# Ecosystem and Wildlife Implications of Brush: Management Systems Designed to Improve Water Yield

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As the purpose of this project is to pave the way for implementation of a program of restoration on rangelands and the quality and quantity of percolation and runoff, a major player is the landowner. It is essential to gain insight on attitude regarding such a program and some definition of willingness and ability to pay in a cost-share program. Those landowners who participated in the stakeholder meetings have our deepest gratitude for contributing their time and their honesty.

Last, the Texas State Soil and Water Board is acknowledged for participating and supporting the research that expands on their program by adding the eco-system component. Any federal-state program that might evolve will surely include the Texas State Soil and Water Conservation Board.

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# Ecosystem and Wildlife Implications of Brush Management Systems Designed to Improve Water Runoff and Percolation

## Summary and Overview

With the settlement of Texas and establishment of ranchers to produce cattle, there was an effort to maximize beef production. This caused serious overgrazing. In addition, there was a reduced incidence of fires across the landscape to clear out brush. These factors led to deterioration of the grazing lands and provided an opportunity for invasive intrusion by brush and other species onto the land and riparian zones. There has been a large-scale conversion from grasslands and savannahs to wildlands over the last 150 years (Scholes and Archer, 1997). The overall impacts are significantly impaired uplands and reduced percolation and surface flow of water from rainfall which caused changes and loss in basic aquatic and terrestrial habitat.

The State of Texas adopted a program to study and implement brush management systems across the state to improve the water availability in streams, rivers, reservoirs and aquifers, as well as to improve the rangelands. The feasibility studies have shown great promise for improving ranchland and improving the water situation. However, there is less known about the aquatic and wildlife species response implications of brush management. Certainly, there are opportunities for improving the viability of an ecosystem through brush management strategies and continuing management practices. The purpose of this study was to evaluate the changes in hydrology and biological diversity associated with brush management in two watersheds where significant data was already available.

This study focused on assessing the aquatic and terrestrial species implications related to specified brush management strategies over time. This involved an integrated analysis including modeling of the landscape, assessing biological diversity and developing economic implications for the two watersheds (Twin Buttes and Edwards regions). Thus, this study is comprised of three parts: modeling of brush management strategies temporally, assessing biological diversity (aquatic and terrestrial) and estimating economic implications. This represents a complex analysis involving variable units and multiple disciplines.

Previous feasibility studies of brush removal have been targeted at maximizing water runoff. This analysis is an extension that is designed to examine the implications of brush management under a more restrictive set of brush removal criteria that were chosen based upon wildlife considerations. To achieve the integration of hydrologic modeling, range ecology, and economic implications, there were three team meetings bringing together all components to review status and set priorities for the remainder of the work. In addition, scientists in the three basic groups of specialization interacted daily along with representatives of the Corps of Engineers to assure that each decision was reflected in other parts of the analyses. The major addition of this analysis to brush management feasibility studies being conducted as part of the Texas brush management plan is the consideration of wildlife and aquatic biota and assessing changes in biological diversity likely to result from alternative brush management scenarios.

## Objectives

Due to the multiple resources considered in this study, the objectives are organized to show methods and implications for each resource. Objectives covering all aspects of the study are as follows:

*Hydrologic Modeling:* Quantify hydrologic parameters of alternative brush management strategies that address wildlife implications.

*Economics/Range:* Identify and describe selected alternative "wildlife-friendly" ecological restoration techniques and materials requirements for the dominant brush-type categories/ecosites within the Twin Buttes watershed and the Edwards Aquifer Recharge Zone watershed.

- Determine the direct and indirect (opportunity) costs of implementing and maintaining each brush and land management practice. Delineate the types and proportions of benefits and costs accruing to participating landowners as opposed to the general public.
- Identify and describe alternative legal instruments (contracts, leases, easements, etc.) that could potentially be used with participating landowners to entice their cooperation in implementing and maintaining the brush control and additional conservation measures and insure their compliance with the accompanying land use and other requirements.
- Survey landowners in the targeted watershed to determine their attitudes toward and likelihood of participation in programs designed to initiate the "wildlife-friendly" ecological restoration practices under provisions of the different legal instruments with an array of possible cost shares for both direct and indirect implementation and maintenance costs

*Terrestrial/Aquatic:* The previous studies are to be extended beyond the comparison of future brush management scenarios' impacts on runoff and percolation to the likely impacts on terrestrial and aquatic species.

- Establish baseline estimates of chosen native vertebrate and invertebrate species groups, correlating these to habitat structure and composition at the landscape scale.
- Project, at landscape scale, the habitat changes likely to result from alternative brush management scenarios.
- Project the likely influence of alternative brush management scenarios on the chosen species groups.

## Study Area

The regions for refining earlier Texas State Soil and Water Conservation Board funded studies by the Texas Agricultural Experiment Station with participation by the Natural Resources Conservation Service were identified cooperatively with the Corps of Engineers. One region is in the Twin Buttes drainage area, which includes the Middle Concho River, the South Concho River, and Spring and Dove Creeks. The other region includes watersheds that drain into the Edwards Aquifer recharge zone west of San Antonio and includes parts of the Frio River, Hondo Creek, Medina River, Sabinal River, and Seco Creek. The study areas are presented in Figure 1.

## Scenarios

This study is an extension of earlier brush management studies for the regions selected incorporating aquatic and terrestrial responses for alternative brush management strategies (scenarios). This meant that brush management alternatives were to be developed that lead to restoration of the riparian and terrestrial landscape. To provide some insight into sensitivity of water yield, economics, and the aquatic and terrestrial impacts, five alternative scenarios were developed. For those areas where treatment is applicable, a goal of reducing the canopy cover to 3-8 percent of the land area underlies the analysis. Not all parts of a watershed are included in the treatment area. Hence, across the watershed the canopy cover can be much greater than 3-8 percent. For the analysis, oak was not treated because of the impact on property values and value to wildlife. The five scenarios are as follows:

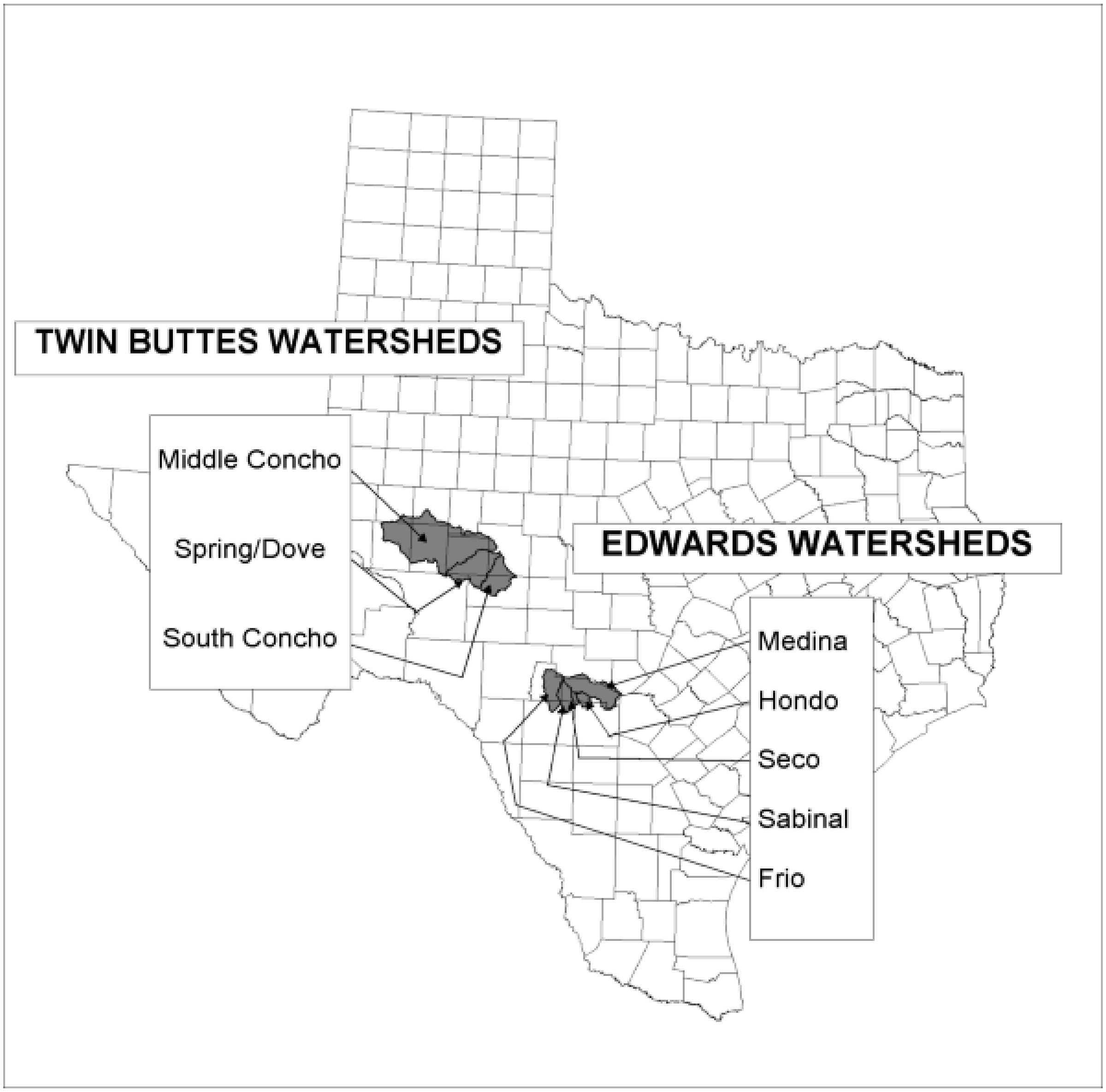


**Figure 1. Watersheds included in study.**

| | |
|---|---|
| Scenario I | Brush is controlled on all of a treatment area except on slopes greater than 15 percent. This scenario allows for the greatest amount of brush control. |
| Scenario II | In addition to no brush control where there is a slope greater than 15 percent, this scenario also does not treat brush within 75 meters of a mapped stream course (150 meter buffer along a stream course). |
| Scenario III | This scenario adds another constraint to the level of brush treatment in addition to the 15 percent slope and 150 meter buffer requirements. Namely, that brush remaining after treatment will be 40 percent of the total land area within each subbasin for each of the eight watersheds. |
| Scenario IV | This constitutes the BASE from which the other scenarios are compared. The assumption is that current conditions continue into the future with no change. |
| Scenario V | Under a special request of the Corps of Engineers, a last scenario was developed whereby the current condition was allowed to become more brush infested over time. In this case, light brush was shifted to moderate, moderate brush moved to heavy brush. There was no economic analysis for Scenario V but there was an evaluation of hydrologic implications and associated aquatic and terrestrial impacts. |

A brief overview of the scenarios in a thumbnail is given in the following. An "X" indicates that no brush treatment is done for the factor identified, e.g., for Scenario I there is no brush treatment if the slope is 15 percent or greater.

| Scenario | >15% Slope | 150m stream buffer | 40%+ subwatershed residual brush |
|---|---|---|---|
| I | X | | |
| II | X | X | |
| III | X | X | X |
| IV | base, current conditions extend into the future | | |
| V | light brush becomes medium, medium becomes heavy (no economic analysis) | | |

To illustrate the implications of the scenarios, Figure 2 shows total percent brush cover associated with each management strategy for the Twin Buttes study area. The transition from Scenario I through V is very evident in moving from light brush cover (3-8 percent) in Scenario I to a range of 30-60 percent for Scenario V. Likewise, Figure 3 presents percent brush cover for the Edwards study area. The same transition is shown but it is clear that the Edwards study area is associated with significantly more brush than the Twin Buttes. Even in Scenario I, the brush cover is 20-40 percent and in Scenario V approaches 70 percent.

Across each of the scenarios presented in Figures 2 and 3, there are detailed results by sub-watershed for the hydrologic impacts (change from Scenario IV and V), economic costs of brush management and cost per acre-foot of increased runoff (except Scenario V), and then the aquatic biota and terrestrial response.

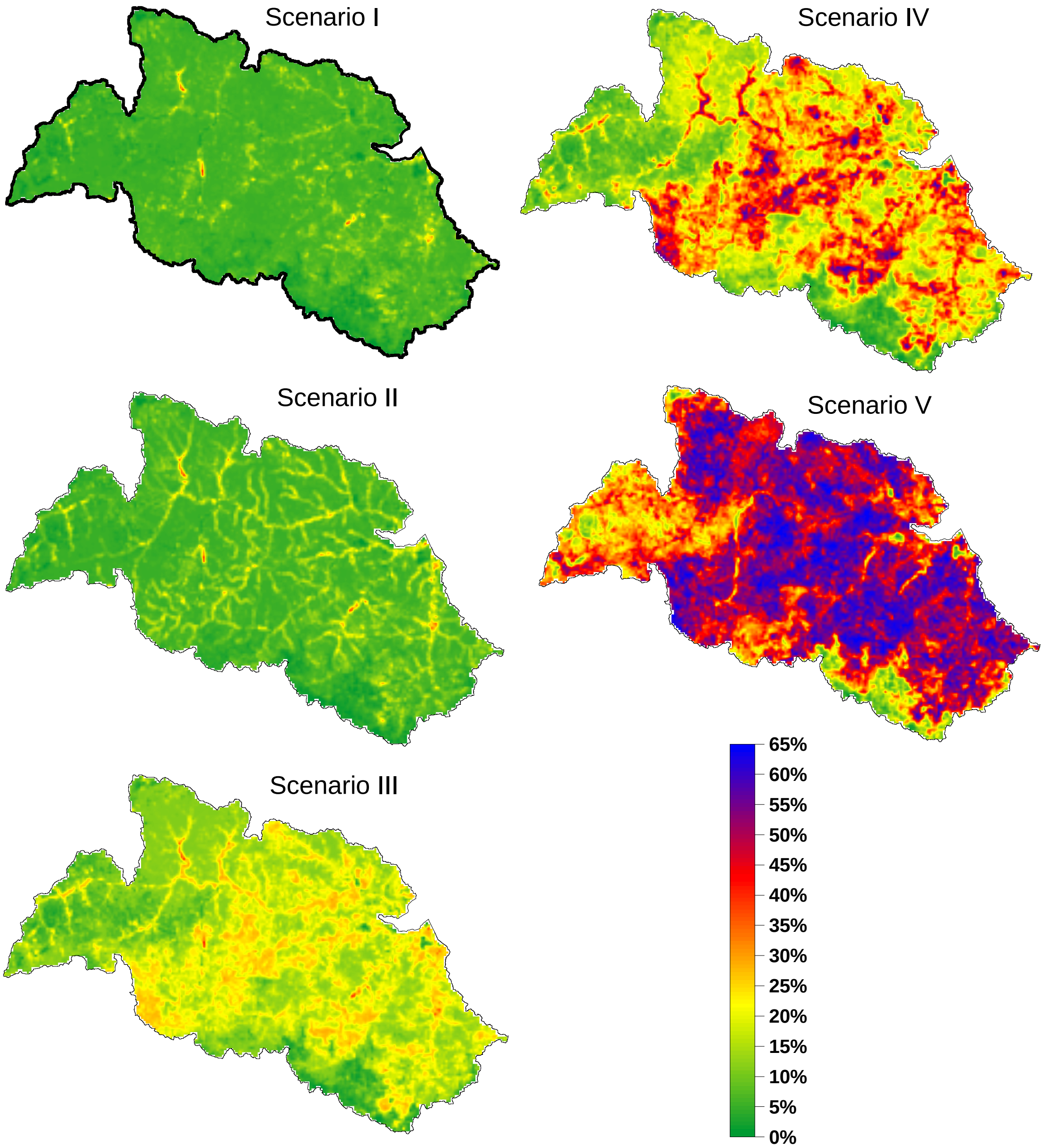


Figure 2. Estimated total percent brush cover under 5 management scenarios, Twin Buttes study area. Scenario IV represents present condition; scenarios I, II, and III represent alternative futures under different brush management program constraints; while scenario V is a projected future condition given no brush control program on the area.

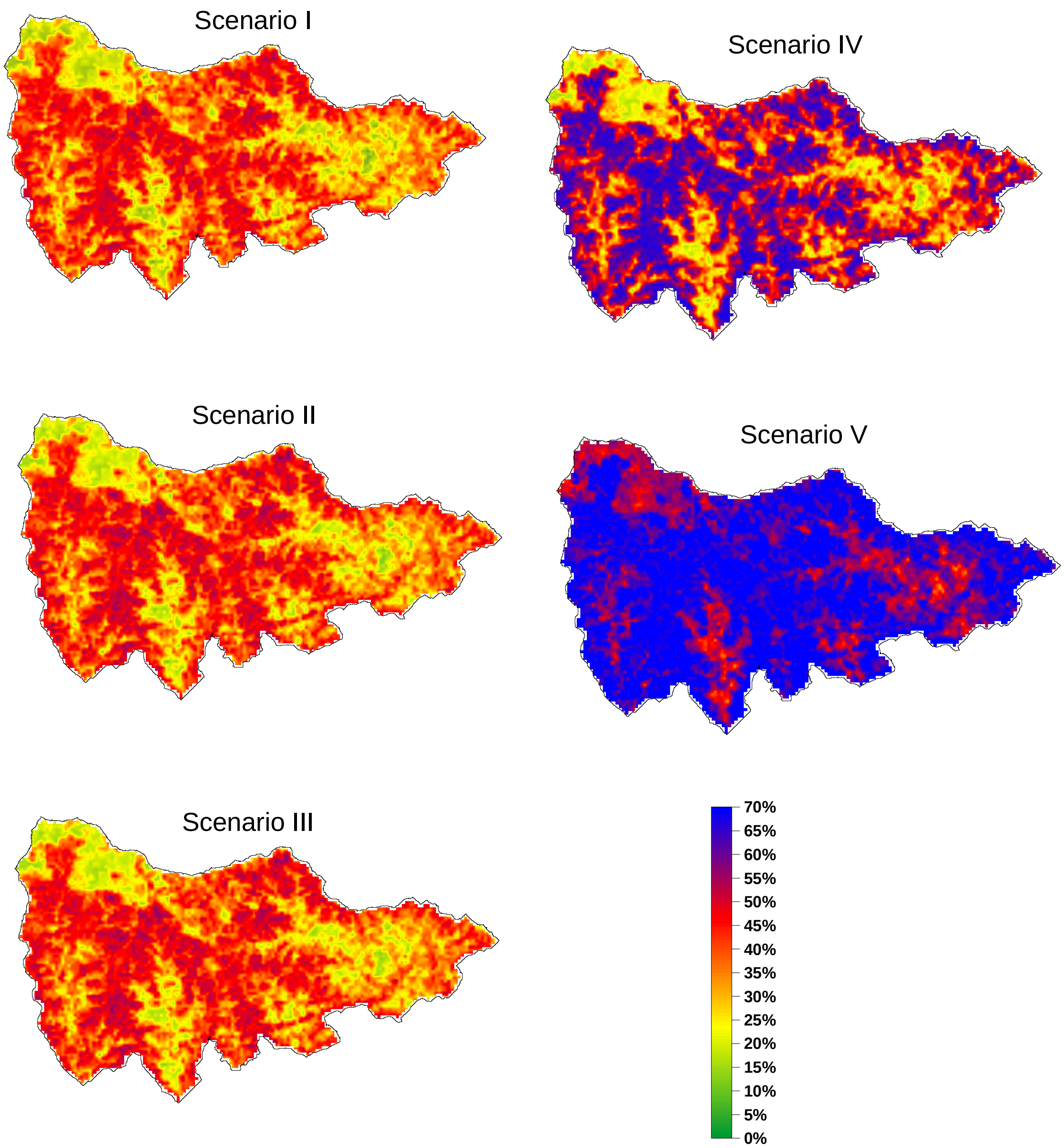


Figure 3. Estimated total percent brush cover under 5 management scenarios, Edwards study area. Scenario IV represents present condition; scenarios I, II, and III represent alternative futures under different brush management program constraints; while scenario V is a projected future condition given no brush control program on the area.

**Organization of the Report**

Because there are several types of analysis required for this study, each is presented in a separate section. The basis of economic, aquatic and terrestrial response to brush management is the definition of current level of brush intensity and subsequent hydrologic estimates of effects of alternative levels of brush management. Therefore, the first set of results is for the hydrologic modeling component. Hydrologic modeling is a refinement of earlier work on these same watersheds and is an integrated work product of the Texas Agricultural Experiment Station at Temple (Blackland Research and Extension Center) and the scientists at the Natural Resources Conservation Service, located at the Blacklands Center.

The second section focuses on the rangeland/brush and economic factors. It was in this part of the study that the stakeholder meetings were organized. This study examines the economic feasibility of three different brush treatment scenarios that incorporate several restoration practices including rangeland reseeding, grazing deferments and the implementation of improved grazing management systems. These restoration practices will enable treated lands to become closer to historic climax communities found in the two study areas. Brush management/restoration Scenarios I, II and III differ mainly in the amount and location of acres treated. The economics includes total cost of the brush management as well as the benefits to a landowner. For the simulated increase in runoff due to brush management assumed in scenarios I-III (compared to Scenario IV), the estimated costs of brush management and associated costs per acre-foot are developed. A last part of the effort was legal alternatives for implementing a cost share brush management program.

The final sections of the report address the aquatic and terrestrial implications of the alternative management scenarios. The focus was on developing a baseline description of current wildlife-habitat relationships, estimating relationships to project changes in aquatics and terrestrial factors, and drawing overall implications associated with the alternative scenarios. Bird guilds were selected as landscape indicators of ecological conditions because of variability in species composition and abundance within communities. In addition, bird guilds have been demonstrated as successful in reflecting the overall structure, function and composition of ecosystems (O'Connell et al., 2000). Each section is an integral part of the total study but is presented essentially as self standing. The authors for each section are specified. Tables are included in the text while Figures are located at the end of each section because of the number involved and disruption in reading.

**Interrelationships of Evaluation Factors**

The multiple evaluation factors of this analysis provide insight into the interrelationships among specific evaluation factors. For example, modeling indicates change in runoff associated with brush management scenarios. This is then input to the economics section where costs of brush management are estimated and converted to the expected cost to society (city, state, nation or other public entity) required to implement. The cost to society is the cost above what a rancher could expect in increased net revenue. These costs are expressed on a total and a per acre-foot of water basis.

Using the changes in the landscape, the aquatic and terrestrial components provide expectations on fish and wildlife (primarily birds). The estimate of amount of restoration associated with each of the brush management scenarios is a major addition not addressed in previous brush management studies. With the components completed and implications for many factors available, the challenge becomes the presentation and interpretation considering all the factors simultaneously. This also provides the opportunity to review the trade-offs that occur in evaluating cost to increase runoff and streamflow along with impact on aquatic and terrestrial habitat. With the results of this analysis, there is information that permits quantifying relative cost effectiveness for achieving multiple goals of restoring aquatic conditions, wildlife habitat, range restoration and off-site water production.

To provide a first simple example of the potential to optimize multi-objective outputs, a cursory overview with implications is presented. This is intended to demonstrate the power of the study and how the components contribute. To facilitate the interpretation, Table 1 pulls data from each section. The information in Table 1 is shown for three river basins in the Twin Buttes watershed and for five in the Edwards watershed. A comparison across scenarios I-IV gives an indication of the change that would be expected going from current conditions (IV) to the three brush management strategies of I-III. Factors chosen include water yield in thousand acre feet over 10 years, cost per acre-foot of water for the brush management strategy (zero for Scenario IV), a measure of fish biotic integrity (a preliminary metric requiring further validation), and percent of total area with suitable habitat for grassland obligates in the Twin Buttes and grassland guild in the Edwards. For the terrestrial measurements (suitable habitat for birds), these are given for the total watershed and not available for sub-areas.

When compared with results from a similar previous study (TAES, 2000), where brush control was assumed to occur on all land that had moderate or heavy brush, this study suggests that both stream flow increases and water yield increases would not be significantly affected if brush control strategies that account for wildlife (e.g., slope and riparian restrictions) were imposed.

For the Twin Buttes watershed, in all cases the change in descriptions for aquatic integrity and birds is estimated to improve substantially with brush management scenarios I-III (going from about 54 to between 64 and 77, depending on the scenario). However, the cost of added water from brush management is much lower in the South Concho (about $63/ac.ft.) compared with the Spring/Dove of about $83/ac.ft. The Middle Concho is highest at $135/ac.ft. or more. The percent of region designated as likely to be suitable habitat for grassland obligates goes from 85 to about 91 to 97 percent. Based on these comparisons, there is the implication that the South Concho would be first priority followed by the Spring/Dove and then Middle Concho.

Similarly, for the Edwards, the least cost region for brush management to increase runoff of water is Hondo ($33/ac.ft.), Medina ($36/ac.ft.), Seco ($46 to $55/ac.ft.) and most expensive is Frio ($51 to $66/ac.ft.). Thus, the amount of increased runoff associated with brush management is far greater in the Edwards compared to Twin Buttes and results in cost per acre-foot that is about 50 percent less in the Edwards. However, looking to the fish biotic integrity index, the improvement is very small (five to nine points). First, this suggests a more careful review and analysis of the fish biotic integrity index and implications of the brush management scenarios, but also suggests there is less benefit in the Edwards relative to Twin Buttes. To make the decision more complex and challenging, the percent suitable habitat for the Edwards goes from 8.1 percent to over 18 percent (a major increase in a region where grassland guild is now uncommon). This is over a doubling of suitable habitat and depending upon values perhaps very beneficial.

