or Nancy Baier of the TNRCC at 512-239-3550. Further information concerning the details and schedule of the Clearinghouses with state and federal agencies will be provided in the near future.

Respectfully,

Mr. Andrew Sansom, Executive Director
Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744

Respectfully,

Mr. Jeffrey A. Saitas, Executive Director
Texas Natural Resource Conservation Commission
P.O. Box 13087
Austin, Texas 78711-3087

Respectfully,

Craig D. Pedersen, Executive Administrator
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

Enclosures (2)

TNRCC

TEXAS NATURAL RESOURCE CONSERVATION COMMISSION
WATER MANAGEMENT STRATEGIES MATRIX
DECEMBER 1999

Potential concerns for water management strategies. Any proposed strategy that results in taking, impounding and using water from rivers, creeks and streams will require a permit from the TNRCC. Changing existing water rights requires analysis and amendment to that water right. This includes the transfer of water from one basin to another or the movement of a water right from its original location to another location for use. A way to prioritize strategies would be to consider the size of the amount transferred or the distance, the larger the amount or the longer distance of the water right move the more impact it will have on the proposed application. For more information about these issues or for additional assistance, contact Nancy Baier, Water Permits and Resource Management Division, (512) 239-3550 or nbaier@tnrcc.state.tx.us.

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
New Diversions or Reservoirs	Some of the problems that could be expected with a request for a new permit are: a) insufficient water available for appropriation; b) the expense involved in creating new reservoir projects (some of which may require the purchase of additional land to be used to mitigate environmental concerns); and c) flow restrictions for the protection of instream needs or downstream senior water rights. For projects which do not include municipal use, the Executive Director may recommend that a permit be granted when water is available for appropriation less than 100% of the time. The Executive Director generally does not recommend granting a new water right for municipal use in excess of a reservoir's firm yield. The Executive Director may make an exception if the applicant has an additional source of water that can be used during drought times.	New projects require a TWC (Texas Water Code) §11.121 water use permit application. Notice of the application will be sent to all of the water right holders in the river basin where the project is located and will also have to be published in a locally circulated newspaper. Before the Executive Director can recommend granting a new permit, staff must determine: a) if there is sufficient water available for appropriation; b) that the applicant has a sufficient water conservation and drought management plan; and c) that the project will not cause environmental damage. In addition, projects close to the coast must be in compliance with the Coastal Management Plan and with the policies of the Coastal Coordination Council.

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
New Interbasin Transfers	The law currently indicates that each of the interbasin transfers not included in the SB 1 exceptions would be junior in priority to all of the other water rights in the basin of origin. A permit allowing an interbasin transfer may be conditioned to avoid or mitigate adverse environmental impacts such as degradation of water quality, significant reduction of freshwater inflows to the bays and estuaries, or the introduction of exotic species to the receiving stream/basin.	A request for a new interbasin transfer (even for an existing water rights permit) would require permitting under a §11.121 permit application or a §11.122 amendment application. The easiest interbasin transfers to obtain are those included in the exceptions under Senate Bill 1 (SB 1 - 75th legislative session) related to such transfers. These exceptions are only for existing water rights where the water may be used in a coastal basin adjacent to the basin of origin or in a river basin that happens to be within the service area of a city or county that includes water in both/multiple basins. A request for an interbasin transfer that is not included in the SB 1 exceptions requires a comprehensive notice, justification for the need of the water in the receiving basin and proof that the future need in the basin of origin would not be harmed by the interbasin authorization.
Aquifer Storage & Recovery	A conservation tool to store water in underground aquifers. Some areas of concern could include: a) water quality (both of the water existing in the aquifer and the water to be stored in the aquifer) and b) ability to retrieve the water (whether or not the hydrological features of the aquifer would actually contain and release the water)	A Water Use permit or amendment would be required

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
Adjustment of Falcon/Amistad Reservoir System Allocations	Water Rights are a property right and the rights in this area were determined pursuant to a lawsuit.	These authorizations are the result the Lower Rio Grande Valley lawsuit. An additional lawsuit or some legislative override might be necessary for reallocation. This issue should be explored in more detail with the Legal Division and the Rio Grande Watermaster.
Re-channeling of the Rio Grande Below Ft. Quitman	Not a water rights issue	Texas (and the United States) share the Rio Grande as a common border this would require coordination between the United States and Mexico, including the International Boundary & Water Commission, other parties in the Rio Grande Compact and the U.S. Army Corps of Engineers.
Reservoir Systems Operation	Operation of more than one reservoir as a system generally increases availability and flexibility in providing water to customers.	The water use permits authorizing the reservoirs would need to be amended to allow systems operation.
Brush Control	TNRCC does not regulate. Any increase in naturalized flows that were brought about via a brush control project would first be considered available to existing water rights of record that were not otherwise satisfied.	
Enhanced Spring Flows to Increase Edwards Aquifer Allocation	The TNRCC does not regulate groundwater. Coordinate with Edwards aquifer Authority.	This is a project under the jurisdiction of the Edwards Aquifer Authority.

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
Reuse	One consideration in developing a reuse system is that the quality of the reclaimed water be appropriate for its intended use. Higher level uses, such as irrigation of public lands or consumable crops without processing require a higher level of wastewater treatment prior to reuse than will lower level uses, such as pasture irrigation. "Indirect" reuse of water subject to special conditions to protect affected water rights and environmental flow needs. May also require water availability review. "Direct" reuse of wastewater may serve to reduce pollutant loadings to a water body, however, the reduction or cessation of effluent flows may also impact the availability of instream flows. In many areas where wastewater discharges have occurred over an extended period of time, the flora and fauna (as well as downstream water right holders) have adapted and, in some cases, become dependent on that discharged water.	This could be initially requested in a §11.121 water use permit application or may require an amendment (TWC §11.122) to an existing right (authorization to use the bed and banks of a stream to convey wastewater from a discharge point to a downstream diversion point may need to be requested in either application). If the reuse is "direct" (diverted from the treatment plant and used prior to discharge into a watercourse), there would be very little technical review done on the project. Normally the associated wastewater permit would also need to be amended. If the reuse is "indirect" (diverted after the water has been discharged into a watercourse), the application could encounter the same concerns occurring for a new water rights project. If the request for "indirect" reuse is for water that has not been historically discharged into a watercourse, there is a possibility that the only review that would be done would be to estimate the amount of water lost between the discharge point and the diversion point.
Import of Groundwater	The import of groundwater is only an issue for the Water Rights Permitting & Availability Section if the bed and banks of a stream are used to transport the groundwater.	The bed and banks authorization would have to be permitted under a new authorization or amendment to an existing water right.

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
Chloride Control Projects	Chloride Control is a water quality issue for the most part. Some specific projects are discussed below: Red River Basin the US Army Corps of Engineers has done some work in this basin with significant plans for more. This would make the water in Lake Texoma more useful for municipalities. However, many of the recreation interests around the Lake are opposed to these projects because they fear improved water quality will result in more use and thus lower lake levels. Also, the environmental/recreation community are convinced that chlorides are beneficial for the striped bass population. Brazos Basin - The Brazos River Authority has done some feasibility studies. Also, a consultant has approached the TNRCC about depleting a saline aquifer that discharges into a tributary of the Brazos River upstream of Possum Kingdom Reservoir. It appears that the development of an area to pump the brine into to allow evaporation is one of the expensive stumbling blocks. This water body is not documented well enough in the TNRCC "affected water bodies" list to enable or encourage the EPA to become involved. Rio Grande (Pecos) - The Red Bluff Water Power Control District and The Pecos River Compact Commission are pursuing a project similar to the Brazos plan approximately 15 miles upstream of the Texas New Mexico state line. No chloride reduction has been accomplished to date, mainly for the same reason as in the Brazos Basin project above.	Any chloride control project that includes an impoundment within a watercourse would require a water use permit and would be subject to all applicable permitting requirements and technical review.
Pipeline from Falcon Reservoir to the Lower Rio Grande Valley	Currently water is transported from the reservoir either down the Rio Grande or through open canals. Use of a pipeline for transport would increase the efficiency of the delivery of the water by eliminating channel losses. Lane easements for pipeline construction might be required. This issue is being explored in more detail with the Rio Grande Watermaster and local planning groups.	The existing Certificates of Adjudication (approximately 900) might need to be amended if there is a change in the diversion point.