Thus, there is a decision within a watershed on where to focus a program and then there is the need to compare one watershed with another. There are major tradeoffs to be reviewed. For example, the Twin Buttes watershed is less cost effective than the Edwards with respect to producing added water with brush management, but the brush management results in substantially more improvement in aquatic conditions than for the Edwards.

To extend the significance of synthesizing results across all factors, going to much smaller regions is warranted. In the Twin Buttes watershed, Spring and Dove Creeks sub-watershed, subbasins 13, 15, and 21 show significant gains in aquatic conditions between brush management scenarios III and IV with subbasin 13 exhibiting substantially greater gains than either 15 or 21. Of these three subbasins, 15 and 21 are estimated to result in modest increases in probability of occurrence of grassland birds while 13 is expected to increase significantly in grassland birds in scenario III compared to IV. Similarly, subbasin 13 is estimated to produce more added water at a lower cost per acre-foot than either subbasin 15 or 21. Clearly subbasin 13 should be given high priority for implementation because it is estimated to produce significantly greater increases in all of the ecosystem functions of interest in this study.

**Table 1. Attributes associated with alternative brush management scenarios.**

| | Scenario | Water Yield Increase Over 10 Years (1000 acre/ft) | Society $/ acre-foot | Fish Biotic Integrity | Percent Suitable Habitat* |
|---|---|---|---|---|---|
| Middle Concho | I | 285 | 158 | 76 | 96.8 |
| | II | 271 | 159 | 75 | 95.7 |
| | III | 118 | 135 | 64 | 90.7 |
| | IV | | | 54 | 85 |
| South Concho | I | 238 | 63 | 77 | b |
| | II | 228 | 63 | 75 | b |
| | III | 94 | 63 | 66 | b |
| | IV | | | 55 | b |
| Spring/Dove | I | 299 | 83 | 76 | b |
| | II | 285 | 83 | 75 | b |
| | III | 119 | 82 | 66 | b |
| | IV | | | 55 | b |
| Frio | I | 249 | 51 | 70 | c |
| | II | 196 | 51 | 70 | c |
| | III | 191 | 66 | 70 | c |
| | IV | | | 67 | c |
| Hondo | I | 124 | 32 | a | 21.4 |
| | II | 104 | 32 | a | 18.4 |
| | III | 101 | 33 | a | 18.4 |
| | IV | | | a | 8.1 |
| Medina | I | 776 | 35 | 70 | c |
| | II | 646 | 36 | 69 | c |
| | III | 621 | 36 | 69 | c |
| | IV | | | 65 | c |
| Sabinal | I | 162 | 45 | 70 | c |
| | II | 132 | 46 | 69 | c |
| | III | 128 | 45 | 68 | c |
| | IV | | | 65 | c |
| Seco | I | 31 | 55 | 69 | c |
| | II | 30 | 46 | 68 | c |
| | III | 30 | 46 | 68 | c |
| | IV | | | 60 | c |

* Percent of area with a >0.5 probability of occurrence of grassland species groups

[a] Data not available for Hondo but for all of the Edwards the value across scenario are similar.

[b] The results are for grassland obligates and apply to the Twin Buttes Watershed (See Middle Concho).

[c] The results are for grassland guild and apply to the Edwards Watershed (See Hondo).

Scenario V not included because there was no economic analysis.

The report illustrates the method whereby society's share of brush control–restoration costs are expressed as $ per acre-foot of water estimated at the sub-subbasin level. In an extension or expansion of this study, there is the opportunity to express the costs as $ per unit of increase in aquatic biotic integrity (F-IBI) between scenario III and IV for each sub-subbasin; or as $ per unit increase in probability of occurrence of grassland birds between scenarios III and IV for each sub-subbasin (or even smaller land units). Similar comparisons could also be done for changes in these indicators between scenarios I or II and IV.

For example, society's share of restoration costs expressed as $/unit increase in F-IBI between scenarios III and IV are $33,018 for Spring – Dove subbasin 13; while they are $61,834 and $51,102 for subbasins 15 and 21 respectively. Similarly, with the average change in probability of occurrence of grassland birds between scenarios III and IV being 10 points for Spring–Dove subbasin 13, and 6 and 4 points for subbasins 15 and 21 respectively, then society's share of restoration costs can be expressed as $46,225/point increase in the probability of occurrence of grassland birds for Spring-Dove–13, $92,751 and $102,204 per point increase for Spring-Dove–15 and S-D–21 respectively.

This reports demonstrates that the methodology used herein can provide decision-makers information that would allow combinations of restoration goals to be met in the most cost-effective manner.

# Section 1. Hydrologic Modeling

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**Introduction**

A report entitled "Brush Management/Water Yield Feasibility Studies of Eight Watersheds in Texas" has been published (TAES, 2000) summarizing the hydrologic and economic implications of brush management on selected Texas watersheds. In that study, a hydrologic model was used to simulate the effect of removing all brush with moderate and heavy canopy cover. This study was undertaken to examine the implications of brush management under a more restrictive set of removal criteria based upon wildlife considerations. A sample of the watersheds examined in TAES (2000) was used in these analyses to examine wildlife and economic implications of more restrictive brush removal strategies. The objective of this study is to quantify hydrologic implications of brush management strategies to related wildlife and aquatic ecological implications.

**Methods**

Methods used in this study follow those described in TAES (2000). The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) was used to simulate water yield (discussed in detail in next section) and to simulate stream flow in watersheds under current conditions and under conditions associated with various vegetation changes (brush removal). SWAT is a continuation of a long-term effort of nonpoint source pollution modeling by the USDA-Agricultural Research Service (ARS), including development of CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985; Arnold et al., 1990), and ROTO (Arnold et al., 1995a). SWAT was developed to predict the impact of management (e.g. climate and vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large un-gauged basins. To satisfy the objective, the model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous-time and capable of simulating long periods. SWAT allows a basin to be divided into hundreds or thousands of grid cells or sub-watersheds.

This study examined eight watersheds in two regions of Texas (Figure 1.1).

1. Watersheds that drain into the Twin Buttes Reservoir near San Angelo, Texas (i.e. the Middle Concho River, the South Concho River, and Spring and Dove Creeks).
2. Watersheds that drain into the Edwards Aquifer recharge zone west of San Antonio, Texas (i.e. the area above the upstream edge of aquifer recharge zone for the Frio River, Hondo Creek, the Medina River, the Sabinal River, and Seco Creek).

*Model Inputs*

A compilation of Geographic Information System (GIS) data (i.e. soils, land use, weather, management, and topography) in GRASS and Arcview formats and other required model parameters (e.g. base flow days) were generated for input into SWAT.

**Climate**

Daily precipitation totals were obtained for National Weather Service (NWS) stations within and adjacent to the watersheds. Data from nearby stations were substituted for missing precipitation data in each station record. Daily maximum and minimum temperatures were obtained for the same NWS stations. A weather generator was used to generate missing temperature data and all solar radiation for each climate station.

Topography

The United States Geological Survey (USGS) database known as Digital Elevation Model (DEM) describes the surface of a watershed as a topographical database. The DEM available for the project area is the 1:24,000 scale map (U.S. Geological Survey, 1999). The resolution of the DEM is 30 meters, allowing detailed delineation of subbasins within each watershed. Sub-watershed boundaries for each watershed, defined using 30 m digital elevation models, were manually checked against USGS Digital Raster Graphic images at 1:24K scale.

**Soils**

The soils database describes the surface and upper subsurface of soils in a watershed and is used to determine a water budget for the soil profile, daily runoff, and erosion. The SWAT model uses information about each soil horizon (e.g., thickness, depth, texture, and water holding capacity). The NRCS (USDA-Natural Resources Conservation Service) soils database used for this project were developed from three sources:

1. The majority of the information is a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. This database is known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display System (MIADS) (Nichols, 1975) soils data.

2. The Soil Survey Geographic (SSURGO) is available as printed county soil surveys for over 90% of Texas counties. Each soil delineation (mapping unit) is described as a single soil series.

3. The State Soil Geographic (STATSGO) 1:250,000-scale soils data base NRCS soils data base is currently available for all of the counties of Texas. In the STATSGO database, each soil delineation of a STATSGO soil is a mapping unit made up of more than one soil series. Dominant SSURGO soil series within an individual STATSGO polygon were selected to represent that area.

The GIS layer representing the soils within the project area is a compilation of CBMS, SSURGO, and STATSGO information. The most detailed information was selected for each county and was patched together to create the final soils layer.

SWAT uses the soils series name as the data link between the soils GIS layer and the soils properties tabular database. County soil surveys were used to verify data for selected dominant soils within each watershed.

## Land Use/Land Cover

Land use and land cover affect surface erosion and water runoff in a watershed. Development of a detailed land use/land cover layer for watersheds in the project area was accomplished by classifying Landsat-7 Enhanced Thematic Mapper Plus ETM+ data. Portions of summer Landsat-7 scenes were classified using ground truth points collected by NRCS field personnel. Summer imagery was used to obtain relatively cloud-free scenes during the growing season for the project areas. Images were radiometrically and precision terrain corrected (personal communication, Gordon Wells, TNRIS, 2001).

## Ground Control Points

Ground control points (GCP) were located and described by NRCS field personnel in each watershed. Global Positioning System receivers were utilized to locate the latitude and longitude of the control points. A database was developed from the GCP's with information including land cover, estimated canopy coverage, aerial extent, and other pertinent information about each point. This database was converted into an ArcInfoTM point coverage.

ERDAS's ImagineTM was used for imagery classification. Landsat-7 images were imported into Imagine (GIS software). Adjoining scenes in each watershed were histogram matched or regression corrected to the scene containing the highest number of GCPs to adjust for differences in scenes because of dates, time of day, atmospheric conditions, etc. Adjoining scenes were mosaiced and trimmed into one image that covered an individual watershed.

ArcInfo coverage of ground points was employed to instruct the software to recognize differing land uses based on their spectral properties. Individual ground control points were "grown" into areas approximating the aerial extent as reported by the data collector. Spectral signatures were collected by overlaying these areas over the imagery and collecting pixel values from the six imagery layers. A supervised maximum likelihood classification of the image was then performed with the spectral signatures for various land use classes. Ground data was used to perform an accuracy assessment of the resulting image. A sampling of the initial classification was further verified by NRCS field personnel.

This process resulted in a land use/land cover GIS map that includes more detailed divisions of land use/land cover. Although vegetation classes varied slightly among all watersheds, land use and cover was generally classified as follows:

| | |
|---|---|
| Heavy Cedar | Mostly pure stands of cedar (juniper) with average canopy cover greater than 30 percent. |
| Heavy Mesquite | Mostly pure stands of mesquite with average canopy cover greater than 30 percent. |
| Heavy Oak | Mostly pure stands of various species of oak with average canopy cover greater than 30 percent. |

| | |
|---|---|
| Heavy Mixed | Mixture of brush species with average canopy cover greater than 30 percent. |
| Moderate Cedar | Mostly pure stands of cedar (juniper) with average canopy cover 10 to 30 percent. |
| Moderate Mesquite | Mostly pure stands of mesquite with average canopy cover10 to 30 percent. |
| Moderate Oak | Mostly pure stands of various species of oak with average canopy cover 10 to 30 percent. |
| Moderate Mixed | Mixture of brush species with average canopy cover 10 to 30 percent. |
| Light Brush | Either pure stands or mixed with average canopy cover less than 10 percent. |
| Open Range | Various species of native grasses or improved pasture. |
| Cropland | All cultivated cropland. |
| Water | Ponds, reservoirs and large perennial streams. |
| Barren | Bare Ground |
| Urban | Developed residential or industrial land. |
| Other | Other small insignificant categories |

Accuracy of classified images was 70% - 80%. Brush species also were split into three categories—those on less than 15% slope, those on greater than 15% slope, and those within 75 meters of defined streams. This allowed for brush removal in any or all of the three categories. All data were assembled at the highest level of detail possible to accurately define the physical characteristics of each watershed. Selected key model inputs are summarized in Table 1.1.

*Model Changes*

For this study, the SWAT model was modified from the version used in TAES (2000) as follows:

1. The canopy interception algorithm was changed to reflect recent tree interception measurements over a spectrum of juniper canopy densities on the Edwards Plateau (personal communication, K. Owens, TAES, Uvalde) based on data from http://uvalde.tamu.edu/intercept/. The fraction of a daily rainfall event (mm/d) intercepted was calculated as follows: fraction = X*-0.1182 * ln(rainfall) + 1, where X was assumed to be 0.2 and 0.5 for moderate and heavy juniper and juniper-mixed canopies, respectively. In general, interception was reduced by about 50% using this equation relative to algorithms used in TAES (2000).

2. The equation for calculation of potential evapotranspiration (PET) using the Priestley-Taylor equation was corrected (it was in error for the TAES (2000) study). This decreased PET relative to that calculated in TAES (2000) by about 25%.

3. The GRASS interface for the SWAT model was modified to allow greater input detail during translation from GIS data to SWAT input data.

*Model Calibration*

The model was calibrated against measured stream flow by varying selected model inputs and model parameters (e.g. runoff curve number, soil evaporation compensation factor, shallow aquifer storage, shallow aquifer re-evaporation, and channel transmission loss, Table 1.1). The calibration period of record was usually defined by the stream flow measurement period, but generally was between 1960 and 1998. A base flow filter (Arnold et al., 1995b) was used to determine the fraction of base flow and surface runoff at selected gauging stations.

Required inputs for each subbasin (e.g. soils, land use/land cover, topography, and climate) were extracted and formatted using the SWAT/GRASS input interface. The input interface divided each subbasin into virtual subbasins or hydrologic response units (HRU). A single land use and soil were selected for each HRU.

*Scenario Analyses*

After calibration, the model simulated the hydrology on a daily basis in each watershed for the 39-year period 1960 through 1998. Simulations were made for five scenarios reflecting various land cover changes (Table 1.2). Scenarios were numbered to reflect varying intensity of brush on the landscape (I = least, V = greatest). Scenario IV assumed stable current vegetation conditions on the landscape for the 39-year period. Other scenarios reflected various vegetation changes.

Scenario V was imposed to reflect a future vegetation condition assuming continued increased brush density. Specifically, light brush was converted to moderate mixed brush and moderate density brush was converted to heavy for scenario V. The vegetation change imposed in TAES (2000) was equivalent to scenario I, except there were no slope restrictions and riparian buffers. To simulate the "brush removal" condition, input files for all areas of heavy and moderate brush (except oak) were converted to native grass rangeland (good condition). Appropriate adjustments were made in growth parameters to simulate the replacement of brush with native grass. All other calibration parameters and inputs were held constant.

**Table 1.1. Key model inputs for each watershed.**

| Watershed | ESCO | Curve No. Change | GWQmin (mm) | REPAPmn (mm) | Trans. Loss*-Sub (mm/hr) | Trans. Loss*-Ch. (mm/hr) | Bank Coeff. |
|---|---|---|---|---|---|---|---|
| Twin Buttes | | | | | | | |
| Dove Ck. | 0.1 | -9 | 2 | 2.04 | 45 | 3 | .5 |
| Middle Concho | 0.1 | -9 | 2 | 2.05 | 50 | 37 | 0 |
| South Concho | 0.1 | -9 | 2 | 2.07 | 60 | 20 | .75 |
| Spring Ck. | 0.1 | -9 | 2 | 2.04 | 45 | 50 | .5 |
| Edwards | | | | | | | |
| Frio | 0.98 | -10 | 0 | 10 | 30 | 25 | 0.8 |
| Hondo | 0.98 | -10 | 0 | 10 | 30 | 25 | 0.46 |
| Medina | 0.98 | -10 | 0 | 2 | 30 | 23 | 0.22 |
| Sabinal | 0.98 | -10 | 0 | 10 | 30 | 25 | 0.65 |
| Seco | 0.98 | -10 | 0 | 10 | 30 | 25 | 0.83 |

ESCO. Soil evaporation compensation coefficient. Controls vertical partitioning of soil evaporation. The smaller the number, the deeper in the soil profile water is extracted for evaporation.
GWQmn. Depth of water required in shallow aquifer for return flow to occur.
REVAPmn. Depth of water required in shallow aquifer for re-evaporation to occur.
Bank Coeff. Fraction of transmission loss that is stored in the river bank and returned quickly to stream flow. The remainder enters the shallow aquifer.
*Source: P. Waldo, NRCS Geologist, Ft. Worth (personal communication, 2002) who calculated values from measured stream flows at multiple locations and from geologic information.

**Table 1.2. Scenarios simulated.**

| Scenario | Number Description |
|---|---|
| I | Remove all heavy and moderate cedar and mesquite on slopes < 15%. |
| II | Same as I, except also exclude brush removal in 75 m riparian zone on either side of defined streams. |
| III | Same as II, except only remove brush cover to 40% in any subwatershed. |
| IV | Existing conditions. |
| V | Convert existing light brush density to moderate density and moderate to heavy. |

**Results and Discussion**

*Calibration*

**Twin Buttes**

**Middle Concho**. Predicted cumulative stream flow matched cumulative measured flow and average monthly predicted and measured flows over the 39-year period were within 5% of each other in this watershed (Figure 1.2). However, the root mean square error (RMSE) between monthly predicted and measured flows was about three times the mean measured monthly flow. Errors were less for annual predictions. The large monthly RMSE implies the model does not accurately predict monthly flows.

**South Concho.** Stream flow was about 50% greater in this watershed (Figure 1.3) than in the Middle Concho. The model under predicted cumulative flow for the first 25 years and over predicted flow for the remainder of the period. Average monthly predicted and measured flows were within about 10% of each other, but the RMSE was more than twice mean monthly flow.

**Spring Creek.** For calibration purposes, Spring and Dove Creeks were analyzed separately. Average monthly predicted and measured flows were within 1% of each other in Spring Creek (Figure 1.4), which had the lowest flow of any of the Twin Buttes watersheds. The RMSE of monthly flows was about three times mean monthly flow, although cumulative traces were very close.

**Dove Creek.** Average monthly predicted and measured flows again were almost equal (Figure 1.5) and the RMSE of monthly flows was more than twice the mean monthly flow.

**Edwards**

**Frio.** Average monthly predicted and measured flows were within 5% of each other (Figure 1.6). The RMSE of monthly flows was only slight greater than mean monthly flow.

**Hondo.** Average monthly predicted and measured flows were within 1% of each other (Figure 1.7). The RMSE of monthly flows was less than twice the mean monthly flow.

**Medina.** The period of record was much shorter for this watershed. Average monthly predicted and measured flows were within 10% of each other (Figure 1.8). Due in part to the smaller number of months for measured flows, the RMSE of monthly flows was more than twice the mean monthly flow.

**Sabinal.** Average monthly predicted and measured flows were within 10% of each other (Figure 1.9). The RMSE of monthly flows was less than twice the mean monthly flow.
**Seco.** Average monthly predicted and measured flows were within 1% of each other (Figure 1.10). The RMSE of monthly flows was about twice the mean monthly flow.

In summary, average monthly flows varied by an order of magnitude between the nine watersheds and average monthly flows were accurately predicted by the model (Figure 1.11). There was a slight tendency for predictions to be greater at high flows and differences between predicted and measured stream flows for any given month were large.

*Scenarios*

**Twin Buttes**

**Middle Concho.** Moderate and heavy brush covered about 50% of the total watershed area (Table 1.3). (Note: Total watershed area in this watershed includes about 588,000 acres of non-contributing subbasins. See TAES (2000) for more details.) For scenarios I through III, 67, 63, and 24% of the treatable brush was removed, respectively. For scenario V, more than 577,000 acres of light brush was converted to moderate brush, which increased the area of treatable brush.

**Table 1.3. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Middle Concho River. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| MIDDLE CONCHO RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Total Area | acres | 1,600,828 | 1,600,828 | 1,600,828 | 1,600,828 | 1,600,828 |
| Total Brush Area | acres | 759,872 | 759,872 | 759,872 | 759,872 | 1,337,857 |
| Brush Removed | acres | 506,529 | 481,744 | 179,213 | 0 | -577,985 |
| Water Yield | Acre-feet / year | 114,022 | 112,131 | 92,646 | 77,468 | 59,086 |
| Water Yield Increase | Acre-feet / year | 36,554 | 34,664 | 15,178 | 0 | -18,382 |
| Water Yield Increase | Gal / ac brush removed / yr | 23,516 | 23,446 | 27,598 | 0 | -10,363 |
| Stream Flow | Acre-feet / year | 18,148 | 17,513 | 13,691 | 9,569 | 6,562 |
| Stream Flow Increase | Acre-feet / year | 8,579 | 7,944 | 4,122 | 0 | -3,007 |
| Stream Flow Increase | Gal / ac brush removed / yr | 5,519 | 5,373 | 7,495 | 0 | -1,695 |

| MIDDLE CONCHO RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Water Yield Increase | Acre-feet / year | 54,937 | 53,046 | 33,561 | 18,382 | 0 |
| Water Yield Increase | Gal / ac brush removed / yr | 16,506 | 16,311 | 14,442 | 10,363 | 0 |
| Stream Flow Increase | Acre-feet / year | 11,586 | 10,951 | 7,129 | 3,007 | 0 |
| Stream Flow Increase | Gal / ac brush removed / yr | 3,481 | 3,367 | 3,068 | 1,695 | 0 |

Absolute water yield and stream flow increases, relative to scenario IV, were essentially equal for scenarios I and II (Table 1.3, top). Thus, excluding the riparian corridor had little effect on acres of brush treated and on the hydrology. There was, however, a large difference in water yield and stream flow increases between scenarios II and III (Table 1.3, top). Leaving 40% of the brush on the watershed in scenario III reduced absolute water yield and stream flow by about 50% relative to scenario II, likely because of the large amount of canopy interception and high transpiration rates (due to high leaf area and deep rooting patterns) of brush species not removed.

Increases of water yield and stream flow per unit treated area were similar for all scenarios. For each scenario, stream flow increases were considerably less than water yield increases due to transmission losses in subbasins and the main channel (Table 1.1). Stream flow increases associated with brush removal for scenarios I and II were about 70% of mean measured flows (Figure 1.2) and were approximately 38% higher than those shown in TAES (2000). Cumulative stream flow over the 39-year simulation period from scenarios I through V ordered from largest to smallest, respectively. Most of the difference in cumulative stream flow after 39 years occurred during a few months with large stream flows (Figure 1.12).

The increase in brush area in scenario V (Table 1.2) resulted in a decrease in water yield and stream flow, relative to scenario IV. The stream flow decrease was about 25% of measured flow (Figure 1.2).

Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.3, bottom). Increases of water yield and stream flow, per unit treated acre, both decreased because the relative change from moderate to heavy and light to moderate brush (scenario V) is less than the change from moderate and heavy to grass in other scenarios.

**South Concho.** Qualitatively, results in the South Concho were similar to the Middle Concho (Table 1.4, top). Treatable brush covered about 58% of the total watershed area. For scenarios I through III, 94, 89, and 37% of the brush was removed, respectively.

**Table 1.4. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for South Concho River. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| SOUTH CONCHO RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Total Area | acres | 312,944 | 312,944 | 312,944 | 312,944 | 312,944 |
| Total Brush Area | acres | 182,921 | 182,921 | 182,921 | 182,921 | 263,840 |
| Brush Removed | acres | 171,258 | 162,854 | 67,232 | 0 | -80,920 |
| Water Yield | Acre-feet / year | 71,460 | 70,238 | 52,938 | 40,891 | 28,861 |
| Water Yield Increase | Acre-feet / year | 30,565 | 29,344 | 12,043 | 0 | -12,033 |
| Water Yield Increase | Gal / ac brush removed / yr | 58,157 | 58,713 | 58,371 | 0 | -48,456 |
| Stream Flow | Acre-feet / year | 39,416 | 38,548 | 27,302 | 19,408 | 12,811 |
| Stream Flow Increase | Acre-feet / year | 20,008 | 19,140 | 7,894 | 0 | -6,598 |
| Stream Flow Increase | Gal / ac brush removed / yr | 38,068 | 38,297 | 38,259 | 0 | -26,568 |

| SOUTH CONCHO RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Water Yield Increase | Acre-feet / year | 42,599 | 41,377 | 24,077 | 12,033 | 0 |
| Water Yield Increase | Gal / ac brush removed / yr | 55,044 | 55,308 | 52,955 | 48,456 | 0 |
| Stream Flow Increase | Acre-feet / year | 26,605 | 25,738 | 14,492 | 6,598 | 0 |
| Stream Flow Increase | Gal / ac brush removed / yr | 34,378 | 34,404 | 31,874 | 26,568 | 0 |

Absolute water yield and stream flow increases, relative to scenario IV, were essentially equal for scenario I and II and stream flow increases were less than water yield increases due to transmission losses. Stream flow increases for scenarios I and II were about equal to mean measured flow (Figure 1.3) and were approximately 24% higher than in TAES (2000). Cumulative stream flow again ordered largest to smallest for scenarios I through V (Figure 1.13). There was a gradual, steady increase throughout the period.

As in the Middle Concho, there was a large difference in water yield and stream flow increase between scenario II and III, and water yield and stream flow increases, per unit treated area, were about equal for scenarios I, II, and III. Increases, per unit treated area, were considerably greater in the South Concho than in the Middle Concho, likely due to soil differences and greater precipitation.

There was a smaller relative increase in treatable brush area in scenario V in this watershed. This assumed the vegetation change decreased water yield and stream flow. The stream flow decrease (Table 1.4, top) was about 35% of measured flow (Figure 1.3).
Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.4, bottom). Increases, per unit treated acre, were less for the same reasons stated above for the Middle Concho.

**Spring and Dove.** Results were similar in Spring and Dove Creeks (Table 1.5, top) to those in the South Concho. Brush covered about 64% of the total watershed area. For scenarios I through III, 95, 90, and 37% of the brush was removed, respectively.

Absolute water yield and stream flow increases, relative to scenario IV, were essentially equal for scenario I and II. Stream flow increases were about equal to the sum of mean measured flow for the two watersheds (Figs. 4 and 5), and stream flow increases were essentially equal to those in TAES (2000). Most of the differences in cumulative stream flow occurred in association with a few months with large stream flows (Figure 1.12). Cumulative totals again were ordered with scenarios (Figure 1.14).

There was a large difference in water yield and stream flow increase between scenario II and III. Increases, per unit treated area, were about equal for scenarios I, II, and III.

The vegetation change in association with scenario V decreased water yield and stream flow (Table 1.5, top). The stream flow decrease was about 25% of measured flow (Figs. 4 and 5).

Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.5, bottom). Increases, per unit treated acre, were less for the same reasons stated above for the Middle Concho.

**Table 1.5. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Spring and Dove Creeks. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| SPRING & DOVE CREEKS - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Total Area | acres | 449,652 | 449,652 | 449,652 | 449,652 | 449,652 |
| Total Brush Area | acres | 286,742 | 286,742 | 286,742 | 286,742 | 401,278 |
| Brush Removed | acres | 272,611 | 258,941 | 106,981 | 0 | -114,536 |
| Water Yield | Acre-feet / year | 89,045 | 87,245 | 66,091 | 50,778 | 40,215 |
| Water Yield Increase | Acre-feet / year | 38,268 | 36,468 | 15,313 | 0 | -10,563 |
| Water Yield Increase | Gal / ac brush removed / yr | 45,741 | 45,891 | 46,641 | 0 | -30,051 |
| Stream Flow | Acre-feet / year | 37,103 | 36,036 | 25,249 | 17,897 | 13,064 |
| Stream Flow Increase | Acre-feet / year | 19,206 | 18,139 | 7,352 | 0 | -4,833 |
| Stream Flow Increase | Gal / ac brush removed / yr | 22,956 | 22,826 | 22,392 | 0 | -13,748 |

| SPRING & DOVE CREEKS - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Water Yield Increase | Acre-feet / year | 48,830 | 47,031 | 25,876 | 10,563 | 0 |
| Water Yield Increase | Gal / ac brush removed / yr | 41,099 | 41,033 | 38,063 | 30,051 | 0 |
| Stream Flow Increase | Acre-feet / year | 24,038 | 22,972 | 12,184 | 4,833 | 0 |
| Stream Flow Increase | Gal / ac brush removed / yr | 20,232 | 20,042 | 17,923 | 13,748 | 0 |

## Edwards

**Frio.** About 81% of this watershed was covered by moderate or heavy brush (Table 1.6, top). For scenarios I, II, and III, 37, 30, and 28% of the brush was removed, respectively. The area of brush removed in the Edwards' watersheds was less than in the Twin Buttes watersheds because of the restriction of not removing brush on steeper slopes. Because the percentages of brush remaining were near 40% in scenarios I and II, there was little effect of scenario III in the Edwards' watersheds. For scenario V, about 25% more brush area was added.

Absolute water yield and stream flow increases, relative to scenario IV (Table 1.6, top), were essentially equal for scenarios II and III, and these were about 20% less than the yield and flow increases for scenario I. These trends are consistent with areas of brush removed.

Stream flow increases were about 80% of water yield increases. Water yield and stream flow increases were closer in the Edwards watersheds because sub-basin transmission losses were returned to streams through the fractured limestone and storage in stream banks. Stream flow increases were about 20 to 25% of measured stream flow (Figure 1.6). Cumulative stream flow showed a consistent increase for all five scenarios (Figure 1.15). Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.6, bottom) and increases, per unit treated acre, decreased for the same reasons stated above for the Middle Concho.

**Table 1.6. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Frio River. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| FRIO RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Total Area | acres | 249,642 | 249,642 | 249,642 | 249,642 | 249,642 |
| Total Brush Area | acres | 202,359 | 202,359 | 202,359 | 202,359 | 247,693 |
| Brush Removed | acres | 74,998 | 60,267 | 56,194 | 0 | -45,334 |
| Water Yield | Acre-feet/year | 207,609 | 200,836 | 200,139 | 175,667 | 158,671 |
| Water Yield Increase | Acre-feet/year | 31,942 | 25,169 | 24,473 | 0 | -16,995 |
| Water Yield Increase | Gal/ac brush removed/yr | 138,785 | 136,083 | 141,910 | 0 | -122,156 |
| Stream Flow | Acre-feet/year | 125,772 | 120,511 | 120,055 | 100,982 | 88,725 |
| Stream Flow Increase | Acre-feet/year | 24,791 | 19,530 | 19,072 | 0 | -12,258 |
| Stream Flow Increase | Gal/ac brush removed/yr | 107,705 | 105,587 | 110,596 | 0 | -88,099 |

| FRIO RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Water Yield Increase | Acre-feet/year | 48,938 | 42,165 | 41,468 | 16,995 | 0 |
| Water Yield Increase | Gal/ac brush removed/yr | 132,521 | 130,108 | 133,090 | 122,156 | 0 |
| Stream Flow Increase | Acre-feet/year | 37,047 | 31,786 | 31,330 | 12,258 | 0 |
| Stream Flow Increase | Gal/ac brush removed/yr | 100,321 | 98,081 | 100,553 | 88,089 | 0 |

**Hondo.** About 82%of this watershed was covered by moderate or heavy brush (Table 1.7, top). For scenarios I, II, and III, 42, 36, and 36 % of the brush was removed, respectively. Absolute water yield and stream flow increases, relative to scenario IV (Table 1.7, top), were essentially equal for scenarios II and III, and these were about 20% less than the yield and flow increases for scenario I. These trends are consistent with areas of brush removed. Stream flow increases were about 85% of water yield increases and were about 35% of measured stream flow (Figure 1.7). Cumulative stream flow showed a consistent increase for all five scenarios (Figure 1.16). Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.7, bottom) and increases, per unit treated acre, decreased for the same reasons stated above for the Middle Concho.

**Medina.** About 82% of this watershed was covered by moderate or heavy brush (Table 1.8, top). For scenarios I, II, and III, 44, 38, and 36% of the brush was removed, respectively. Absolute water yield and stream flow increases, relative to scenario IV (Table 1.8, top), were slightly less for scenario III and for II, and both of these were about 18% less than the yield and flow increases for scenario I. These trends are consistent with areas of brush removed. Stream flow increases were about 32% of water yield increases and were about 28% of measured stream flow (Figure 1.8). Cumulative stream flow showed a consistent increase for all five scenarios (Figure 1.17). Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.8, bottom) and increases, per unit treated acre, decreased for the same reasons stated above for the Middle Concho.

Absolute water yield and stream flow increases, relative to scenario IV (Table 1.9, top), were essentially equal for scenarios II and III and these were about 20% less than the increase for scenario I. These are consistent with areas of brush removed. Stream flow increases were about 80% of water yield increases and were about 20 to 25% of measured stream flow (Figure 1.9). Cumulative stream flow showed a steady consistent increase for all five scenarios (Figure 1.18).

**Table 1.7. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Hondo Creek. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| HONDO CREEK - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Total Area | acres | 61,227 | 61,227 | 61,227 | 61,227 | 61,227 |
| Total Brush Area | acres | 49,604 | 49,604 | 49,604 | 49,604 | 60,299 |
| Brush Removed | acres | 21,294 | 18,210 | 17,786 | 0 | -10,695 |
| Water Yield | Acre-feet / year | 73,954 | 71,327 | 67,398 | 58,056 | 50,824 |
| Water Yield Increase | Acre-feet / year | 15,864 | 13,253 | 12,972 | 0 | -7,231 |
| Water Yield Increase | Gal / ac brush removed / yr | 242,759 | 237,150 | 237,655 | 0 | -220,340 |
| Stream Flow | Acre-feet / year | 47,350 | 44,999 | 44,671 | 33,847 | 28,818 |
| Stream Flow Increase | Acre-feet / year | 13,503 | 11,152 | 10,824 | 0 | -5,029 |
| Stream Flow Increase | Gal / ac brush removed / yr | 206,629 | 199,555 | 198,302 | 0 | -226,623 |

| HONDO CREEK - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Water Yield Increase | Acre-feet / year | 23,095 | 20,484 | 20,203 | 7,231 | 0 |
| Water Yield Increase | Gal / ac brush removed / yr | 353,411 | 366,542 | 370,132 | 220,340 | 0 |
| Stream Flow Increase | Acre-feet / year | 18,532 | 16,181 | 15,853 | 5,029 | 0 |
| Stream Flow Increase | Gal / ac brush removed / yr | 283,586 | 289,544 | 290,437 | 226,623 | 0 |

**Sabinal.** About 82% of this watershed was covered by moderate or heavy brush (Table 1.9, top). For scenarios I, II, and III, 39, 32, and 31% of this brush was removed, respectively. For scenario V, brush area increased about 20%.

**Table 1.8. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Medina River. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| MEDINA RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | **UNITS** | **I** | **II** | **III** | **IV** | **V** |
| Total Area | acres | 405,397 | 405,397 | 405,397 | 405,397 | 405,397 |
| Total Brush Area | acres | 329,922 | 329,922 | 329,922 | 329,922 | 396,581 |
| Brush Removed | acres | 145,948 | 123,908 | 118,560 | 0 | -66,659 |
| Water Yield | Acre-feet / year | 452,635 | 436,341 | 434,346 | 354,526 | 313,905 |
| Water Yield Increase | Acre-feet / year | 98,042 | 82,452 | 79,721 | 0 | -41,233 |
| Water Yield Increase | Gal / ac brush removed / yr | 218,894 | 216,831 | 219,106 | 0 | -201,560 |
| Stream Flow | Acre-feet / year | 172,318 | 146,516 | 120,714 | 94,912 | 81,191 |
| Stream Flow Increase | Acre-feet / year | 32,417 | 26,492 | 25,802 | 0 | -13,721 |
| Stream Flow Increase | Gal / ac brush removed / yr | 72,376 | 69,668 | 70,914 | 0 | -67,075 |

| MEDINA RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | **UNITS** | **I** | **II** | **III** | **IV** | **V** |
| Water Yield Increase | Acre-feet / year | 139,275 | 123,685 | 120,954 | 41,233 | 0 |
| Water Yield Increase | Gal / ac brush removed / yr | 310,953 | 325,264 | 332,431 | 201,560 | 0 |
| Stream Flow Increase | Acre-feet / year | 46,138 | 40,213 | 39,523 | 13,721 | 0 |
| Stream Flow Increase | Gal / ac brush removed / yr | 103,010 | 105,751 | 108,625 | 67,075 | 0 |

**Table 1.9. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Sabinal River. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| SABINAL RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Total Area | acres | 131,795 | 131,795 | 131,795 | 131,795 | 131,795 |
| Total Brush Area | acres | 107,739 | 107,739 | 107,739 | 107,739 | 128,922 |
| Brush Removed | acres | 42,323 | 35,233 | 33,537 | 0 | -21,183 |
| Water Yield | Acre-feet / year | 101,797 | 97,957 | 97,367 | 81,053 | 72,098 |
| Water Yield Increase | Acre-feet / year | 20,744 | 16,904 | 16,314 | 0 | -8,956 |
| Water Yield Increase | Gal / ac brush removed / yr | 159,698 | 156,322 | 158,513 | 0 | -137,751 |
| Stream Flow | Acre-feet / year | 81,556 | 77,976 | 77,402 | 62,464 | 54,439 |
| Stream Flow Increase | Acre-feet / year | 19,093 | 15,514 | 14,938 | 0 | -8,025 |
| Stream Flow Increase | Gal / ac brush removed / yr | 146,990 | 143,468 | 145,143 | 0 | -123,446 |

| SABINAL RIVER - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | UNITS | I | II | III | IV | V |
| Water Yield Increase | Acre-feet / year | 29,699 | 25,859 | 25,269 | 8,956 | 0 |
| Water Yield Increase | Gal / ac brush removed / yr | 152,387 | 149,358 | 150,474 | 137,751 | 0 |
| Stream Flow Increase | Acre-feet / year | 27,117 | 23,537 | 22,963 | 8,025 | 0 |
| Stream Flow Increase | Gal / ac brush removed / yr | 139,138 | 135,947 | 136,742 | 123,446 | 0 |

**Seco.** About 86% of this watershed was covered by moderate or heavy brush (Table 1.10, top). For scenarios I, II, and III, 35, 28, and 28% of the brush was removed, respectively. Absolute water yield and stream flow increases, relative to scenario IV (Table 1.10, top), were equal for scenarios II and III, and both of these were only 3% less than the yield and flow increases for scenario I. These trends are consistent with areas of brush removed. Stream flow increases were about 87% of water yield increases and were about 23% of measured stream flow (Figure 1.10).

Cumulative stream flow showed a consistent increase for all five scenarios (Figure 1.19). Water yield and stream flow increases were greater when expressed relative to scenario V (more brush) (Table 1.10, bottom) and increases, per unit treated acre, decreased for the same reasons stated above for the Middle Concho.

**Table 1.10. Total watershed area, total area of treatable brush (i.e. heavy and moderate cover) and brush removed, and water yield and stream flow increases for scenarios I through V (see Table 1.2) for Seco Creek. Water yield and stream flow increases are expressed relative to scenario IV (top) and scenario V (bottom). For scenario V, brush removed area is equal to the area of light brush.**

| SECO CREEK - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | Units | I | II | III | IV | V |
| Total Area | acres | 28,834 | 28,834 | 28,834 | 28,834 | 28,834 |
| Total Brush Area | acres | 25,360 | 25,360 | 25,360 | 25,360 | 28,646 |
| Brush Removed | acres | 8,734 | 7,106 | 7,106 | 0 | -3,286 |
| Water Yield | Acre-feet / year | 24,218 | 24,142 | 24,142 | 20,304 | 18,788 |
| Water Yield Increase | Acre-feet / year | 3,914 | 3,836 | 3,836 | 0 | -1,608 |
| Water Yield Increase | Gal / ac brush removed / yr | 146,024 | 175,902 | 175,902 | 0 | -159,455 |
| Stream Flow | Acre-feet / year | 18,399 | 18,356 | 18,356 | 14,967 | 13,453 |
| Stream Flow Increase | Acre-feet / year | 3,432 | 3,389 | 3,389 | 0 | -1,514 |
| Stream Flow Increase | Gal / ac brush removed / yr | 128,042 | 155,405 | 155,405 | 0 | -150.098 |

| SECO CREEK - 1960 through 1998 | | | | | | |
|---|---|---|---|---|---|---|
| | | SCENARIO | | | | |
| | Units | I | II | III | IV | V |
| Water Yield Increases | acre-feet/year | 5,522 | 5,444 | 5,444 | 1,608 | 0 |
| Water Yield Increases | gal/ac brush removed/yr | 206,016 | 249,639 | 249,639 | 159,455 | 0 |
| Stream Flow Increases | acre-feet/year | 4,946 | 4,903 | 4,903 | 1,514 | 0 |
| Stream Flow Increases | gal/ac brush removed/yr | 184,527 | 224,830 | 224,830 | 150,098 | 0 |

**Comparisons Across Watersheds**

Watershed area varied from less than 30,000 to 1,600,000 acres (Figure 1.20). Along with precipitation, these differences in areas affected measured flows and simulated stream flows for the different scenarios.

Average annual precipitation decreased from east to west (Figs. 1 and 21). In general, precipitation ranged from 28 to 33 inches for the Edwards' watersheds and from 18 to 21 inches for the Twin Buttes' watersheds. The 18-inch average in the Middle Concho is near the minimum value suggested by Griffin and McCarl (1989) where brush control is problematic. Simulated stream flows under current vegetation conditions (scenario IV) were greater in the Edwards' watersheds (Figure 1.22), which had more precipitation (Figure 1.21), and flows were, in general, proportional to watershed area (Figure 1.20).

The fraction of watershed area where brush was removed, for each scenario, was consistent across watersheds (Figure 1.23). In the Edwards' watersheds, about 20 to 35% of the total watershed area was treated; there were small differences between scenarios I, II, and III; and the area assumed to have increased brush density in scenario V was about 10 to 30%. For the Twin Buttes' watersheds, the treated fraction for scenario I was slightly greater than scenario II and varied from 30 to 60%, was much lower for scenario III, and was about 30% for scenario V. In all eight watersheds, the fraction removed in the previous study (TAES, 2000) was about equal to the fraction removed in scenario I in this study except for the Seco and Middle Concho.

Simulated stream flow increases associated with the various scenarios (Figure 1.24) showed a similar pattern to simulated stream flow (Figure 1.22). In the Edwards' watersheds, there was little difference in stream flow increases associated with scenarios I, II, and III, but in general, increases were greatest for scenario I. Increases varied from about 4,000 to slightly greater than 30,000 acre-feet/year. These stream flow increases were similar to those shown in TAES (2000), except for the Medina, which in the current study had a lesser increase due to a lower stream bank coefficient that allowed for more storage in the bank before release. The slight differences in simulated stream flow between these two studies were due to different brush control strategies, model changes (e.g. revised interception algorithms and PET equation), different watershed delineations for the Edwards watersheds, and different inputs (e.g. channel and subbasin transmission rates, stream bank coefficients, etc.). Stream flow decreases associated with scenario V varied from 2,000 to more than 10,000 acre-feet/year.

In the Twin Buttes' watersheds, stream flow increases always ordered with scenario I > II > III (Figure 1.24) and there was a much smaller increase in flow associated with scenario III because much less brush was removed in association with this scenario (Figure 1.23). Stream flow increases for scenario I in this study were similar to TAES (2000). Stream flow decreases associated with scenario V varied from 2,000 to 5,000 acre-feet/year. Stream flow increases, relative to scenario V (Figure 1.25), showed the same pattern when comparisons were made across scenarios or watersheds, but, as expected, were greater than those expressed relative to scenario IV (Figure 1.24).

Stream flow increase, when expressed per unit treated acre, showed little effect of scenario I, II, or III in all watersheds, and showed a much smaller increase in the Twin Buttes' watersheds (Figure 1.26), where precipitation is much less (Figure 1.21). In the Edwards' watersheds, increases varied from 70,000 to 200,000 gallons/(treated acre year). These increases are similar to those shown in TAES (2000), except for Hondo and Medina due to different bank coefficients, and are comparable to those measured or calculated for other watersheds in this area after imposition of a treatment (Table 1.11). The decrease in stream flow associated with scenario V varied from 40,000 to 160,000 gallons/(acre year).

In the Twin Buttes' watersheds, there was essentially no difference in stream flow increase, per unit treated acre, between scenarios I, II, and III (Figure 1.26). Increases varied from 5,000 to 40,000 gallons/(acre year) and are similar to those shown in TAES (2000) and to those simulated in the North Concho River (Table 1.11). Stream flow increases were greater when expressed relative to scenario V (Figure 1.27).

Water yield increases, relative to scenario IV, also were greater in the Edwards' watersheds (Figure 1.28). Increases were essentially equal for scenarios I, II, and III, ranged from 130,000 to 220,000 gallons/(acre year), and tended to be greater than those shown in TAES (2000) (for the same reasons there were differences in absolute stream flow increase). Decreases associated with scenario V varied from 100,000 to 210,000 gallons/(acre year). For the Twin Buttes' watersheds, increases varied from 20,000 to 50,000 gallons/(acre year) and increases were only slightly greater than those in TAES (2000). Decreases for scenario V varied from 10,000 to 50,000 gallons/(acre year). Water yield increases were greater when expressed relative to scenario V (Figure 1.29).

**Table 1.11. Annual water savings (gallons per treated acre) from brush removal at selected locations.**

| Location | Reference | Land Use Change | Water Savings |
|---|---|---|---|
| Sonora | Thurow and Taylor (1995) | 60% Juniper / 40% grass to 100% grass | 100,000 |
| Annandale | Owens and Knight (1992) | Removal all Juniper | 130,000* |
| Seco Ck. | Dugas et al. (1998) | Removal all Juniper (3 year average after treatment) | 30,000 |
| Seco Ck. | Dugas et al. (1998) | Removal all Juniper (2 years after treatment) | 130,000 |
| Seco Ck. | Wright (1996) | Remove 70% of Juniper (14 months after treatment) | 120,000 |
| N. Concho | UCRA (1998) | Remove all Brush (Mesquite and Juniper) | 30,000 |

*Calculated from ratio of average runoff to precipitation and from measured increase in runoff.

**Conclusions**

A hydrologic simulation model was used to quantify hydrologic implications of brush management strategies (Scenarios I through V, Table 1.2) that were selected to account for wildlife implications. Simulated changes in stream flow and water yield (equal to the sum of surface runoff + shallow aquifer flow + lateral soil flow minus transmission losses) were evaluated for eight watersheds in two regions of Texas (Figure 1.1). Watershed area varied from less than 30,000 to 1,600,000 acres and precipitation was about 30 inches per year for the Edwards' watersheds and about 20 inches per year for the Twin Buttes' watersheds.

In the Edwards' watersheds, there was little difference in stream flow increases associated with scenarios I, II, and III, but in general, increases were greatest for scenario I. Stream flow decreases associated with scenario V (more moderate and heavy brush) varied from 2000 to more than 10,000 acre-feet/year. In the Twin Buttes' watersheds, there were much smaller increases in flows. Stream flow increases, when expressed per unit treated acre, also were much smaller in the Twin Buttes' watersheds, where precipitation is much less. Water yield increases also were greater in the Edwards' watersheds.

When compared with results from a similar previous study (TAES, 2000) where brush control was assumed to occur on all land that had moderate or heavy brush, this study suggests that both stream flow increases and water yield increases would not be significantly affected if brush control strategies that accounted for wildlife (e.g. slope and riparian restrictions) were imposed. This conclusion, however, needs to be tempered by the differences in the model and methods between the two studies.