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
Sediment Removal in Existing Reservoirs	There may be significant water quality concerns with dredging up sediments which have accumulated in large reservoirs. Since most reservoirs are authorized to impound a specific amount of water, there is no need to amend a water right to recover storage lost to sediment. As for sediment gathering structures upstream of large municipal supply reservoirs, these structures would require a new permit but would likely be something the agency could easily support, since they would require very little water to be available to justify. Also, it should be noted that the new water availability models (WAM's) can be modified to determine the yield of all large reservoirs with "as built" parameters and Year 2000 sedimentation levels. In addition, preliminary analysis of the new Neches WAM has introduced the idea that term water right availability may be offset by the loss of efficiency in large reservoirs due to sedimentation (less ability to store water and increased evaporation losses for the same quantity of water in storage). There may be significant water quality concerns with dredging up sediments which have accumulated in large reservoirs. In some instances, toxic pollutants and heavy metals bound to sediments in the bottom of reservoirs could be reintroduced into the water column, exposing biological communities to risk. Reservoirs of concern appear on the Clean Water Act 303(d) List of Threatened or Impaired Water Bodies.	Developing and implementing appropriate best management practices to remove sediments by avoiding or minimizing sediment resuspension may prove to be beneficial to both water quantity and quality.

Proposed Water Strategy	Potential Water Rights Impacts	General Actions
New or Expanded Drinking Water Supplies The TNRCC has adopted a Regionalization Initiative which may impact development of new retail drinking water supply entities. Before a new public drinking water system can be created extensive efforts must be made by a new applicant to obtain water service from a neighboring system or regional provider.		
A. Public Water System	New public water systems must demonstrate adequate financial, managerial and technical capability before construction can begin. Water quality must meet State and Federal standards. If an existing public water system has lines within ½ mile, a proposed system must first apply for service from the existing provider.	Applications for service from neighboring systems, if within ½ mile, must be initiated. If service is not available, engineering plans must be submitted & approved prior to construction and in some instances a business plan may also be required. Plan approval can take from 30 to 60 days or longer if a business plan is required.
B. Certificate of Convenience and Necessity (CCN) (A CCN is required for all investor owned utilities and water supply corporations. It may also be required for cities and districts if they want to serve where service is already being lawfully provided.)	The existence of a retail water supplier holding a CCN may limit the expansion or development of water supply systems and require use of existing suppliers. A new CCN applicant must demonstrate adequate financial, managerial and technical capability before construction can begin.	If there are existing CCN holders within 2 miles of the proposed service area, a new applicant must apply for service from the neighboring provider. If service is not available, a CCN application is filed with TNRCC and public notice is provided. An applications typically takes 6 months to process, but if it is contested hearings may delay a decision for up to 12 months.
C. District Creations	The existence of a retail water supplier in the area may limit the creation of a district to supply water and require use of existing suppliers. A new District must possess financial, managerial and technical capability.	The requirements for public water systems above would apply to a district supplying drinking water as would potential overlaps with existing CCN areas. In addition, an application and public notice are required. Special care must be taken when selecting the type of district to ensure it has the proper powers.

Attachment A
Texas Natural Resource Conservation Commission
Authority over Water Systems

		Non-Community		Community Water Systems						
Requirements		Non-Trans	Trans	Non-Util	IOU	WSC	Affctd Cos	Dists	Cities	Authority 30 TAC §
Must apply for service from neighboring system		✔	✔	✔	✔	✔	✔	✔	✔	290.39(c)(1)
Engineering Plan Review		✔	✔	✔	✔	✔	✔	✔	✔	290.39(c)(2)
Business Plan		✔[1]	✔	✔	✔		✔			290.39(c)(2)(a)
Financial Assurance	290	✔	✔	✔	✔	✔	✔	✔	✔	290.39(f)
	291				✔	✔	✔	✔[3]	✔[3]	291.102(d)
Must demonstrate FMT	290	✔	✔	✔	✔	✔	✔	✔	✔	290.39(a) & (b)
	291				✔	✔	✔	✔[3]	✔[3]	291.102
	293							✔		293.59
Adequacy of supply	290	✔	✔	✔	✔	✔	✔	✔	✔	290
	291				✔	✔	✔	✔[3]	✔[3]	291.93(a)
Quality of supply	290	✔	✔	✔	✔	✔	✔	✔	✔	290
	291				✔	✔	✔	✔[3]	✔[3]	291.93(b)
	293							✔		293.43
CCN					✔	✔	✔	✔[2]	✔[2]	291.102