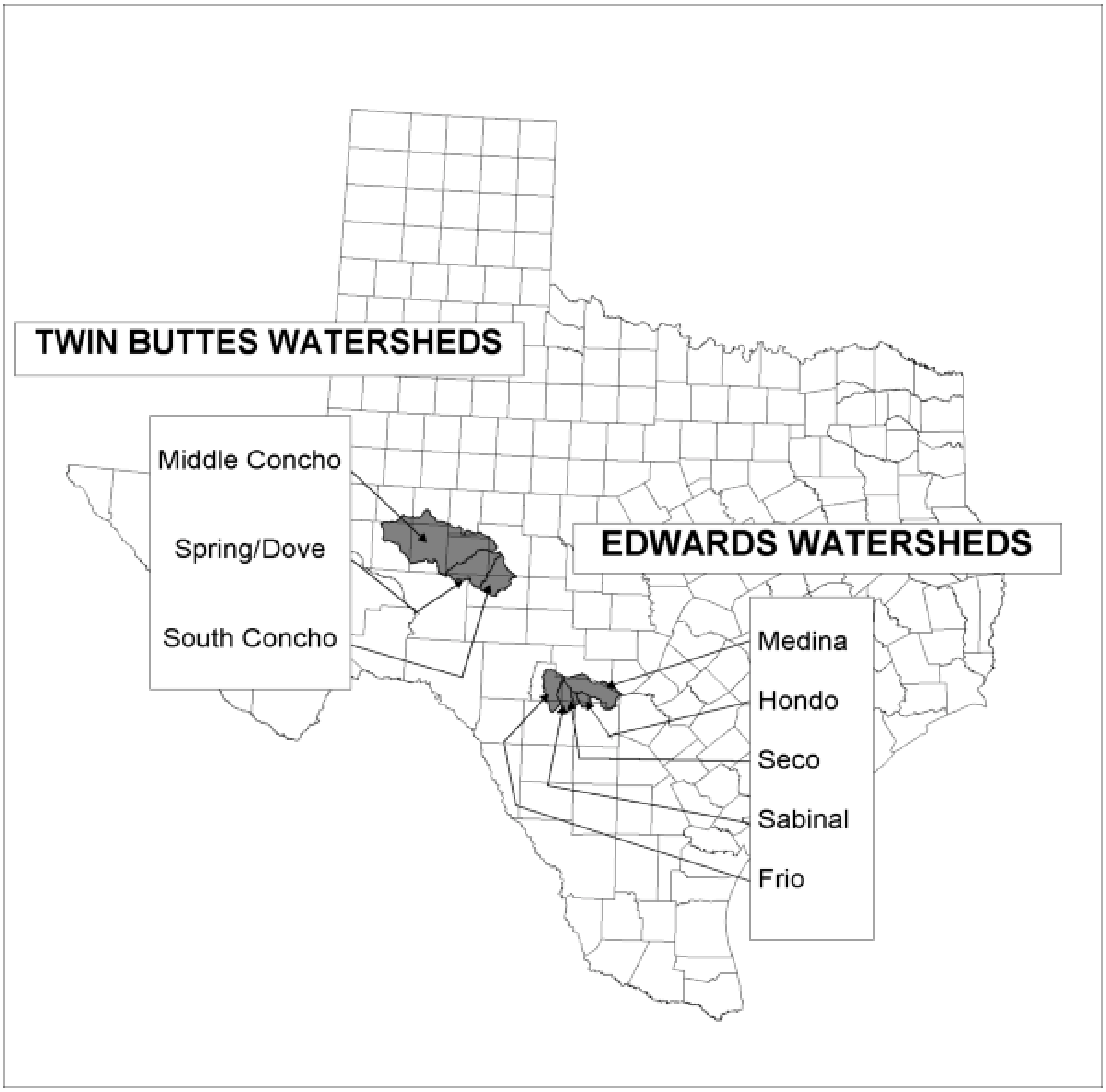


**Figure 1.1. Watersheds included in study.**

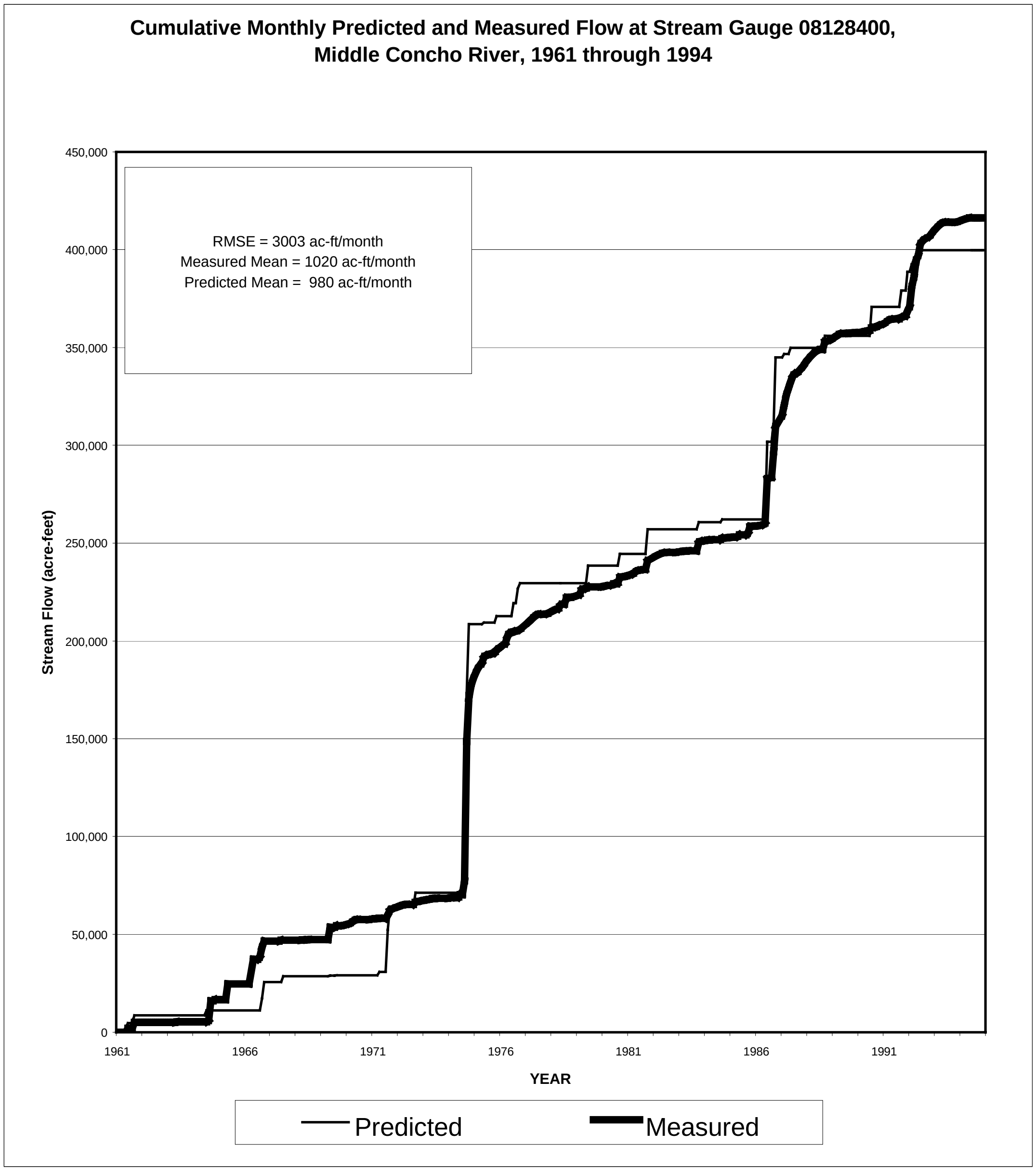


**Figure 1.2.** **Cumulative monthly stream flow predicted by SWAT and measured near outlet of Middle Concho River. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

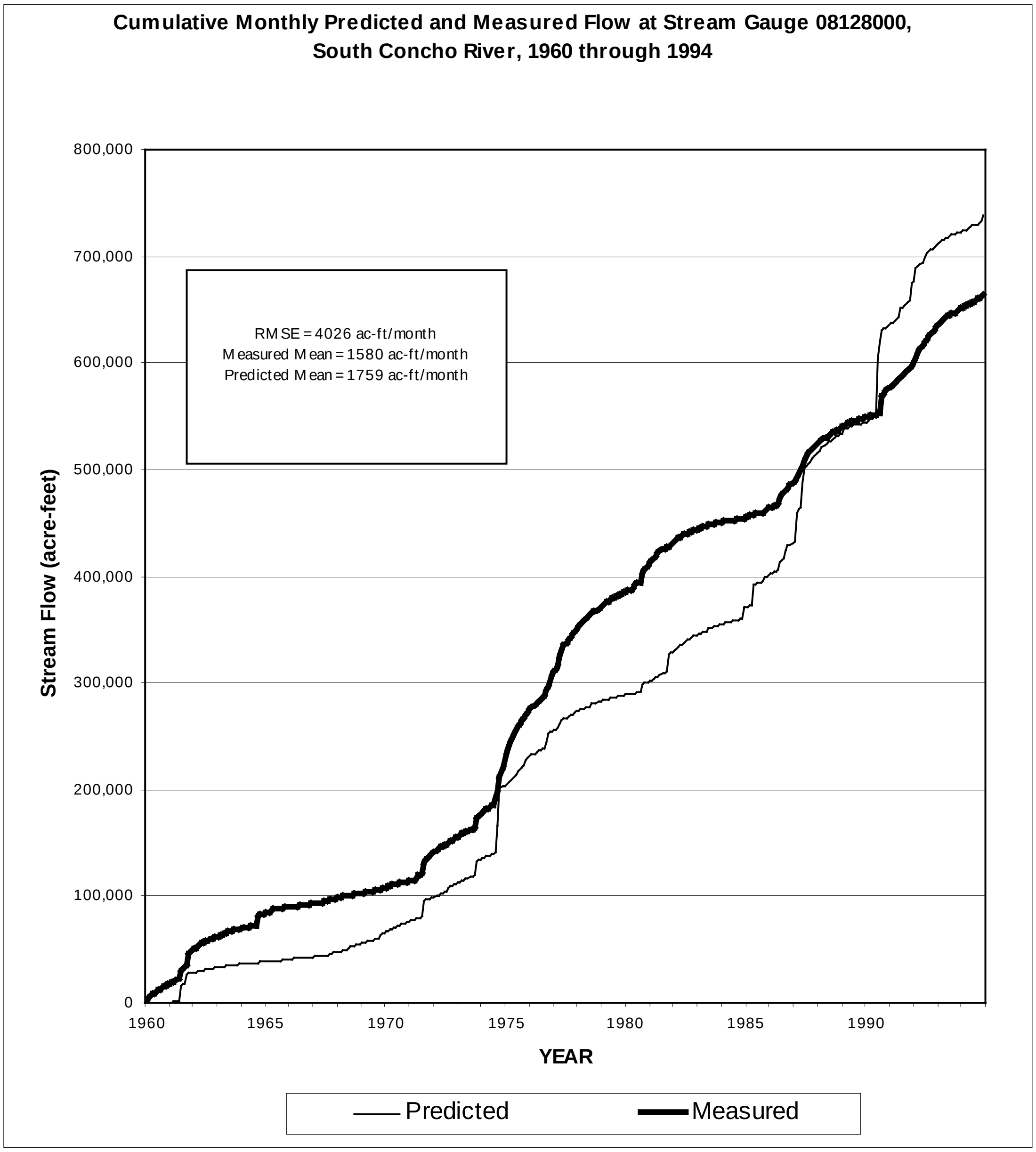


**Figure 1.3. Cumulative monthly stream flow predicted by SWAT and measured near outlet of South Concho River. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

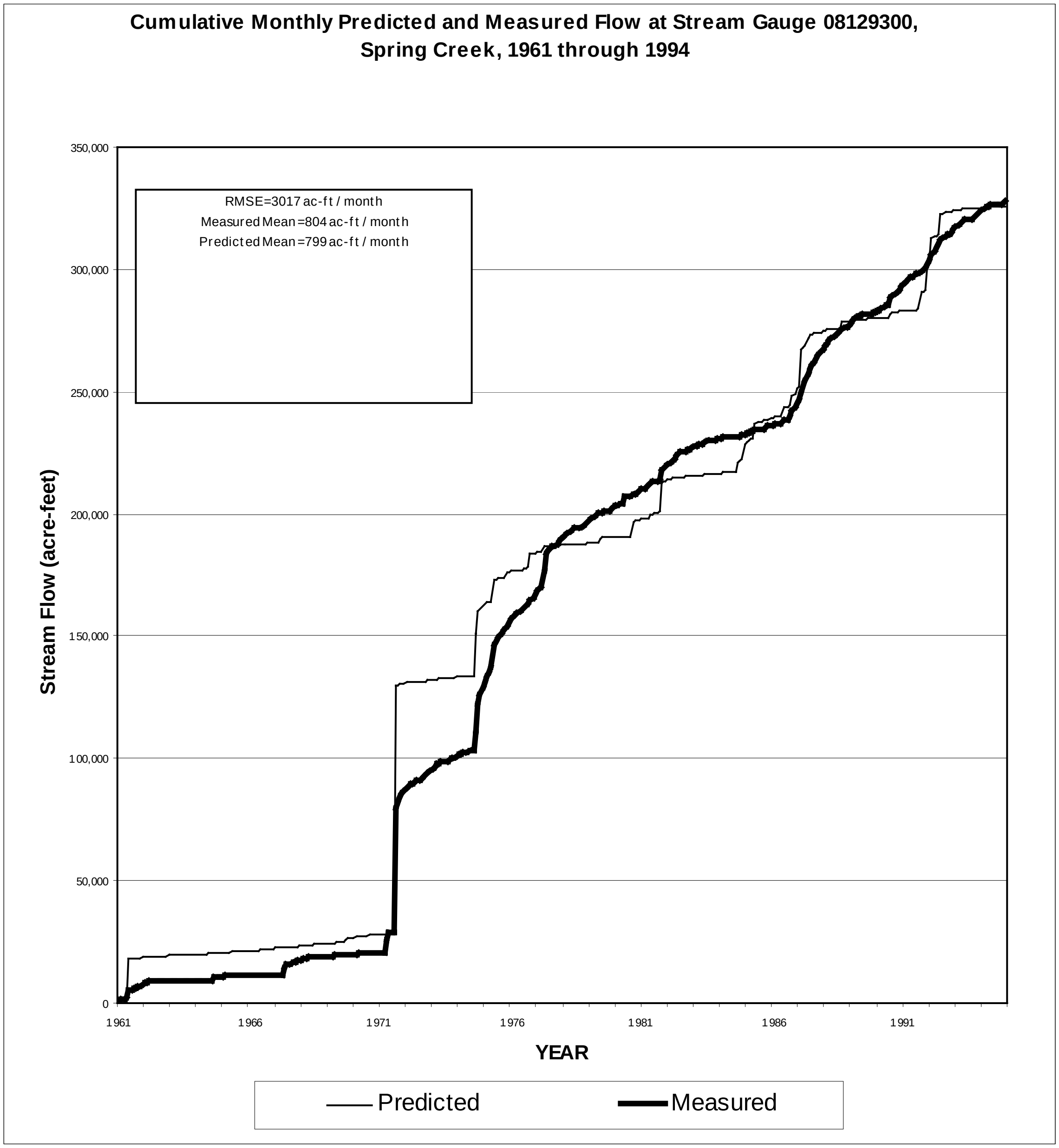


**Figure 1.4. Cumulative monthly stream flow predicted by SWAT and measured near outlet of Spring Creek. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

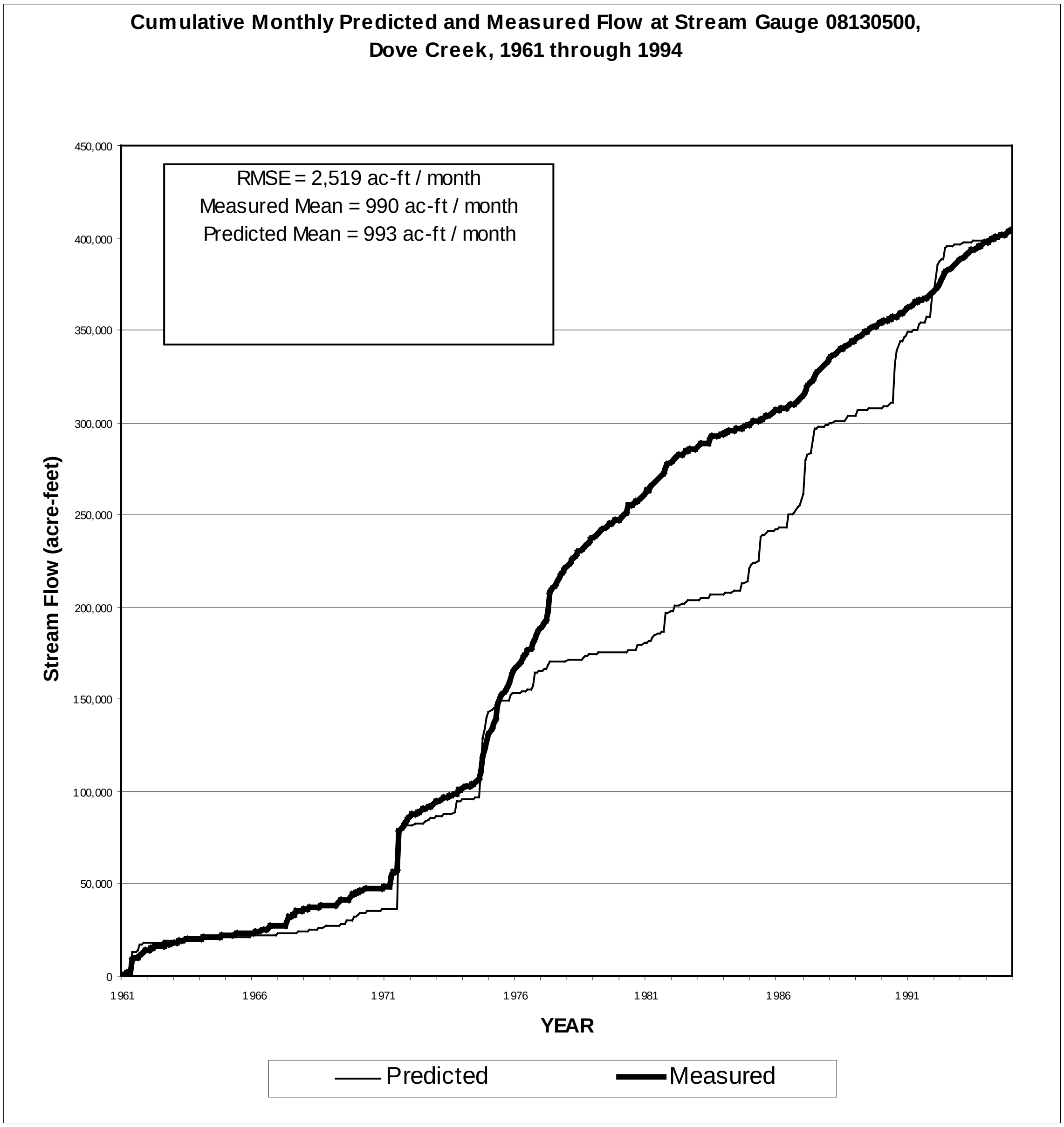


**Figure 1.5. Cumulative monthly stream flow predicted by SWAT and measured near outlet of Dove Creek. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

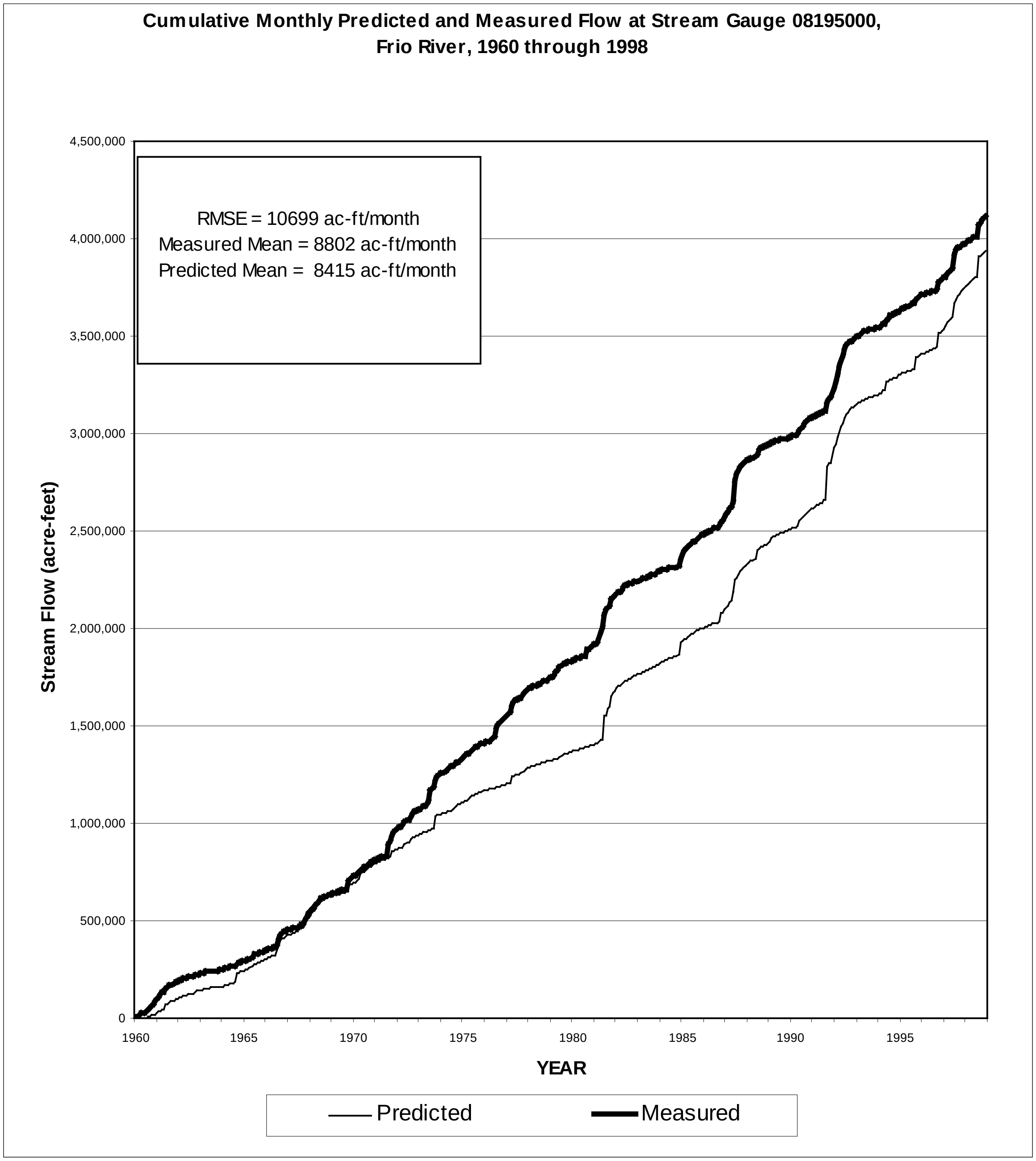


**Figure 1.6. Cumulative monthly stream flow predicted by SWAT and measured near outlet of Frio River. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

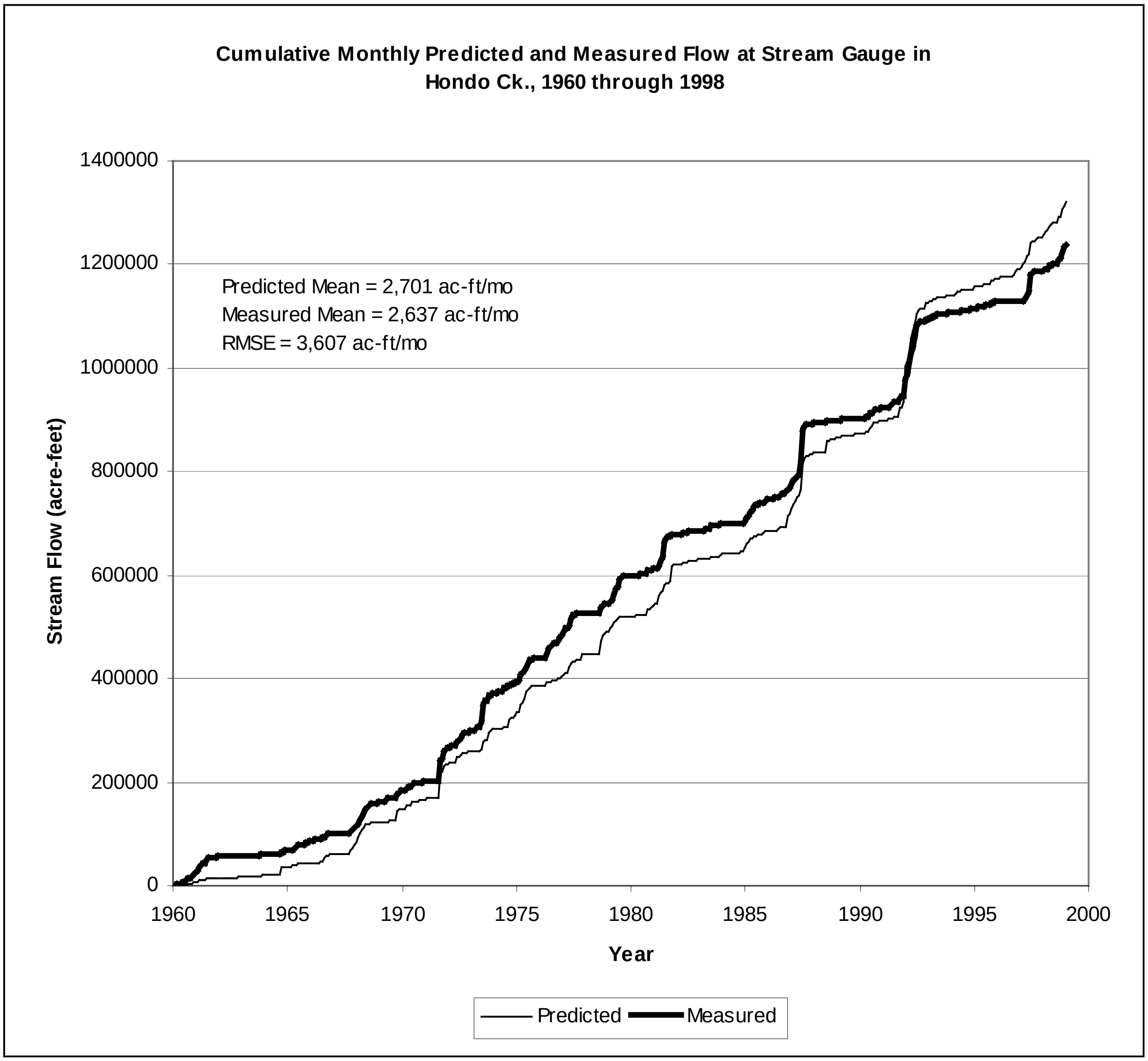


**Figure 1.7. Cumulative monthly stream flow predicted by SWAT and measured near outlet of Hondo Creek. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