Notes:
[1] Must provide business plan unless the owner has previously provided financial assurance to the Commission.
[2] Not required, but entity may request a CCN
[3] Not subject to these provisions unless the entity applies for a CCN

Texas Natural Resource Conservation Commission
Classification of Requirements by Type of System

Type of Entity	Classification of Requirements		
	Financial	**Managerial**	**Technical**
Municipalities	✓Financial Assurance ✓If CCN requested, must adequately complete FMT portion of CCN application ✓Plan review ✓Must adequately demonstrate FMT	✓Must apply for service from neighboring system ✓Adequacy of Supply ✓CCN, if requested by city ✓If CCN requested, must adequately complete FMT portion of CCN application ✓Plan review ✓Must adequately demonstrate FMT	✓Plan review ✓Quality of Supply ✓If CCN requested, must adequately complete FMT portion of CCN application ✓Must adequately demonstrate FMT
Districts	✓Financial Assurance ✓If CCN requested, must adequately complete FMT portion of CCN application ✓Creation & Bond Issue Reviews ✓Plan review ✓Must adequately demonstrate FMT	✓Must apply for service from neighboring system ✓Adequacy of Supply ✓CCN, if requested by district ✓If CCN requested, must adequately complete FMT portion of CCN application ✓Creation & Bond Issue Reviews ✓Plan review ✓Must adequately demonstrate FMT	✓ Plan review ✓Quality of Supply ✓Adequacy of Supply ✓If CCN requested, must adequately complete FMT portion of CCN application ✓Creation & Bond Issue Reviews ✓Must adequately demonstrate FMT

Texas Natural Resource Conservation Commission
Classification of Requirements by Type of System (Cont.)

Type of Entity	Classification of Requirements		
	Financial	**Managerial**	**Technical**
Affected Counties	✓Business Plan ✓Financial Assurance ✓Must adequately demonstrate FMT ✓Plan review	✓Business Plan ✓Must apply for service from neighboring system ✓Adequacy of Supply ✓Must adequately demonstrate FMT ✓CCN ✓Plan review	✓Plan review ✓Quality of Supply ✓Adequacy of Supply ✓Must adequately demonstrate FMT
Water Supply Corporations (WSCs)	✓Financial Assurance ✓Must adequately demonstrate FMT ✓Plan review	✓Must apply for service from neighboring system ✓Adequacy of Supply ✓Must adequately demonstrate FMT ✓CCN ✓Plan review	✓Plan review ✓Quality of Supply ✓Adequacy of Supply ✓Must adequately demonstrate FMT
Investor Owned Utilities (IOUs)	✓Business Plan ✓Financial Assurance ✓Must adequately demonstrate FMT ✓Plan review	✓Business Plan ✓Must apply for service from neighboring system ✓Adequacy of Supply ✓Must adequately demonstrate FMT ✓CCN ✓Plan review	✓Plan review ✓Quality of Supply ✓Adequacy of Supply ✓Must adequately demonstrate FMT

Texas Natural Resource Conservation Commission
Classification of Requirements by Type of System (Cont.)

Type of Entity	Classification of Requirements		
	Financial	Managerial	Technical
Non-Utilities	✓Business Plan ✓Financial Assurance ✓Must adequately demonstrate FMT ✓Plan review	✓Business Plan ✓Must apply for service from neighboring system ✓Adequacy of Supply ✓Must adequately demonstrate FMT ✓Plan review	✓Plan review ✓Quality of Supply ✓Adequacy of Supply ✓Must adequately demonstrate FMT
Non-Community Non-Transient	✓Business Plan (unless previous financial assurance has been provided to TNRCC) ✓Financial Assurance ✓Must adequately demonstrate FMT ✓Plan review	✓Business Plan (unless previous financial assurance has been provided to TNRCC) ✓Must apply for service from neighboring system ✓Adequacy of Supply ✓Must adequately demonstrate FMT ✓Plan review	✓Plan review ✓Quality of Supply ✓Adequacy of Supply ✓Must adequately demonstrate FMT
Non-Community Transient	✓Business Plan ✓Financial Assurance ✓Must adequately demonstrate FMT ✓Plan review	✓Business Plan ✓Must apply for service from neighboring system ✓Adequacy of Supply ✓Must adequately demonstrate FMT ✓Plan review	✓Plan review ✓Quality of Supply ✓Adequacy of Supply ✓Must adequately demonstrate FMT