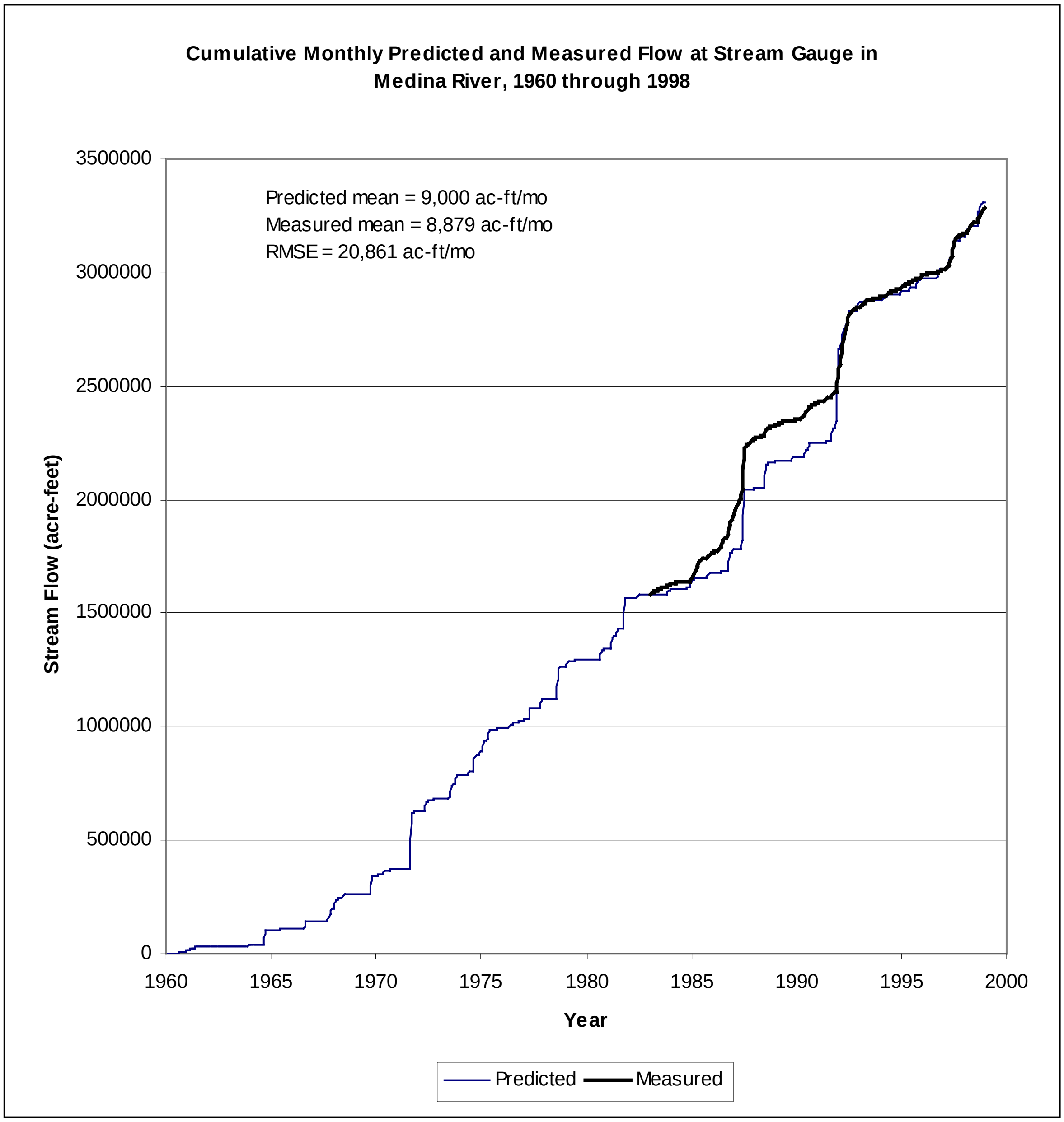


**Figure 1.8.** **Cumulative monthly stream flow predicted by SWAT and measured near outlet of Medina River. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

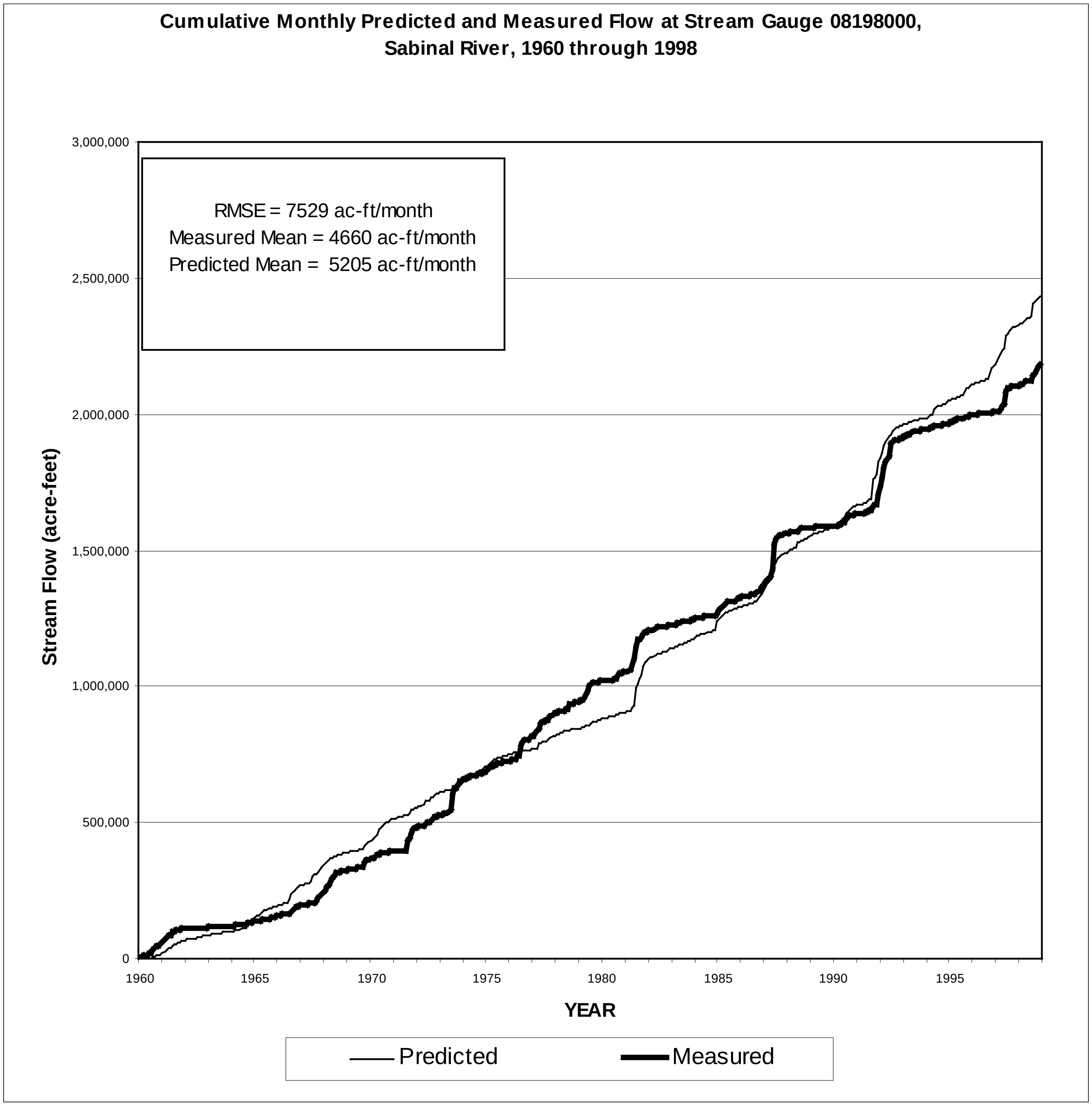


**Figure 1.9.** **Cumulative monthly stream flow predicted by SWAT and measured near outlet of Sabinal River. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

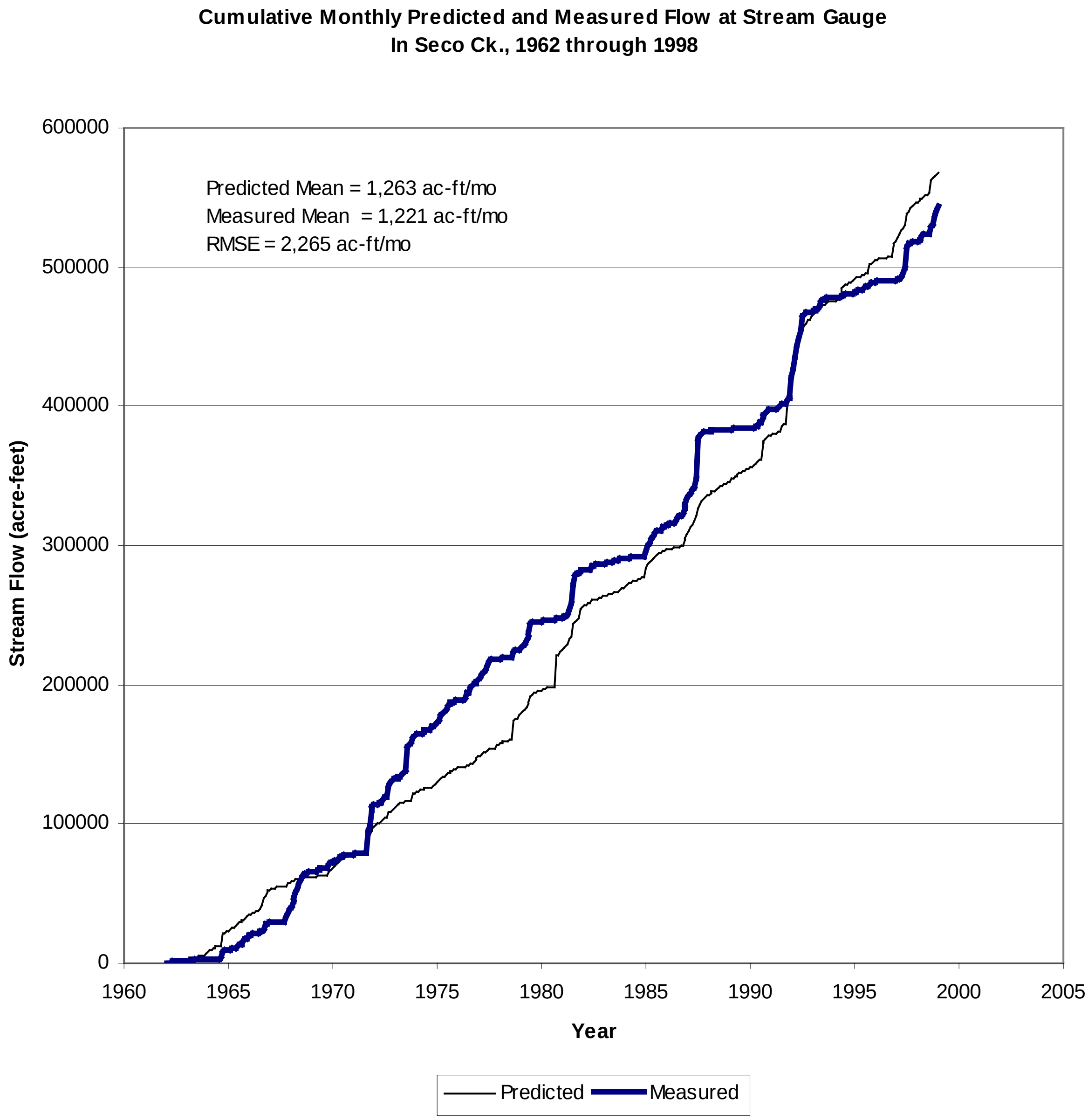


**Figure 1.10. Cumulative monthly stream flow predicted by SWAT and measured near outlet of Seco Creek. Average measured and predicted monthly flows for the entire calibration period and the root mean square error (RMSE) between monthly predicted and measured flows are shown.**

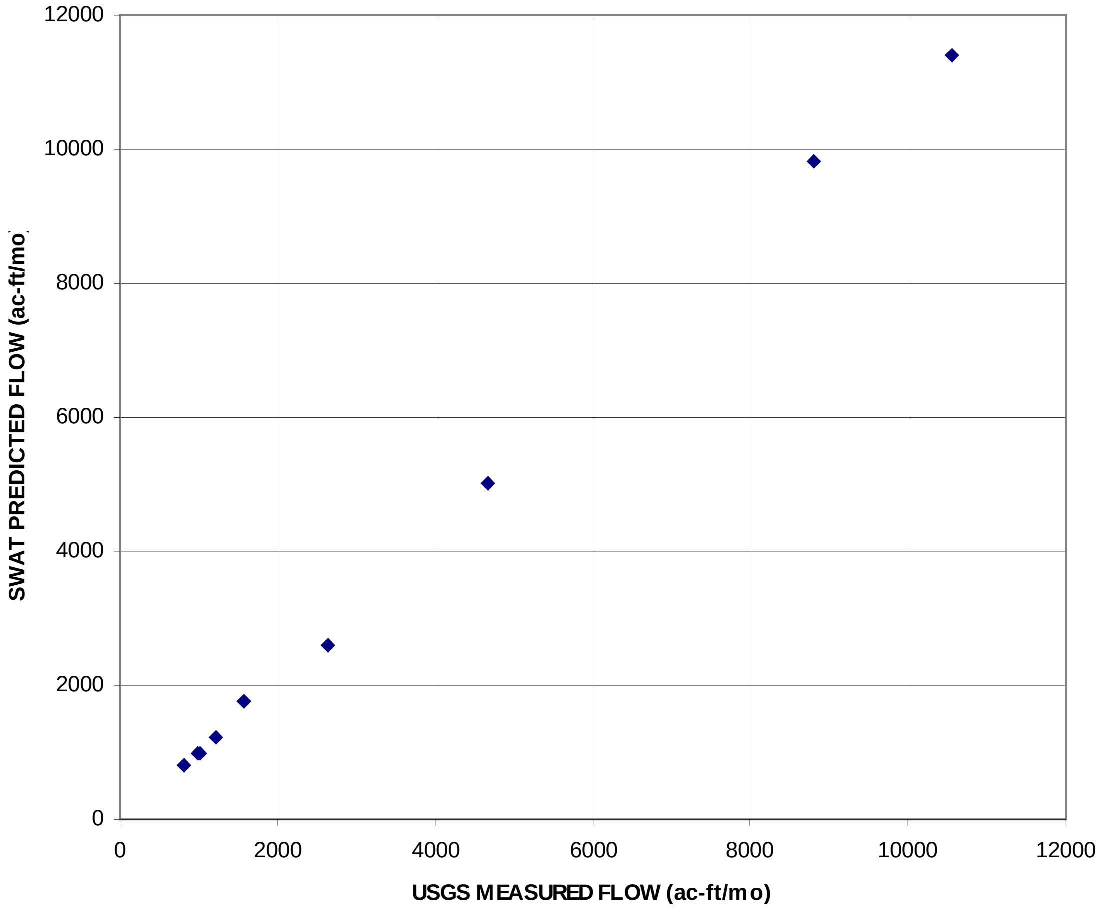


**Figure 1.11. Average monthly measured and predicted stream flow for watersheds in this study. Averages are for varying periods, but typically 1960 through 1998.**

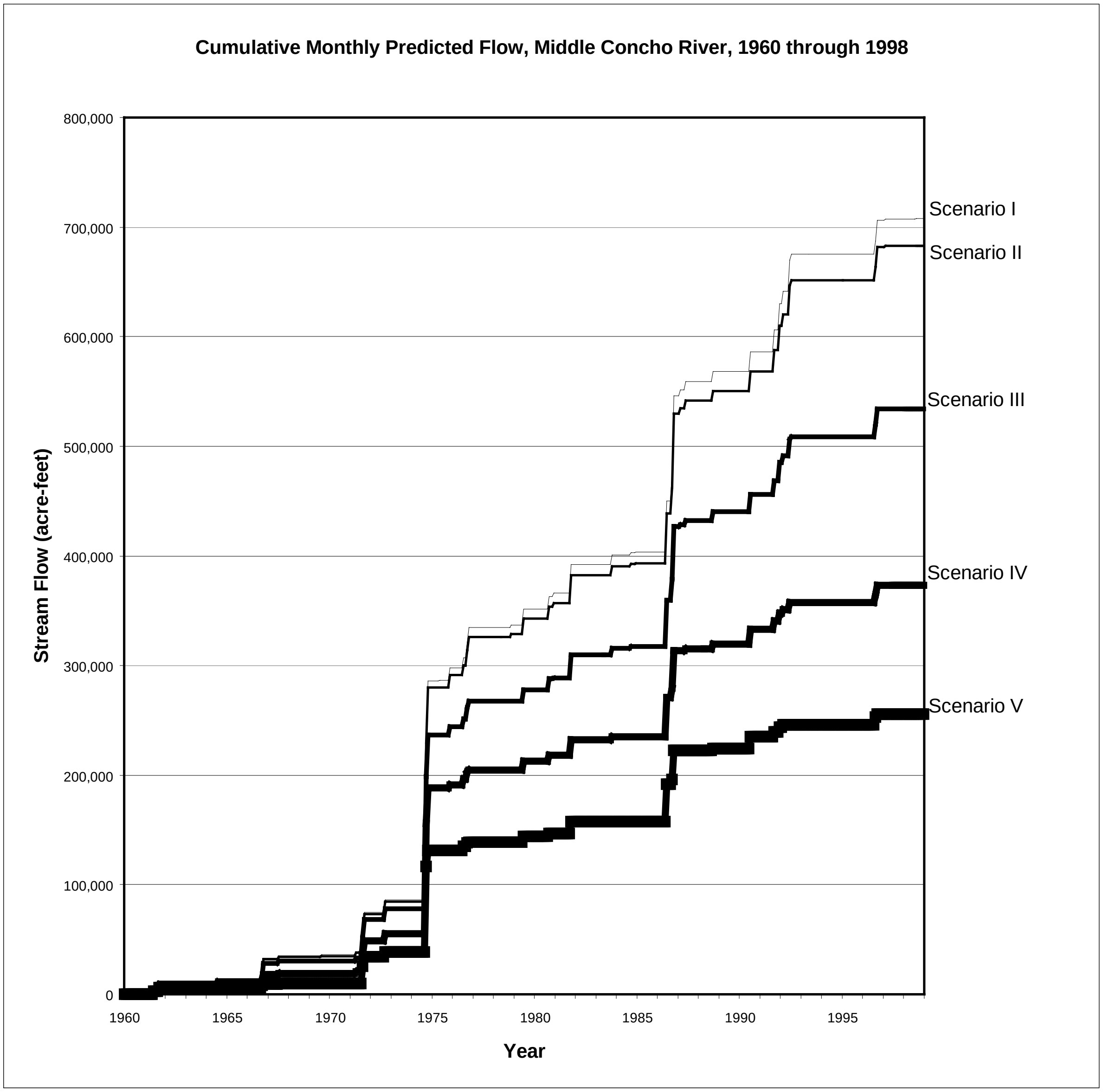


**Figure 1.12. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Middle Concho River.**

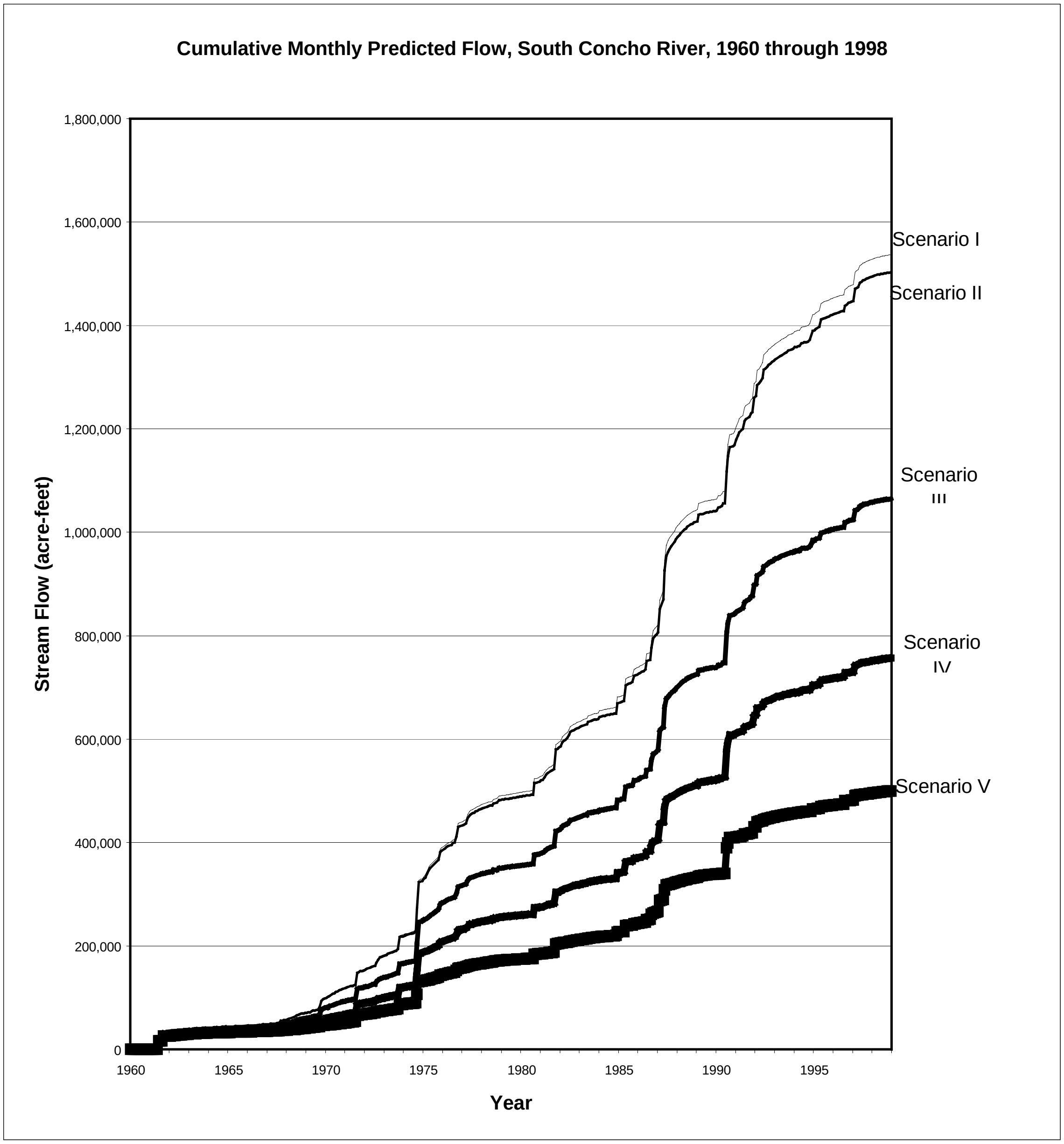


**Figure 1.13. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of South Concho River.**

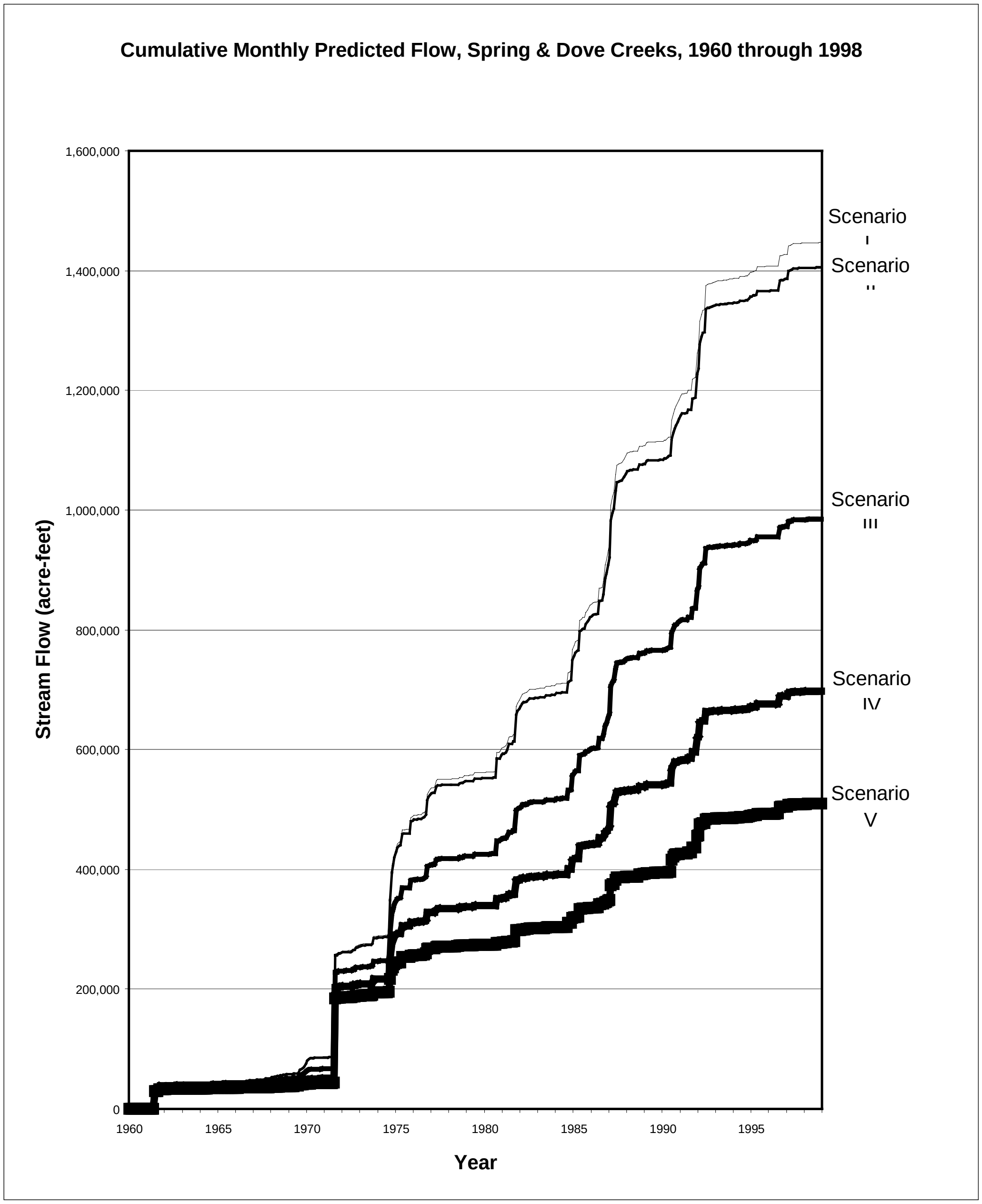


**Figure 1.14. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Spring and Dove Creeks**

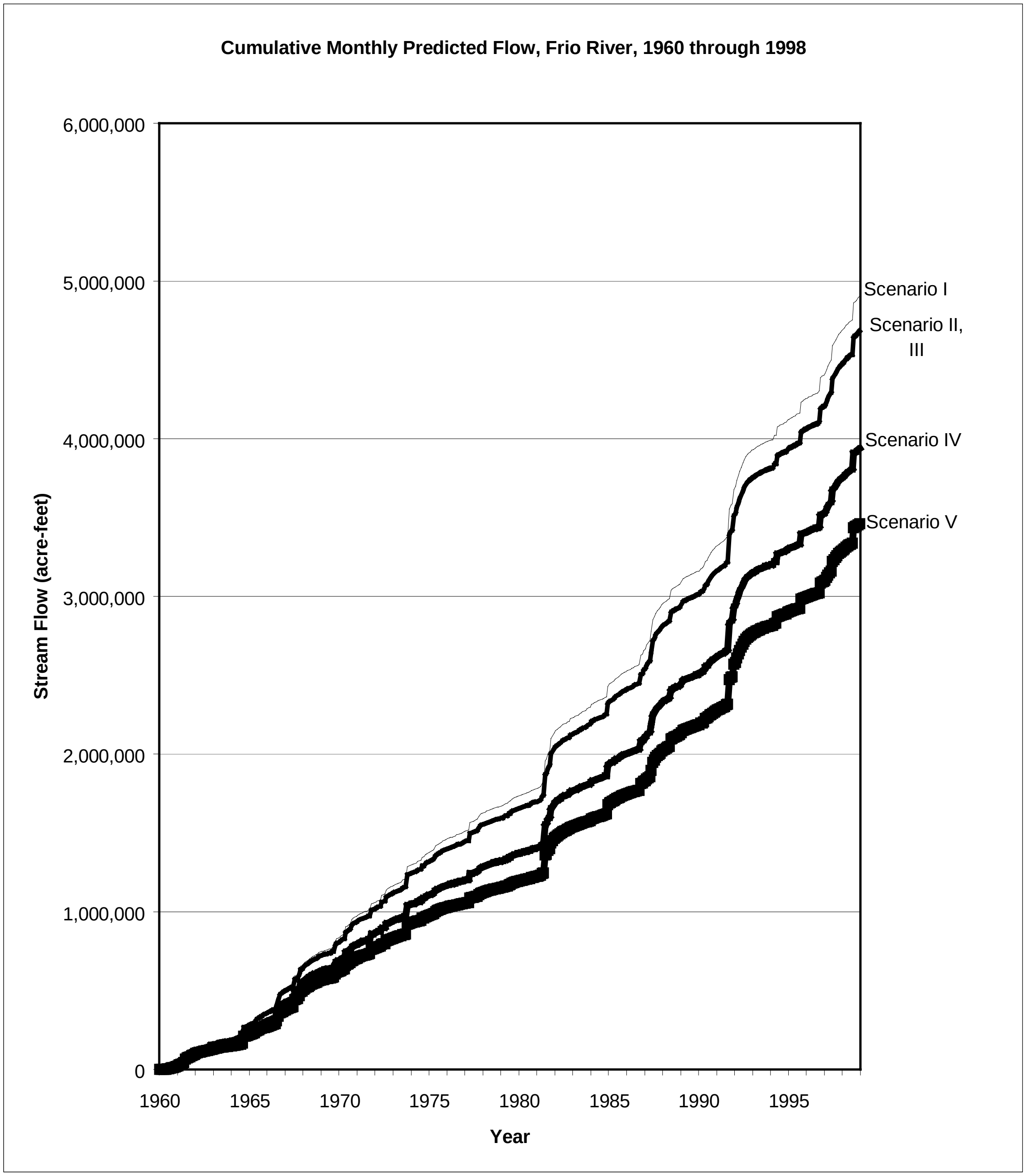


**Figure 1.15. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Frio River.**

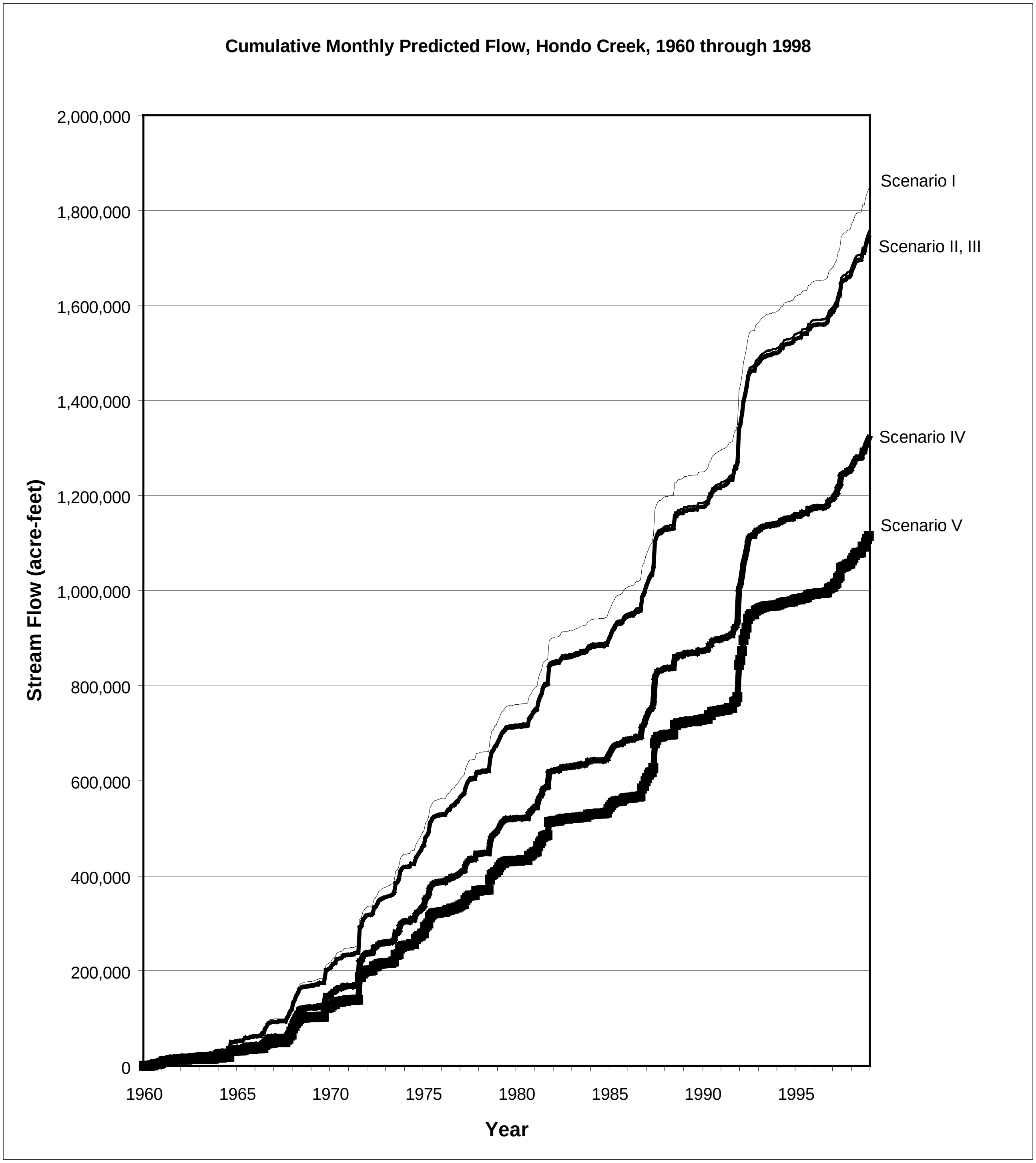


**Figure 1.16. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Hondo Creek.**

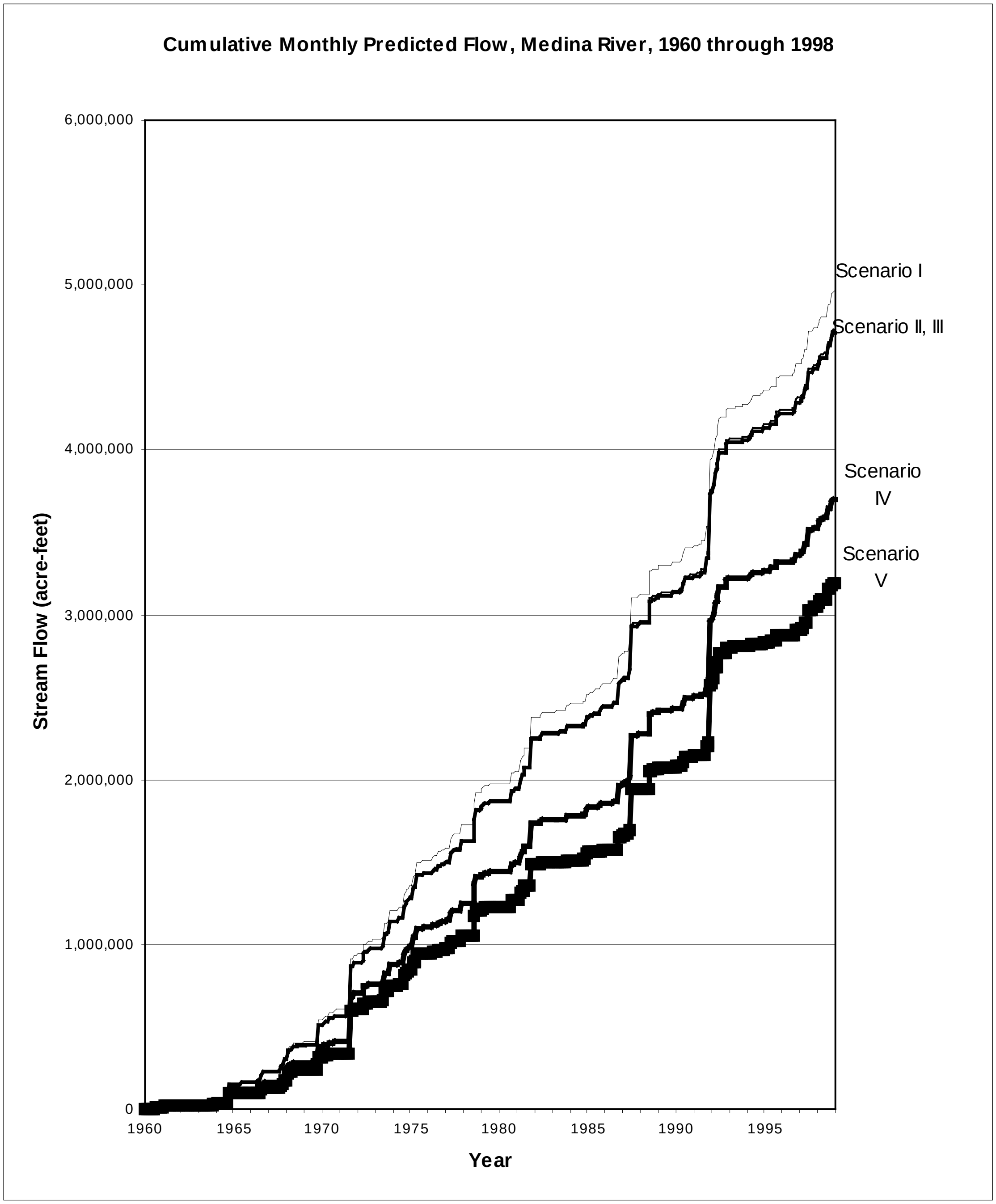


**Figure 1.17. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Medina River.**

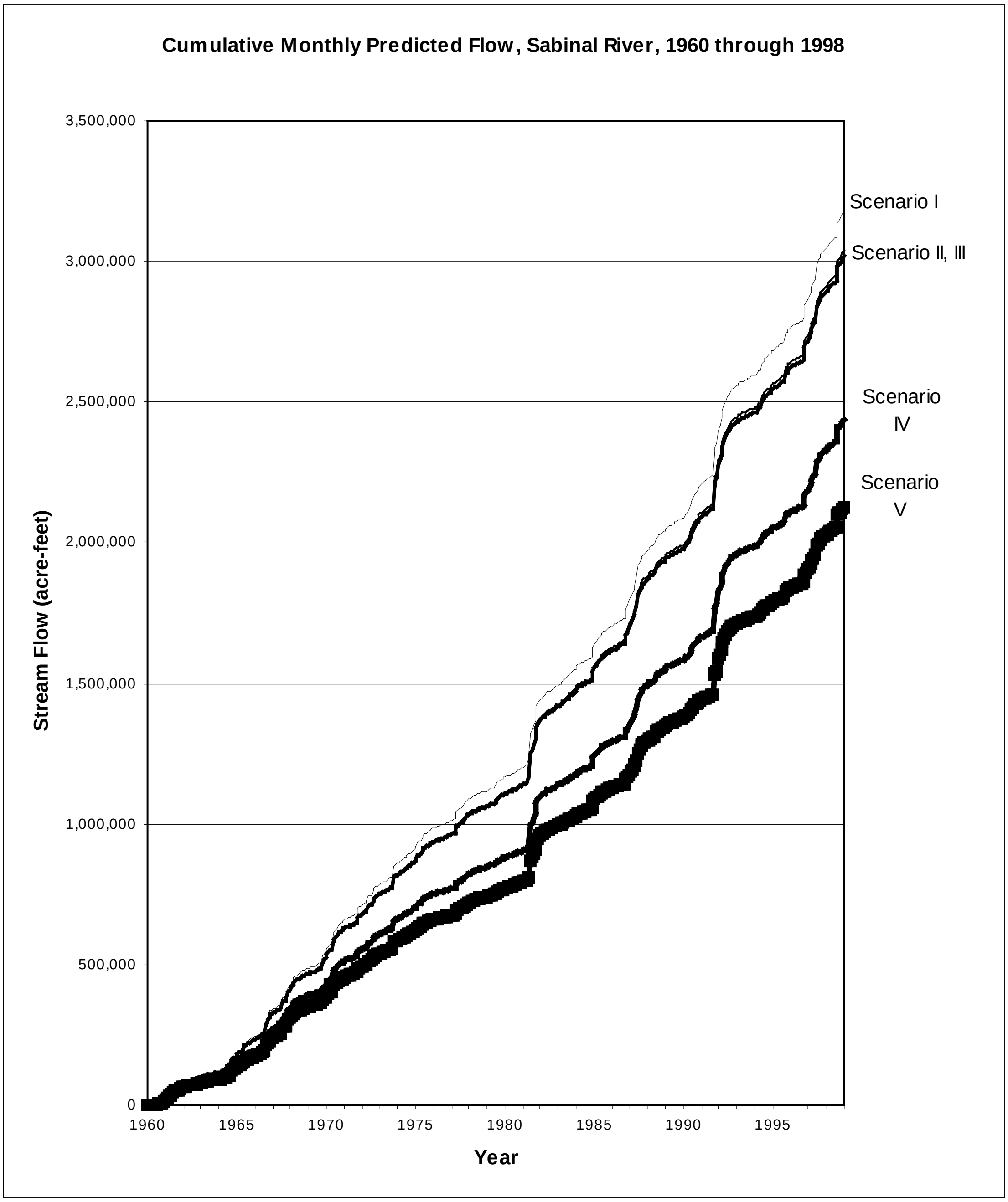


**Figure 1.18. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Sabinal River.**

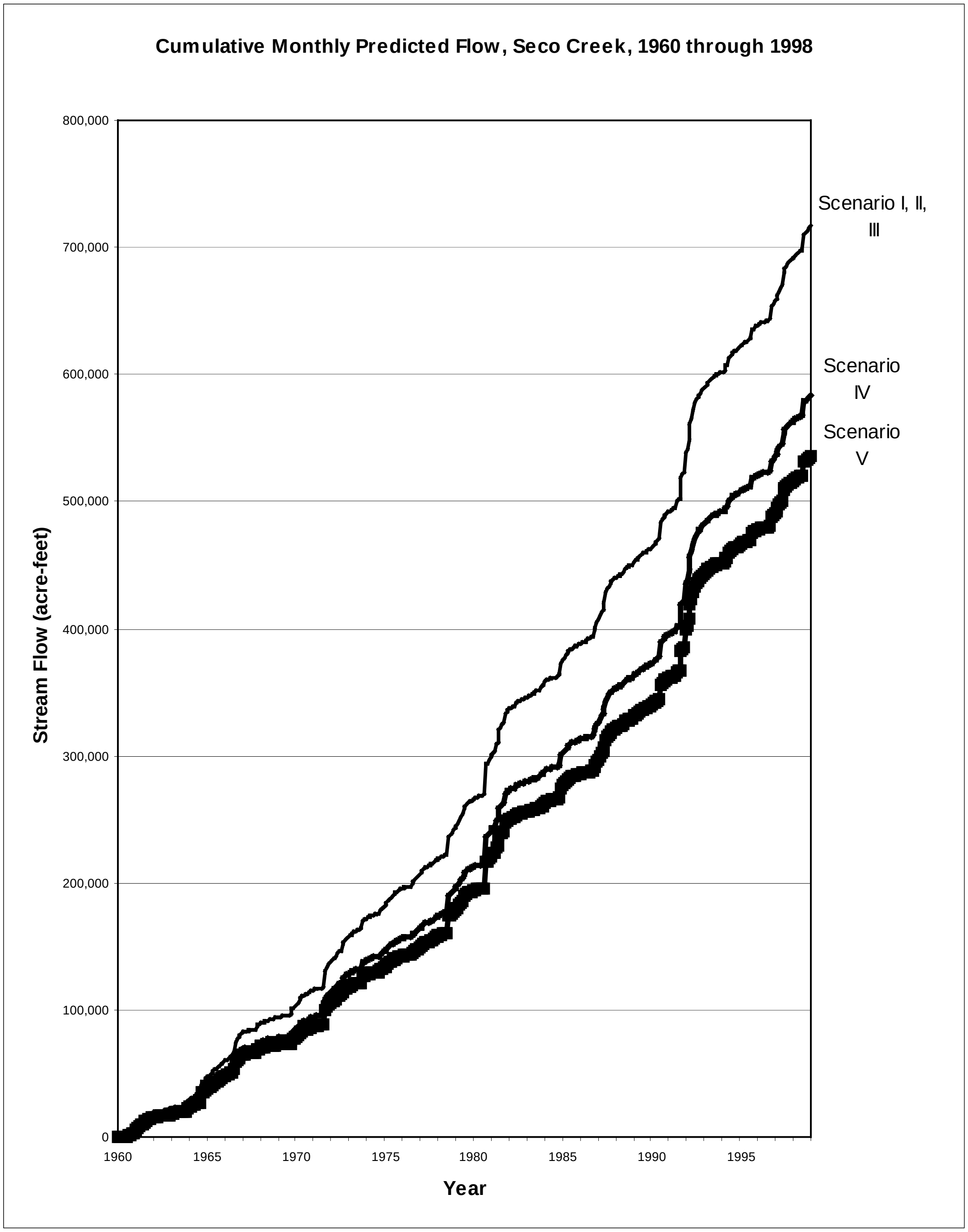


**Figure 1.19. Cumulative monthly stream flow predicted by SWAT for scenarios I through V near outlet of Seco Creek.**

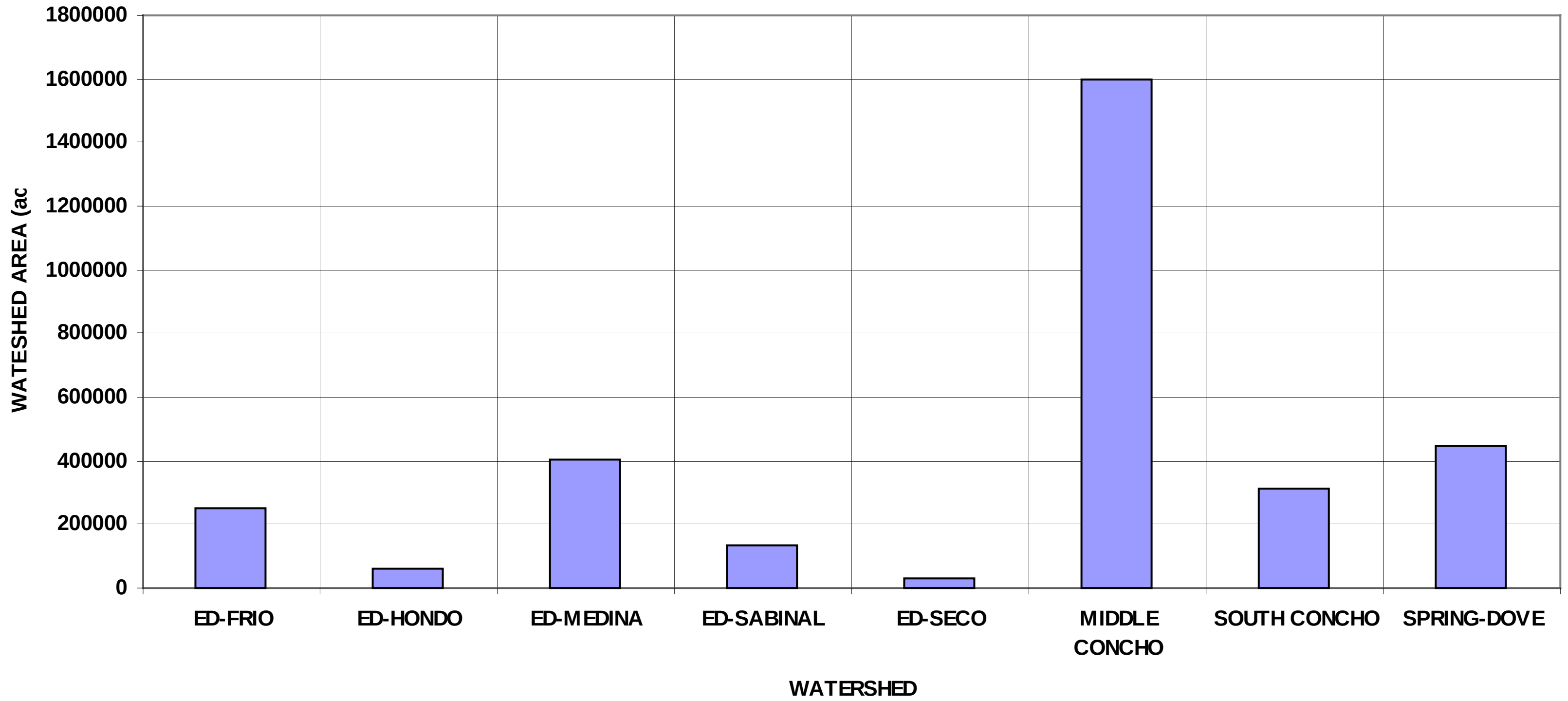


**Figure 1.20. Area of each watershed.**

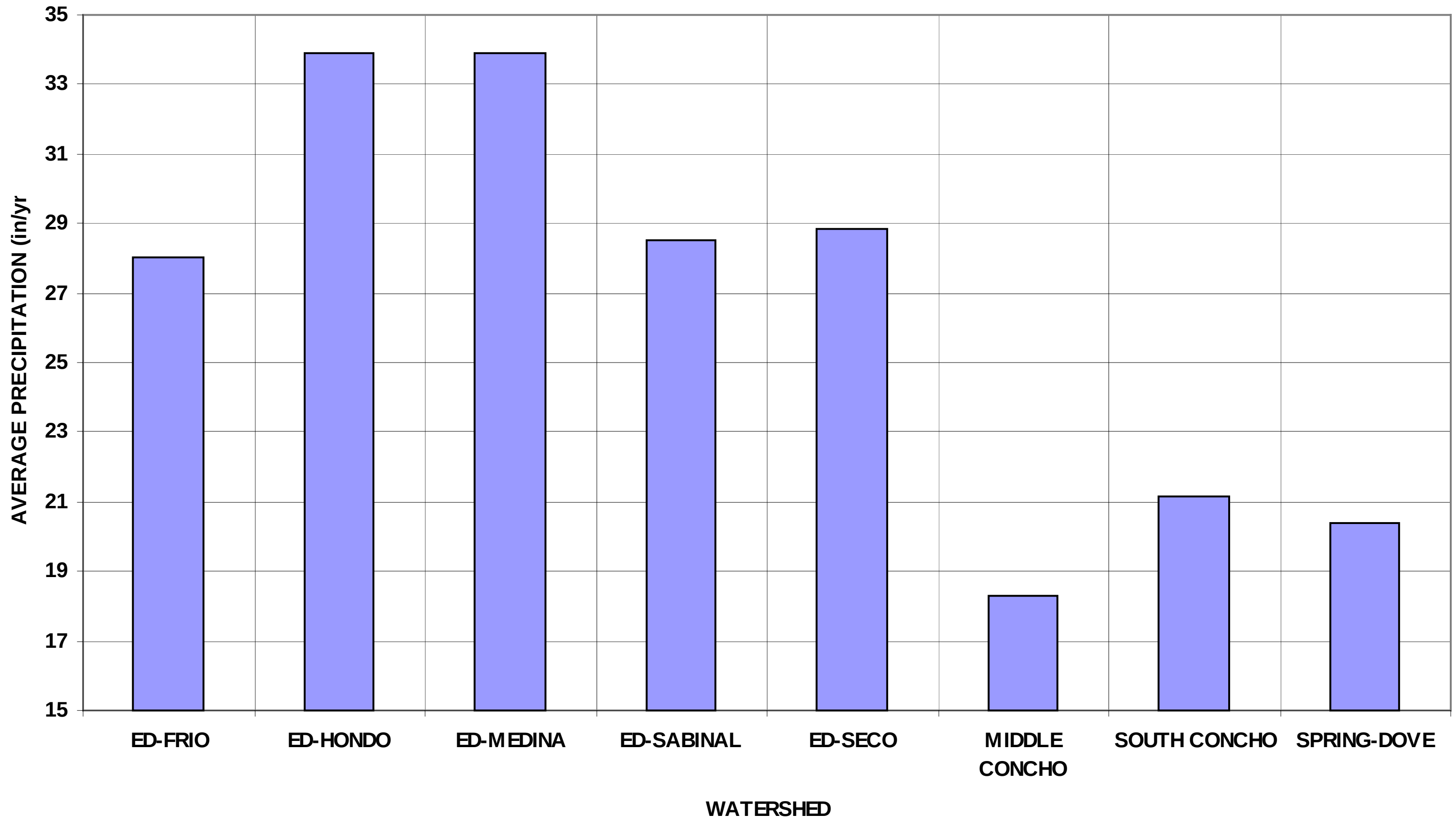


**Figure 1.21. Average annual precipitation in each watershed.**

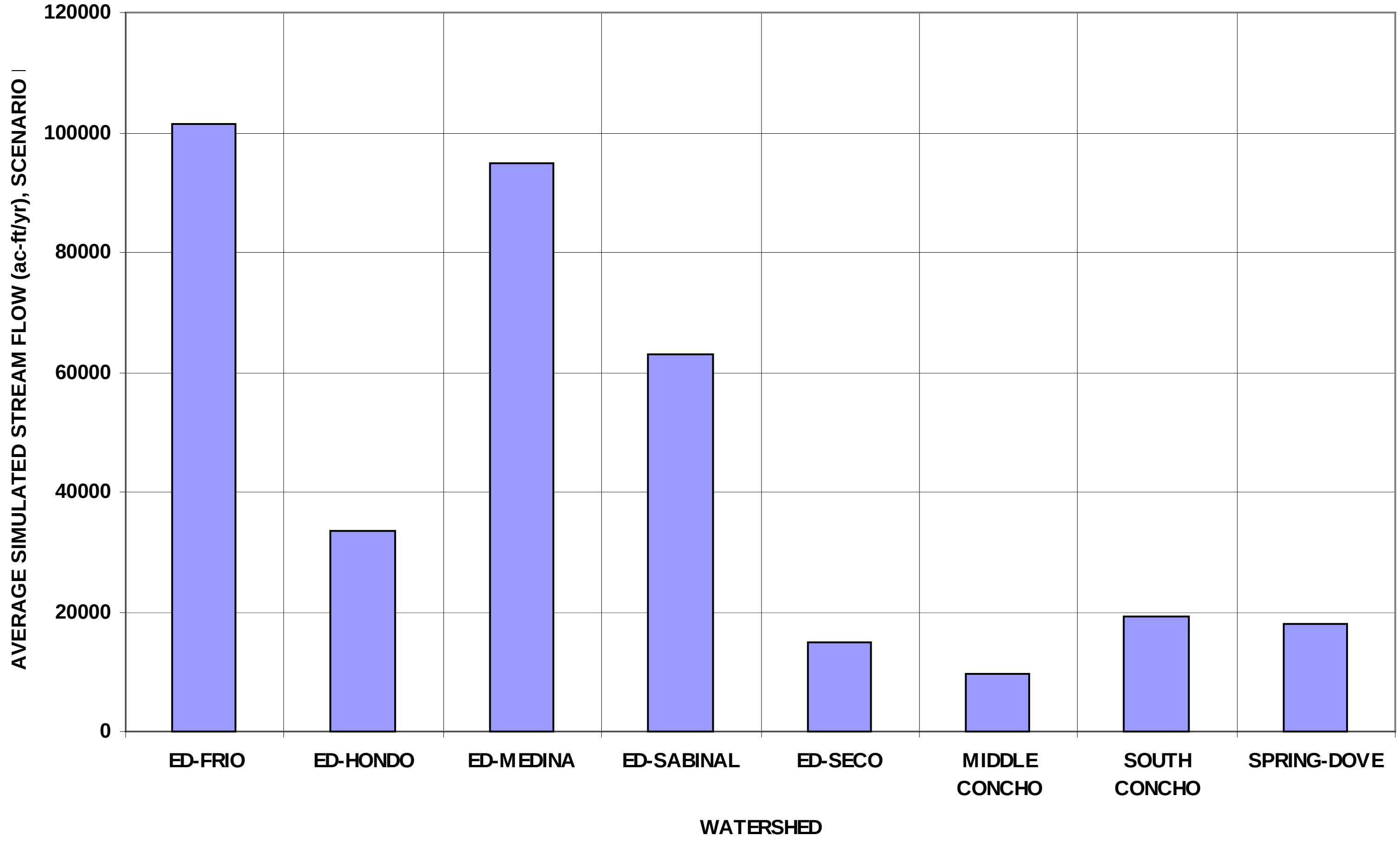