Attachment B
Texas Natural Resource Conservation Commission

District Powers and Duties
(For General Law Districts Only)

Type of District	Statute	Constitutional Authority *	Creating Entity **	Regulate Groundwater	Supply Untreated Water	Supply Treated Water	Drainage & Flood Control	Street Lighting	Road Powers	Irrigation	Navigation	Eminent Domain	Recreation	Hydroelectric	Tax Bond Authority	Comments
Municipal Mgmt. Dist.	Local Govt. Code Ch. 375	Both	TNRCC		✔	✔	✔	✔	✔				✔	✔	✔	
Regional Dist.	Texas Water Code Ch. 59	XVI, 59	TNRCC		✔	✔	✔			✔	✔	✔	✔	✔	✔	
Water Control & Improv. Dist.	TWC Ch. 51	XVI, 59	CC or TNRCC		✔	✔	✔			✔	✔	✔		✔	✔	A
Water Control & Improv. Dist.	TWC Ch. 51	III, 52	CC or TNRCC		✔		✔			✔	✔	✔			✔	
Groundwater Conserv. Dist.	TWC Chs. 35, 36 & 52	XVI, 59	TNRCC	✔	✔	✔	✔					✔			✔	B
Fresh Water Supply Dist.	TWC Ch. 53	XVI, 59	CC		✔	✔						✔			✔	
Municipal Utility Dist.	TWC Ch. 54	XVI, 59	TNRCC		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	
Water Improv. Dist.	TWC Ch. 55	XVI, 59	CC or TNRCC		✔	✔	✔			✔		✔			✔	
Water Improv. Dist.	TWC Ch. 55	III, 52	CC or TNRCC		✔		✔			✔		✔			✔	
Drainage Dist.	TWC Ch. 56	Both	CC				✔					✔			✔	
Levee Improvement Dist.	TWC Ch. 57	XVI, 59	CC				✔					✔			✔	
Irrigation Dist.	TWC Ch. 58	Both	CC or TNRCC		✔		✔			✔		✔			✔	
Navigation Dist.	TWC Ch. 61	III, 52	CC								✔	✔			✔	C
Navigation Dist.	TWC Ch. 62	XVI, 59	CC				✔				✔	✔			✔	C
Self-Liquidating Nav. Dist.	TWC Ch. 63	XVI, 59	CC		✔		✔			✔	✔	✔			✔	C
Special Utility Dist.	TWC Ch. 65	XVI, 59	TNRCC		✔	✔	✔			✔		✔				
Stormwater Control Dist.	TWC Ch. 66	XVI, 59	TNRCC				✔					✔			✔	
Investor Owned Utilities	TWC Ch. 13		N/A			✔										D
Water Supply or Sewer Service Corporation	TWC Ch. 67		N/A			✔										E

NOTES: The name given to a district (MUD, WCID, etc.) does not always indicate which primary statute it operates under. For example, Blue River MUD may operate as a WCID or a FWSD.

The powers for special law districts are dictated by each district's enabling legislation.

General law district powers may be limited under a given category. Powers that all general law districts have include: regional waste disposal (including sewage)—Texas Water Code Section 30.021; enforcement by police officers—Texas Water Code Sections 49.216 and 60.077; issue revenue bonds (specific general laws); and levy operation and maintenance tax—Texas Water Code Section 49.107. Additionally, general law districts that provide potable water or wastewater services to household users have the power to provide fire fighting services—Texas Water Code Section 49.351.

*Under the column heading *Constitutional Authority*, the phrase "both" means that both Article 16, Section 59 and Article 3, Section 52 of the Texas Constitution apply.

**Under the column heading *Creating Entity*, the phrase "CC" means created by a local county commissioners court.

A—Voter approval required for revenue bonds.

B—Regulate well spacing and production.

C—Port operation and regulation.

D—TNRCC has original rate jurisdiction.

E—TNRCC has appellate rate jurisdiction.

TNRCC REGULATORY GUIDANCE

Attachment C

Water Utilities Division, Utility Rates & Services Section 512/239-6960
RG-245 FAX 512/239-6972
October 1999

SUBJECT: TNRCC Jurisdiction—Utility Rates & Service Policies

When Do Utilities Come under TNRCC Rate Jurisdiction?

(For explanation of abbreviations used in this chart, see next page)

Utility Service Provider	TNRCC Rate Jurisdiction			
	Retail			Wholesale, Appellate
	Original	Appellate	Notice to Customers Required?	
IOU - Outside City	Yes	N/A	Yes	Yes
IOU - Inside City	No Unless city surrenders its jurisdiction to TNRCC	Yes 10% customer protest or on request from party to rate case before city	Yes	Yes
Exempt IOU	Yes	N/A	Yes	Yes
WSC	No	Yes 10% customer protest	No	Yes
Exempt WSC	No	Yes 10% customer protest	No	Yes
District	No	Yes In-district customers - 10% Out-of-district customers-10%	In-district - No Out-of-district - Yes*	Yes
Affected County	No	Yes 10% customer protest	Yes*	Yes
Counties (excl. Affected Co.)	No	No	No	No
City - Only out-of-city customers	No	Yes 10% customer protest	Yes*	Yes

* Notice must tell old rates, new rates, and effective date. TNRCC recommends you also tell the customer he can appeal.

When Must Utilities Obta a CCN and Observe TNRCC riff and Service Policies?

(For explanation of abbreviations used in this chart, see below)

Utility Service Provider	CCN Required?	TNRCC Tariff and Service Policies Apply?
IOU - Outside City	Yes	Yes
IOU - Inside City	Yes	Yes If city does not adopt its own
Exempt IOU	No*	Yes
WSC	Yes	No But must file tariff with TNRCC
Exempt WSC	No*	No But must file tariff with TNRCC
District	No*	No
Affected County	Yes	Yes
Counties (Excl. Affected Co.)	No*	No
City	No*	No

* Unless serving within another utility service provider's lawful service area.

Terms Used in This Guidance Document

Affected County. Certain counties located within 50 miles of an international border, known as "affected counties," given specific authority to provide water or sewer utility service under Chapter 13 Water Code.

CCN, Certificate of Convenience and Necessity. Authorizes a utility to provide water or sewer utility service to a specific area and obligates the utility to provide continuous and adequate service to every customer who requests service in that area.

District. A "district" created by the legislature or under the Texas Water Code. Also known as a MUD (Municipal Utility District), FWSD (Fresh Water Supply District), WCID (Water Control and Improvement District), SUD (Special Utility District) or PUD (Public Utility District).

Exempt IOU or Exempt WSC. A Water or Sewer Utility or Water Supply Corporation with less than 15 potential service connections.

IOU, Investor-Owned Utility. See definition of *Water and Sewer Utility*

Retail Public Utility. Any person, corporation, public utility, water supply or sewer service corporation, municipality, political subdivision, or agency operating, maintaining, or controlling in this state facilities for providing potable water service or sewer service, or both, for compensation.

Water and Sewer Utility ("Utility"):

❑ **any** person, corporation, cooperative, affected county, or any combination of those persons or entities, or their lessees, trustees, and receivers,

❑ **that own and operate for compensation** in this state equipment or facilities for (1) production, transmission, storage, sale, distribution, or provision of **potable water** to the public or for the resale of potable water to the public for any use; or for (2) collection, transportation, treatment, or **disposal of sewage** or other operation of a sewage disposal service to the public.

❑ **The term "utility" excludes** any person or corporation not otherwise a public utility that furnishes the services or commodity only to itself or to its employees or tenants as an incident of that employee service or tenancy when that service or commodity is not resold to or used by others.

The term "utility" (by itself) also excludes any municipal corporation, water supply or sewer service corporation, or a political subdivision of the state. These are referred to as a "retail public utility" (see preceding definition of that term).

WSC, Water Supply Corporation. A nonprofit water supply and sewer services corporation owned and controlled by its members.