**Figure 1.22. Average annual simulated stream flow in each watershed.**

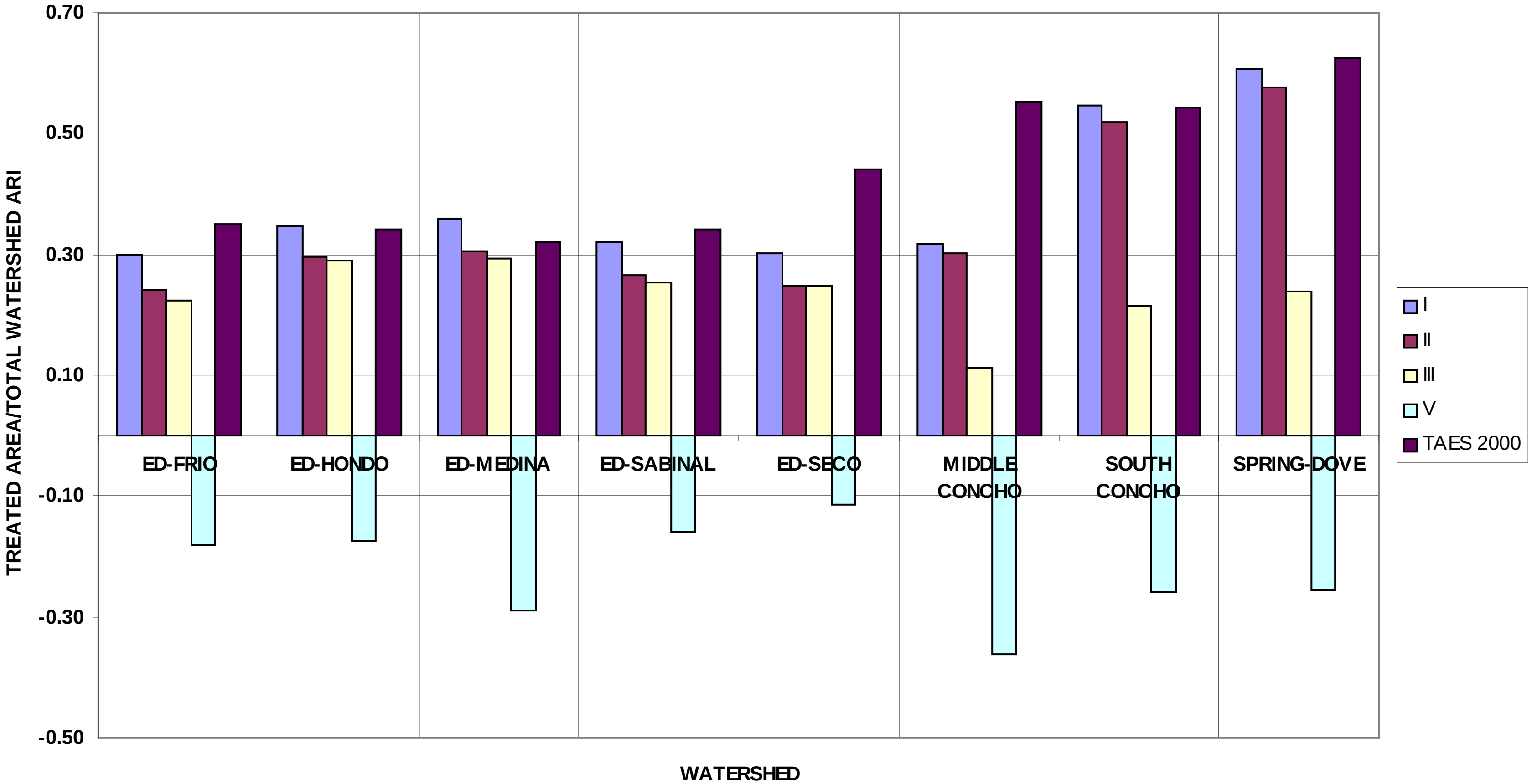


**Figure 1.23. Fraction of total watershed area treated (i.e. area with moderate and heavy brush removed) for scenarios I, II, and III, and in a previous study (TAES 2000). Negative area for scenario V represents area of light brush added.**

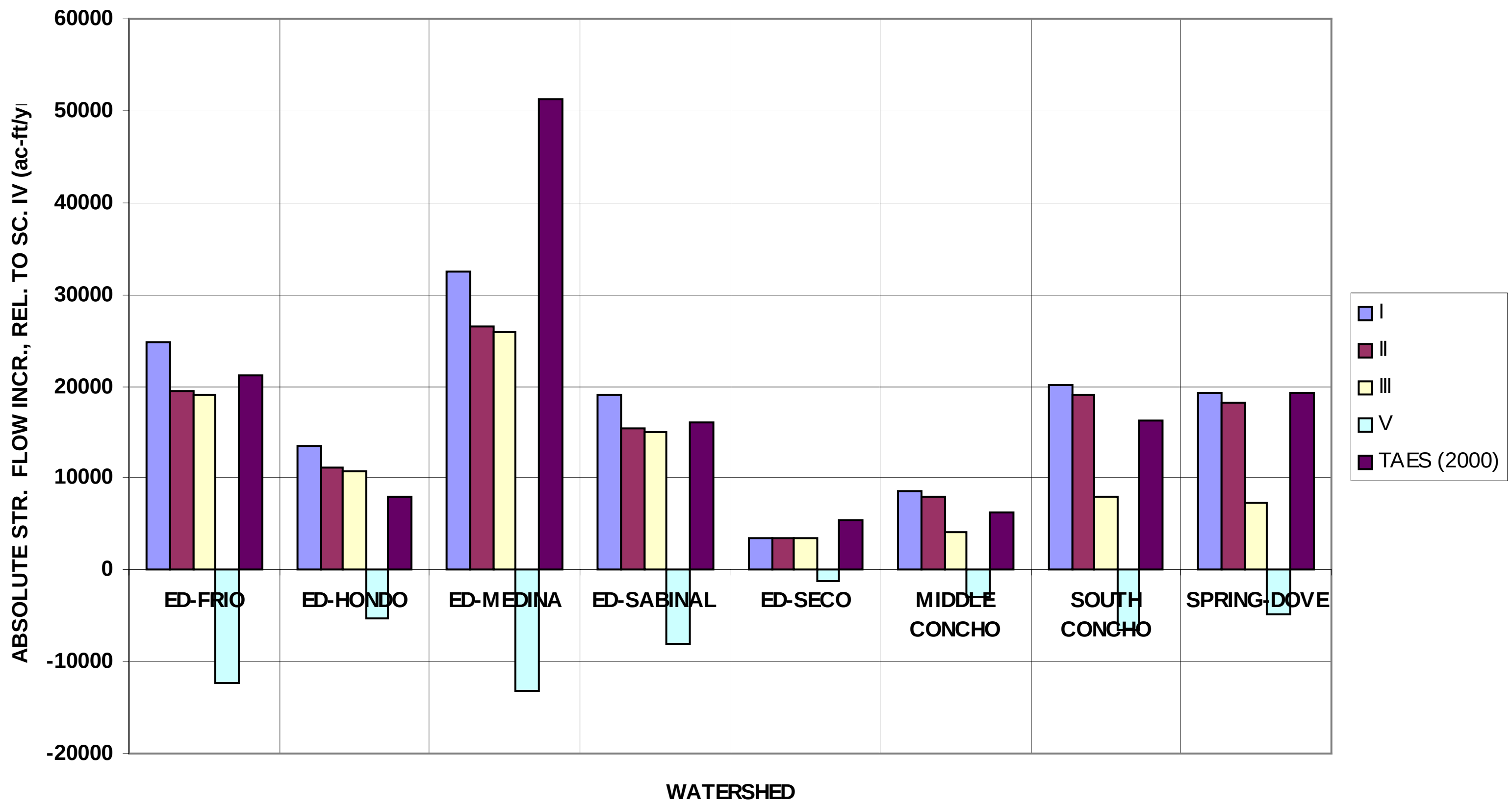


**Figure 1.24. Annual average stream flow increase, relative to scenario IV, for scenarios I, II, III, and V, and in a previous study (TAES 2000). Negative stream flow for scenario V represents a flow decrease.**

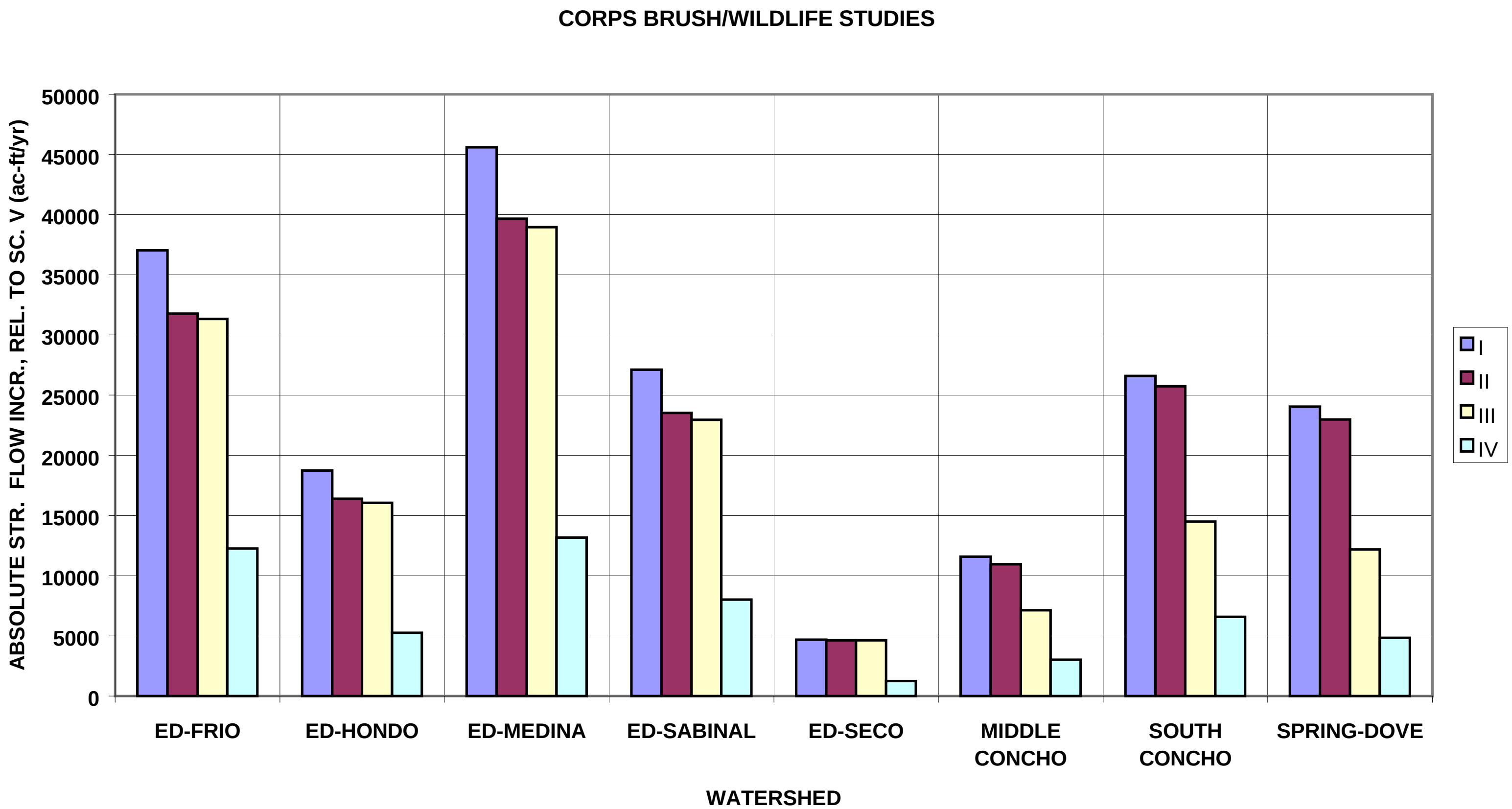


**Figure 1.25. Annual average stream flow increase, relative to scenario V, for scenarios I, II, III, and IV.**

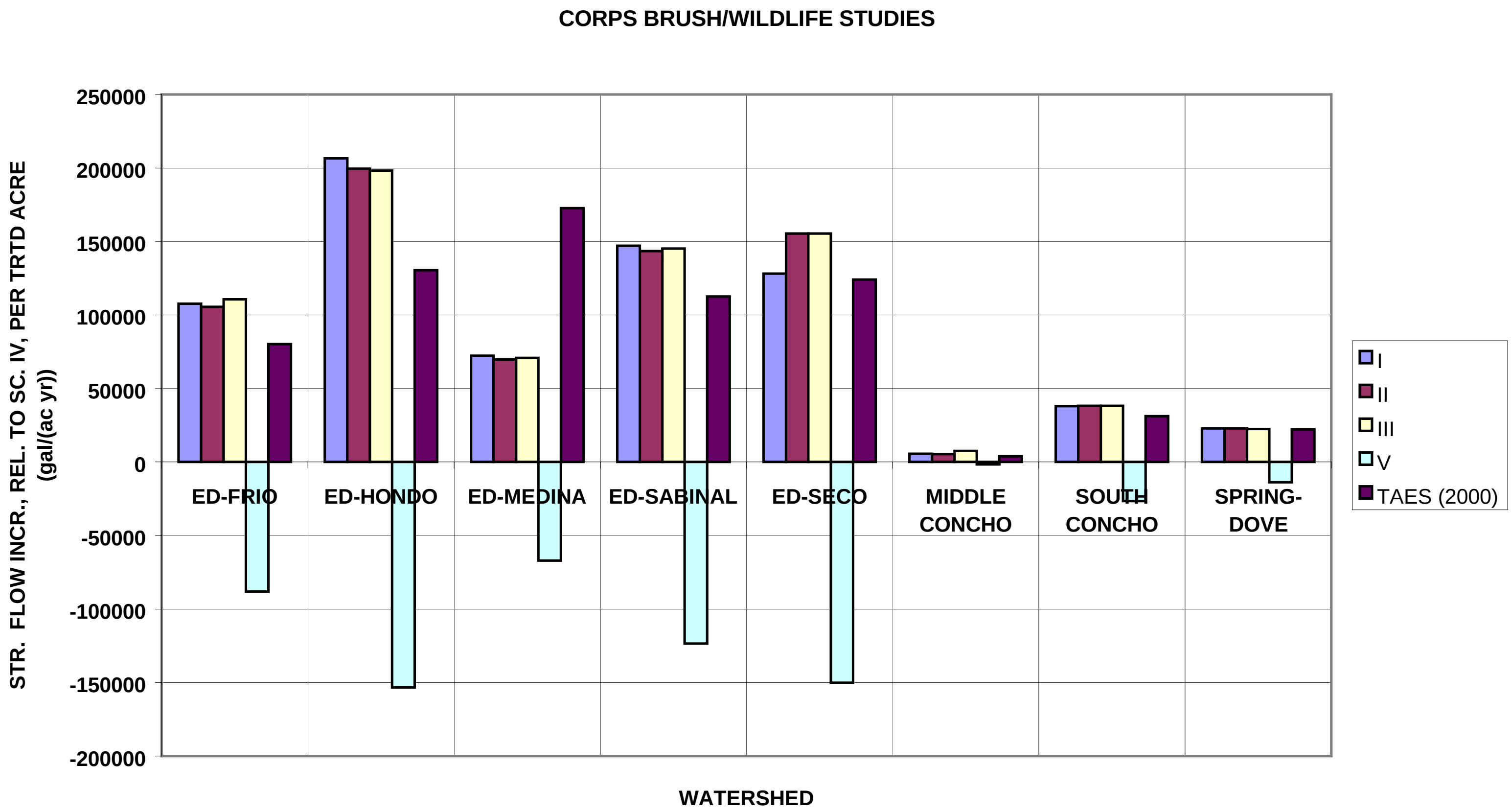


**Figure 1.26. Annual average stream flow increase, per treated acre and relative to scenario IV, for scenarios I, II, III, and V, and in a previous study (TAES 2000). Negative stream flow for scenario V represents a flow decrease.**

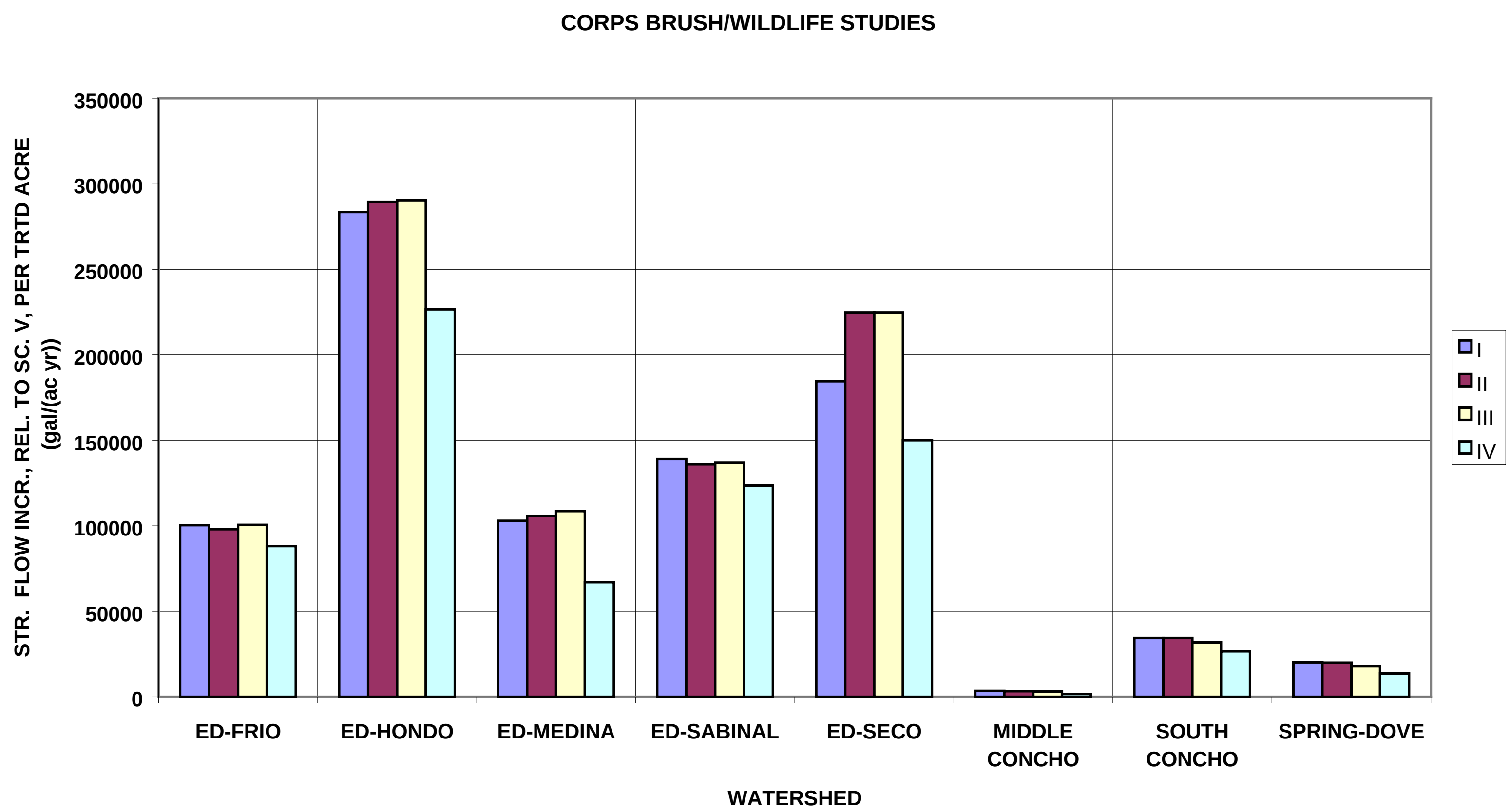


**Figure 1.27. Annual average stream flow increase, per treated acre and relative to scenario V, for scenarios I, II, III, and IV.**