Attachment D
Texas Natural Resource Conservation Commission
Weather Modification Licenses and Permits

Licenses

A valid Texas weather-modification license is issued for the duration of a fiscal year. A licensee may request renewal of a license, but only for the length of a new fiscal year. The licensee can be either an individual or an organization.

Requirements for a license are: applicant must submit a completed license application and pay a license fee of $150. The application must identify the person(s) who will be in control and in charge of day-to-day weather-modification operations. The person(s) to be licensed must furnish resumes and other pertinent data and information on their academic background, technical training and experience.

Permits

Only a Texas weather-modification licensee may obtain a weather-modification permit. A licensee can hold one, or any number of, permits. A permit is required for each individual project to be conducted by the licensee. A permit can be for any length up to a maximum of four years.

A licensee seeking a permit must furnish the TNRCC a completed application along with a permit fee of $75. The application must contain:

1. A comprehensive Operations Plan, to be approved by the TNRCC staff and the TNRCC Weather Modification Advisory Committee;
2. Proof of liability insurance coverage; and
3. A draft Notice of Intention to Engage in Weather Modification Activities.

Once the draft Notice is approved by the TNRCC, the Notice must be published, once a week for three consecutive weeks, in the area to be affected by the proposed weather-modification operation. Proof of publication (affidavits from newspapers) must be furnished the TNRCC once the publication process is completed.

Potential Environmental Impacts Associated with Water Development Strategies

Environmental assessments to determine extent of impacts on threatened and endangered species, critical vegetation types and water quality/quantity issues are required for major water development projects. Major project sponsors will also need to determine if instream flow and/or freshwater inflow study results are available. If study results are not available, environmental planning criteria may be used for planning but detailed, site-specific studies will be required for permitting. Proposed project types below are listed in order of generally more environmentally impacting to those projects having the least environmental impacts. More information concerning sensitive natural resources can be found on the Texas Parks and Wildlife Department web site: http://www.tpwd.state.tx.us/conserve/sb1/index.htm. Documents describing natural resource issues within the context of natural resource management and protection may be found on the Department's web site as well.

Proposed Water Strategy	Potential Environmental Impacts	General Actions
On-Channel Reservoir	Direct impacts: inundation and loss of habitat types such as terrestrial, wetland, riverine, riparian and bottomland hardwoods Indirect impacts: reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods Changes in water quality conditions Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Changes to sediment transport processes Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Mitigation required to compensate for terrestrial wetland, riverine, and riparian habitats and bottomland hardwoods inundated by the reservoir and dam Mitigation required to compensate for terrestrial and wetland habitat lost or altered downstream of reservoir and dam Reservoir pass-throughs required to provide daily instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats, aquatic and terrestrial communities and ecosystem processes Reservoir pass-throughs required to prevent degradation of water quality Over-banking flows recommended to maintain riparian and bottomland hardwood habitats and floodplain connectivity and seasonal channel maintenance flows recommended to maintain sediment transport and scouring processes

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Off-Channel Reservoir	Direct impacts: inundation and loss of habitat types such as terrestrial, wetland, riverine, riparian and bottomland hardwoods Indirect impacts: reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods Changes in water quality conditions Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Changes to sediment transport processes Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Mitigation required to compensate for terrestrial wetland, riverine, and riparian habitats and bottomland hardwoods inundated by the reservoir and dam Mitigation required to compensate for terrestrial and wetland habitat lost or altered downstream of reservoir and dam Reservoir pass-throughs required to provide daily instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats, aquatic and terrestrial communities and ecosystem processes Reservoir pass-throughs required to prevent degradation of water quality Over-banking flows recommended to maintain riparian and bottomland hardwood habitats and floodplain connectivity and channel maintenance flows recommended to maintain sediment transport and scouring processes

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Chloride Control	Reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods Changes in water quality conditions Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Brine disposal and contaminants issues Ecological changes in aquatic communities adapted to highly saline environment Changes to sediment transport processes Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Recommend studies to ensure survival of species dependent on physical and chemical conditions of the highly saline environment Brine disposal and contaminants rules and guidelines must be followed Contaminants monitoring or test wells may be required Mitigation required to compensate for terrestrial wetland, riverine, and riparian habitats and bottomland hardwoods inundated by the reservoir and dam Mitigation required to compensate for terrestrial and wetland habitat lost or altered downstream of reservoir and dam

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Interbasin Transfer	Reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods in both basin of origin and receiving basin Changes in water quality conditions in both basin of origin and receiving basin Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Changes to sediment transport processes Possible transfer of exotic, nuisance, or atypical species to receiving basin Possible transfer of disease and/or parasites Possible hybridization of similar, but genetically distinct species Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Reservoir pass-throughs required to provide daily instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats, aquatic and terrestrial communities and ecosystem processes Mitigation required to compensate for terrestrial and wetland habitat lost or altered downstream Over-banking flows recommended to maintain riparian and bottomland hardwood habitats and floodplain connectivity and channel maintenance flows recommended to maintain sediment transport and scouring processes Removal of exotic, nuisance, or atypical species through water treatment or other means Requirements to prevent degradation of water quality in basin of origin and receiving basin

Proposed Water Strategy	Potential Environmental Impacts	General Actions
New Direct Diversion	Reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods Changes to sediment transport processes Changes in water quality conditions Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Diversion restrictions required to provide daily instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats, to maintain water quality standards, and ecosystem processes Mitigation recommended to compensate for terrestrial and wetland habitat lost or altered downstream Over-banking flows recommended to maintain riparian and bottomland hardwood habitats and floodplain connectivity and channel maintenance flows recommended to maintain sediment transport and scouring processes
Groundwater pumping	Possible reduction, alteration or cessation of springflow due to groundwater level decline Possible reduction in baseflows of rivers and streams that cross aquifer outcrop areas Subsidence with corresponding loss of shoreline, riparian and shallow water, nearshore habitat Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Pumping limits recommended to protect aquatic ecosystems. Pumping limits may be required to protect endangered species Prevent subsidence by following subsidence district rules and regulations

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Water marketing	Reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods Changes to sediment transport processes Changes in water quality conditions Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Diversion restrictions required to provide daily instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats, to maintain water quality standards and ecosystem processes Mitigation recommended to compensate for terrestrial and wetland habitat lost or altered downstream Diversion limits required to prevent degradation of water quality Over-banking flows recommended to maintain riparian and bottomland hardwood and floodplain connectivity and channel maintenance flows recommended to maintain sediment transport and scouring processes
Rechannelization or in-channel brush control	Alteration and/or loss of instream and riparian habitat Changes to sediment transport processes Increased sediment runoff and erosion Reduction in groundwater discharge Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Consultation with TPWD recommended

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Brush Control	Alteration of terrestrial habitat Increased sediment runoff and erosion Impacts from chemical control measures Potential for increased groundwater recharge Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Consultation with TPWD recommended
Aquifer Storage and Recovery	Reduction and/or alteration of downstream habitat types such as riverine, estuarine, riparian, wetland, and bottomland hardwoods Changes to sediment transport processes Changes in water quality conditions Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Diversion restrictions required to provide daily instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats, to maintain water quality standards and ecosystem processes Mitigation recommended to compensate for terrestrial and wetland habitat lost or altered downstream Diversion limits required to prevent degradation of water quality Over-banking flows recommended to maintain riparian and bottomland hardwood habitats and floodplain connectivity and channel maintenance flows recommended to maintain sediment transport and scouring processes

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Sediment removal from existing reservoirs	Resuspension of sediments and possible contaminants Disposal of potentially contaminated sediments Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Laboratory sediment analysis required prior to disposal of sediments
Desalinization	Alteration of brackish water habitat Brine disposal Alteration of water quality Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Brine disposal rules and guidelines must be followed Consultation with TPWD recommended

Proposed Water Strategy	Potential Environmental Impacts	General Actions
Reuse	Reduction and alteration of instream flows, over-banking flows and freshwater inflows to bays and estuaries relative to magnitude, timing, and frequency of hydrologic events Changes to sediment transport processes Changes in water quality conditions Concentrations of salts, nutrients and contaminants Impacts to aquatic and terrestrial communities and ecosystem processes Influence on energy and nutrient inputs and processing	Bed and banks permit restrictions required to provide instream flows and freshwater inflows on a seasonal or monthly basis to conserve and protect downstream habitats Permit restrictions required to prevent degradation of water quality and to maintain water quality standards
Water Conservation	Positive impact	None required