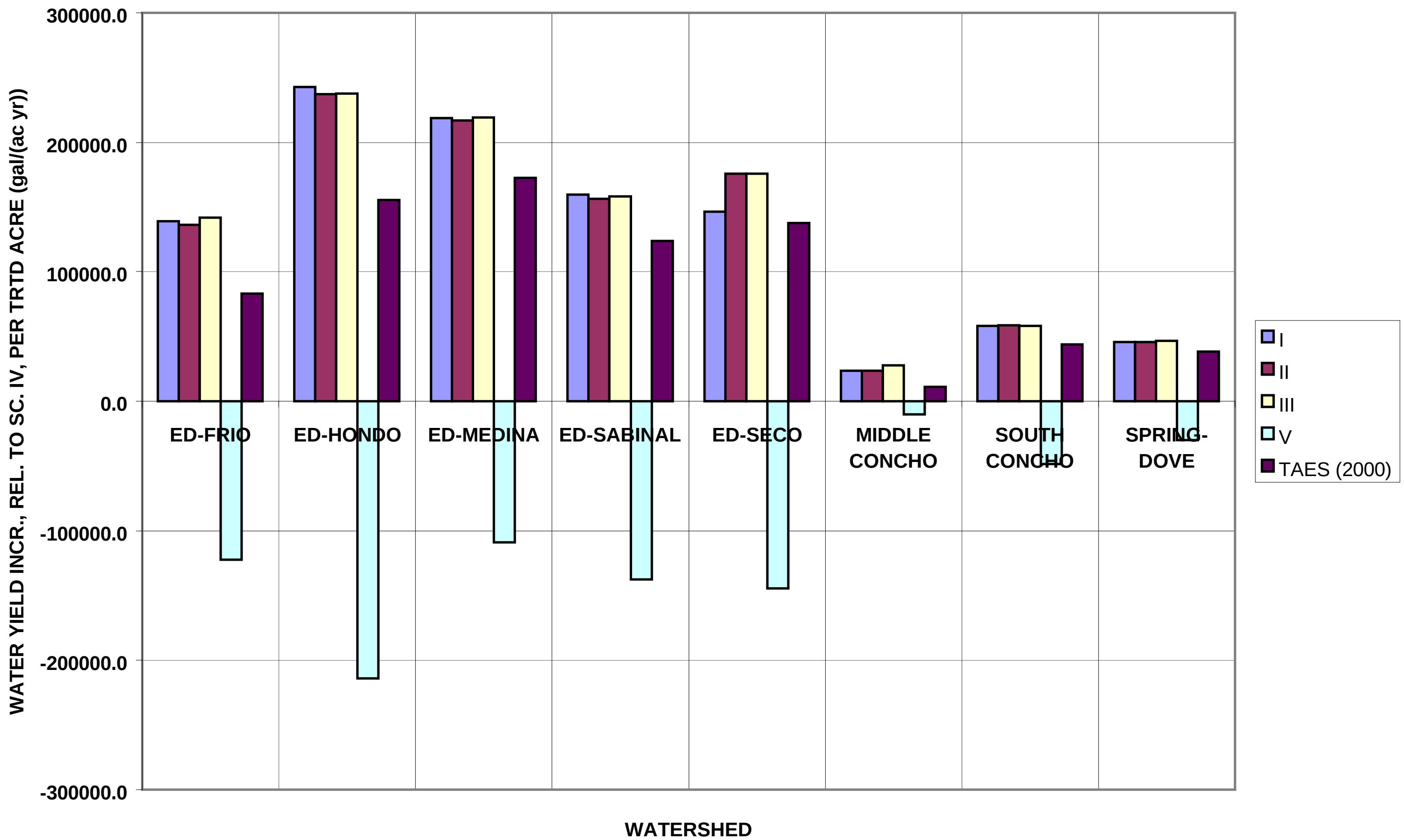


**Figure 1.28. Annual average water yield increase, per treated acre and relative to scenario IV, for scenarios I, II, III, and V, and in a previous study (TAES 2000). Negative water yield for scenario V represents a decrease.**

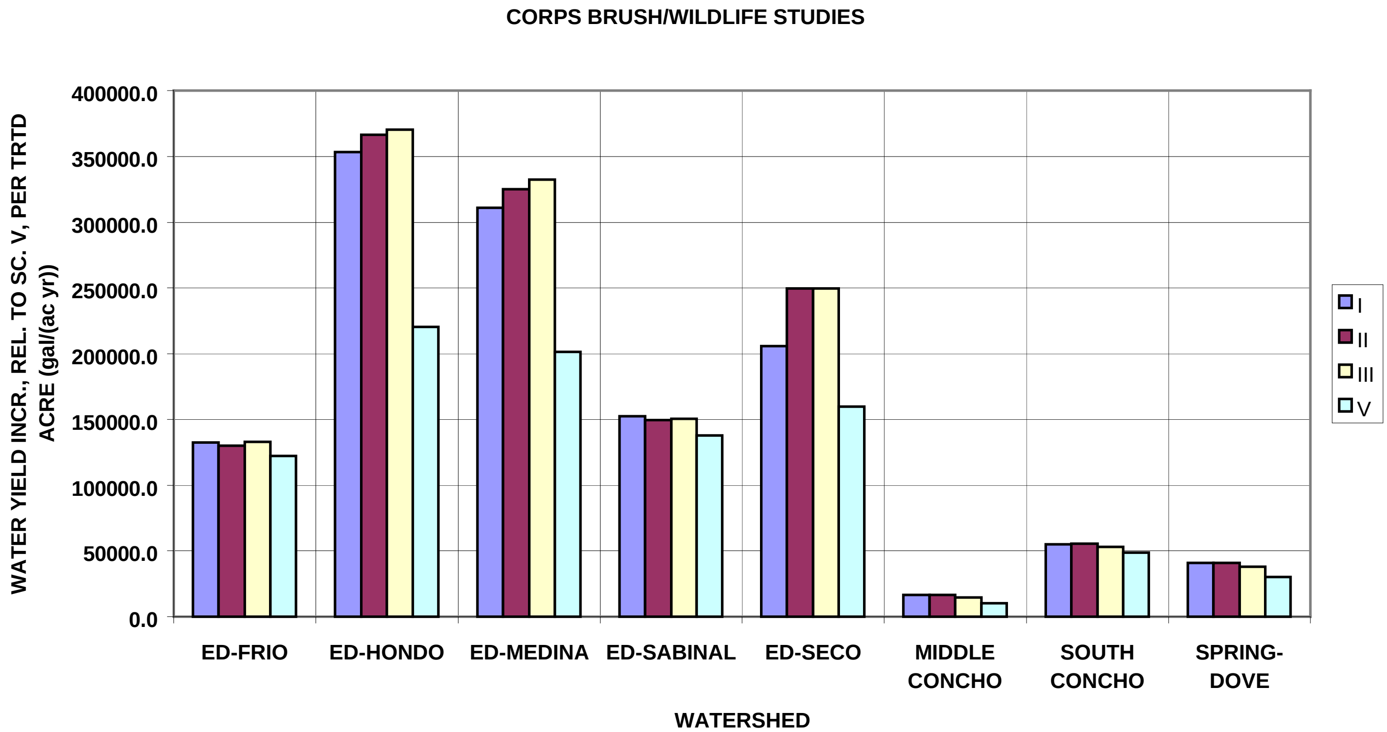


**Figure 1.29. Annual average water yield increase, per treated acre and relative to scenario V, for scenarios I, II, III, and I.**

# Section 2. Rangeland/Economic Analysis

**Participants**

TAES
- Olenick, Keith L.
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- Hamilton, Wayne T.
- Conner, J. Richard
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**Introduction**

The previous chapter presented the hydrologic implications of different brush management/restoration scenarios for the Twin Buttes and Edwards Aquifer recharge zone watersheds. By using data included in that section and economic analysis methodology used in the TAES study (2000), this chapter will examine the economic implications for three different brush management/restoration strategies.

Specifically, the objectives of this portion of the study are to identify the different brush control and ecological restoration treatments and associated costs for the dominant brush-types within the Twin Buttes and Edwards Aquifer recharge zone watersheds. Next, assumptions, methodology, and results for the private and society cost of implementing each brush control scenario are presented. Lastly, an estimate of society's cost of additional water for both watersheds and all subbasins within them is made. In all references to society cost, the assumption is made that there is no incentive for the landowner to incur the cost.

**Methods**

The methodology used in this chapter is similar to that used in the economic feasibility portions of the TAES study (2000). This technique integrates information from hydrologic modeling, focus groups, and range scientists to form an economic model that is used to study the economic implications of each brush control scenario for all sub-basins within the eight watersheds found in the two study areas over a 10 year time horizon. First, changes in carrying capacity caused by brush management and animal enterprise inputs were utilized in the estimation of landowner benefits per acre of each targeted brush type-density category. Next, per acre benefits of brush management/restoration to livestock and wildlife enterprises was subtracted from the total per acre cost of brush control and restoration efforts to arrive at society's cost share. The amount and type of brush removed for each brush management scenario was then multiplied by society's cost share for each respective brush type-density to arrive at a total society cost of brush management/restoration for all sub-basins within the eight Edward/Twin Buttes watersheds.

Lastly, the total society cost of brush management for each scenario was divided by the additional water produced under each scenario to estimate society's cost of additional acre-feet of water. Geographic differences between the Eastern and Western portions of the Edwards Aquifer recharge zone watershed necessitated the use of separate carrying capacity, brush treatments and costs, and livestock enterprise assumptions.

*Inputs*

Data gathered from focus groups and range scientists was used to estimate differences in livestock carrying capacity, develop the brush control and restoration techniques and costs for the dominant brush-types, and characterize typical livestock/wildlife enterprises. The amount and type of brush removed and additional water provided by each scenario was provided by the Blackland Research Center, Texas Agriculture Experiment Station, Temple, Texas. Where the previous TAES study (2000) used the investment analysis program ECON to conduct economic analyses, this study used Microsoft Excel.

One of the biggest obstacles of engaging in brush control practices is cost. A key assumption of this model is that costs of brush management/restoration treatments in excess of rancher benefits would need to be paid for by Society. Society can be State of Texas, U.S. Government, a city, county or other entity.

Brush control and restoration techniques and prices for both watersheds are shown in Tables 2.1a, 2.1b and 2.1c. The discount rate used is six percent. Initial and follow-up brush treatments were provided by focus groups and range scientists. Reseeding costs were determined by using current market prices for an area-specific native grass mix purchased in bulk. The per acre costs of cross fencing were calculated by taking the cross distance in feet of the mean ranch size of that particular study area, multiplying by the per foot cost of fencing, $1.25 and dividing this product by the mean ranch size in acres. Ranches were assumed to be square in shape with mean ranch size determined from a 2002 Texas Agricultural Experiment Station landowner survey (Narayanan et al., 2002). Grazing deferment costs were calculated by taking the inverse of the Year 0 carrying capacity for that particular brush type and multiplying by the cost to lease one animal unit for one year, $100. The cost of an additional water source was determined by dividing the cost of a water well, $12,000, by the mean ranch size in acres of the respective study area.

Estimated livestock carrying capacity changes are presented in Tables 2.2a, 2.2b and 2.2c. These figures follow those used in the TAES study (2000) except where mechanical means of initial brush control are conducted and reseeding follows. Tables 2.3a, 2.3b and 2.3c show the livestock and wildlife enterprise assumptions. For a detailed description of how this information was used to estimate the appropriate landowner share of total cost see TAES, 2000.

*Model Changes*

For this study, the economic analysis model was modified from those included in the TAES study (2000) in the following ways:

1. The initial study did not incorporate ecological restoration practices such as rangeland reseeding, grazing deferments, and implementation of improved grazing management systems through additional cross fencing and water sources.
2. Livestock carrying capacity for brush types where mechanical means of brush control are recommended have increased in this study due to rangeland reseeding.
3. The discount rate used to determine present values for brush management cost and changes in incremental livestock / wildlife enterprise income was changed from 8 percent in the TAES study (2000) to 6 percent in this study.

4. For some brush types, recommended follow up brush treatments, i.e. individual plant treatments or prescribed burns, may occur once more often and / or in different years following initial treatment.

5. The investment analysis tool ECON was not used in the livestock / wildlife enterprise modeling. Instead, this study relied on spreadsheets developed on Microsoft Excel.

6. In this study, the Sabinal watershed uses livestock/wildlife enterprise assumptions for the Western Edwards. In the TAES study (2000), the Sabinal watershed uses assumptions for the Eastern Edwards.

**Table 2.1a. Cost of Brush Management/Restoration Treatments by Brush Type–Density Category—Twin Buttes.**

**Heavy Cedar—Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Mech. Choice | 85.00 | 85.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 1.43 | 1.43 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 15.00 | 12.59 |
| 7 | IPT or Burn | 10.00 | 6.65 |
| | | Total | 142.21 |

[1] Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Heavy Mesquite—Chemical

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Aerial Herbicide | 26.00 | 26.00 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 15.00 | 12.59 |
| 7 | IPT or Burn | 10.00 | 6.65 |
| | | Total | 51.78 |

**Heavy Mesquite – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Mech. Choice | 85.00 | 85.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 2.63 | 2.63 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 15.00 | 12.59 |
| 7 | IPT or Burn | 10.00 | 6.65 |
| | | Total | 143.42 |

1 Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

**Heavy Mixed Brush – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Treedoze | 85.00 | 85.00 |
| 0 | Reseeding | 15.00 | 15.00 |

**Table 2.1a. Cost of Brush Management/Restoration Treatments by Brush Type–Density Category—Twin Buttes.**

| | | | |
|---|---|---|---|
| 0 | Grazing Deferment | 2.00 | 2.00 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 15.00 | 12.59 |
| 7 | IPT or Burn | 10.00 | 6.65 |
| | | Total | 127.78 |

1 Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

**Moderate Cedar – Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Doze, Reseeding | 55.00 | 55.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 1.92 | 1.92 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 15.00 | 12.59 |
| 7 | IPT or Burn | 10.00 | 6.65 |
| | | Total | 97.71 |

1 Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

**Moderate Mesquite – Chemical**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Aerial or IPT Herbicide | 26.00 | 26.00 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 20.00 | 16.79 |
| 7 | IPT or Burn | 15.00 | 9.98 |
| | | Total | 59.31 |

**Moderate Mesquite – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Choice of Mechanical Method | 55.00 | 55.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 3.13 | 3.13 |
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 20.00 | 16.79 |
| 7 | IPT or Burn | 15.00 | 9.98 |
| | | Total | 106.43 |

1 Choice of tree dozing, stack, & burn, tree shearing with stump spray and later burn, or excavation and later burn.

**Moderate Mixed – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Choice of Mechanical Method | 55.00 | 55.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.50 | 2.50 |

**Table 2.1a. Cost of Brush Management/Restoration Treatments by Brush Type–Density Category—Twin Buttes.**

| | | | |
|---|---|---|---|
| 0 | Cross fencing | 2.66 | 2.66 |
| 0 | Additional Water Source | 3.88 | 3.88 |
| 3 | IPT or Burn | 15.00 | 12.59 |
| 7 | IPT or Burn | 10.00 | 6.65 |
| | | Total | 98.28 |

1 Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

## Table 2.1b. Cost of Brush Management/Restoration Treatments by Brush Type-Density Category—Western Edwards.

**Heavy Cedar—Two Way Chain[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Mech. Choice | 90.00 | 90.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 2.00 | 2.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 178.99 |

1 Two way chain, stack, and burn.

**Heavy Cedar—Tree Doze[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Mech. Choice | 145.00 | 145.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 2.00 | 2.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 233.99 |

1 Doze, stack, and burn.

**Heavy Cedar—Tree Shear or Flat Cutting[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Mech. Choice | 130.00 | 130.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 2.00 | 2.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 218.99 |

1 Tree shear or flat cutting by hand, stack, and burn.

**Heavy Mesquite—Chemical[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Aerial Herbicide | 35.00 | 35.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 91.99 |

1 Aerial or individual chemical application may be used.

**Heavy Mesquite – Rootplow[1]**

## Table 2.1b. Cost of Brush Management/Restoration Treatments by Brush Type-Density Category—Western Edwards.

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Rootplow | 155.00 | 155.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 3.33 | 3.33 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 245.32 |

1 Rootplow, rake, stack, and burn.

**Heavy Mesquite – Rootplow with Pre-Doze[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Pre-doze and Rootplow | 180.00 | 180.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 3.33 | 3.33 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 270.32 |

1 Heavy tree-doze, rootplow, rake, stack, and burn.

**Heavy Mixed Brush – Tree Doze[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Treedoze | 160.00 | 160.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.50 | 2.50 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 234.49 |

1 Heavy tree-doze, rootplow, rake, stack, and burn.

**Moderate Cedar – Tree Doze[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Tree Doze, Reseeding | 95.00 | 95.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.50 | 2.50 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 169.49 |

1 Doze, rake, stack, and burn.

## Table 2.1b. Cost of Brush Management/Restoration Treatments by Brush Type-Density Category—Western Edwards.

**Moderate Cedar – Tree Shearing or Flat Cutting[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Tree Doze, Reseeding | 75.00 | 75.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.50 | 2.50 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 149.49 |

1 Tree shear or flat cutting by hand, stack, and burn.

**Moderate Mesquite – Chemical[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Aerial or IPT Herbicide | 35.00 | 35.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 91.99 |

1 Either aerial or individual chemical applications may be used.

**Moderate Mesquite – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Choice of Mechanical Method | 60.00 | 60.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 4.00 | 4.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 135.99 |

1 Choice of tree dozing, stack, & burn, tree shearing, stump spray and later burn, or low power grubbing and burning.

**Moderate Mixed – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($)/Acre | Present Value($)/Acre |
|---|---|---|---|
| 0 | Choice of Mechanical Method | 60.00 | 60.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.86 | 2.86 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 134.85 |

1 Choice of tree dozing, stack, & burn, tree shearing, stump spray and later burn, or low power grubbing and burning

**Table 2.1c. Cost of Brush Management Restoration Treatments by Brush Type—Density Category—Eastern Edwards.**

**Heavy Cedar—Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Mech. Choice | 165.00 | 165.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Deferment | 1.67 | 1.67 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 253.66 |

[1] Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

**Heavy Mesquite—Chemical**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Aerial Herbicide | 35.00 | 35.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 91.99 |

**Heavy Mesquite – Rootplow[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Rootplow | 160.00 | 160.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 2.86 | 2.86 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 249.85 |

1 Rootplow, rake, stack, and burn.

**Heavy Mesquite – Rootplow with Pre-Doze[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Pre-doze and Rootplow | 185.00 | 185.00 |
| 0 | Reseeding | 30.00 | 30.00 |
| 0 | Grazing Deferment | 2.86 | 2.86 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 274.85 |

1 Heavy tree-doze, rootplow, rake, stack, and burn.

**Heavy Mixed Brush – Rootplow[1]**

**Table 2.1c. Cost of Brush Management Restoration Treatments by Brush Type—Density Category—Eastern Edwards.**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Treedoze | 160.00 | 160.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.22 | 2.22 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 234.21 |

1 Rootplow, rake, stack, and burn.

**Heavy Mixed Brush – Rootplow with Pre-Doze[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Treedoze | 185.00 | 185.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.22 | 2.22 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 259.21 |

1 Heavy tree-doze, rootplow, rake, stack, and burn.

**Moderate Cedar – Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Doze, Reseeding | 100.00 | 100.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.22 | 2.22 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 174.21 |

1 Doze or shear, stack, and burn.

**Moderate Mesquite – Chemical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Aerial or IPT Herbicide | 35.00 | 35.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 91.99 |

1 Either aerial or individual chemical applications may be used.

**Table 2.1c. Cost of Brush Management Restoration Treatments by Brush Type—Density Category—Eastern Edwards.**

**Moderate Mesquite – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Choice of Mechanical Method | 60.00 | 60.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 4.00 | 4.00 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 135.99 |

1 Choice of tree dozing, stack, & burn, tree shearing, stump spray and later burn, or low power grubbing and burning.

**Moderate Mixed – Mechanical Choice[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Choice of Mechanical Method | 60.00 | 60.00 |
| 0 | Reseeding | 15.00 | 15.00 |
| 0 | Grazing Deferment | 2.86 | 2.86 |
| 0 | Cross fencing | 8.86 | 8.86 |
| 0 | Additional Water Source | 13.84 | 13.84 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 134.85 |

1 Choice of tree dozing, stack, & burn, tree shearing, stump spray and later burn, or low power grubbing and burning

**Table 2.2a. Grazing Capacity With and Without Brush Control (Acres/AUY)—Twin Buttes.**

| | | Program Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brush Type / Category** | **Brush Control** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Heavy Cedar** | **Control (Mech)** | 70.0 | 55.0 | 45.0 | 33.3 | 33.3 | 33.3 | 33.3 | 29.2 | 29.2 | 29.2 |
| | **No Control** | 70.0 | 70.0 | 70.1 | 70.2 | 70.3 | 70.4 | 70.5 | 70.6 | 70.7 | 70.8 |
| **Heavy Mesquite** | **Control (Chem)** | 38.0 | 33.0 | 28.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| | **Control (Mech)** | 38.0 | 33.0 | 28.0 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | **No Control** | 38.0 | 38.0 | 38.1 | 38.1 | 38.2 | 38.2 | 38.3 | 38.3 | 38.4 | 38.4 |
| **Heavy Mixed Brush** | **Control (Mech)** | 50.0 | 43.0 | 36.0 | 28.6 | 28.6 | 28.6 | 28.6 | 25.0 | 25.0 | 25.0 |
| | **No Control** | 50.0 | 50.0 | 50.1 | 50.2 | 50.3 | 50.4 | 50.5 | 50.5 | 50.6 | 50.6 |
| **Moderate Cedar** | **Control (Mech)** | 52.0 | 43.0 | 35.0 | 33.3 | 33.3 | 33.3 | 33.3 | 29.2 | 29.2 | 29.2 |
| | **No Control** | 52.0 | 52.3 | 52.7 | 53.0 | 53.4 | 53.8 | 54.1 | 54.4 | 54.7 | 54.9 |
| **Moderate Mesquite** | **Control (Chem)** | 32.0 | 28.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| | **Control (Mech)** | 32.0 | 28.0 | 25.0 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | **No Control** | 32.0 | 32.2 | 32.4 | 32.6 | 32.8 | 33.0 | 33.2 | 33.4 | 33.6 | 33.7 |
| **Moderate Mixed Brush** | **Control (Mech)** | 40.0 | 35.0 | 30.0 | 28.6 | 28.6 | 28.6 | 28.6 | 25.0 | 25.0 | 25.0 |
| | **No Control** | 40.0 | 40.2 | 40.5 | 40.8 | 41.0 | 41.3 | 41.6 | 41.8 | 42.0 | 42.2 |

**Table 2.2b. Grazing Capacity With and Without Brush Control (Acres/AUY)—Western Edwards.**

| | | Program Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brush Type / Category** | **Brush Control** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Heavy Cedar** | **Control (Mech)** | 50.0 | 43.3 | 36.7 | 28.6 | 28.6 | 28.6 | 28.6 | 25.0 | 25.0 | 25.0 |
| | **No Control** | 50.0 | 50.1 | 50.1 | 50.2 | 50.2 | 50.3 | 50.3 | 50.4 | 50.4 | 50.5 |
| **Heavy Mesquite** | **Control (Chem)** | 30.0 | 26.7 | 23.3 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| | **Control (Mech)** | 30.0 | 26.7 | 23.3 | 19.0 | 19.0 | 19.0 | 19.0 | 16.7 | 16.7 | 16.7 |
| | **No Control** | 30.0 | 30.0 | 30.1 | 30.1 | 30.2 | 30.3 | 30.3 | 30.4 | 30.4 | 30.3 |
| **Heavy Mixed Brush** | **Control (Mech)** | 40.0 | 35.0 | 30.0 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | **No Control** | 40.0 | 40.0 | 40.1 | 40.2 | 40.2 | 40.3 | 40.3 | 40.4 | 40.4 | 40.4 |
| **Moderate Cedar** | **Control (Mech)** | 40.0 | 35.0 | 30.0 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | **No Control** | 40.0 | 40.1 | 40.2 | 40.3 | 40.4 | 40.5 | 40.6 | 40.7 | 40.8 | 40.9 |
| **Moderate Mesquite** | **Control (Chem)** | 25.0 | 23.2 | 21.6 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| | **Control (Mech)** | 25.0 | 23.2 | 21.6 | 19.0 | 19.0 | 19.0 | 19.0 | 16.7 | 16.7 | 16.7 |
| | **No Control** | 25.0 | 25.1 | 25.3 | 25.4 | 25.6 | 25.7 | 25.8 | 26.0 | 26.1 | 26.3 |
| **Moderate Mixed Brush** | **Control (Mech)** | 35.0 | 31.6 | 28.3 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | **No Control** | 35.0 | 35.2 | 35.4 | 35.6 | 35.8 | 36.0 | 36.2 | 36.4 | 36.6 | 36.8 |

**Table 2.2c. Grazing Capacity With and Without Brush Control (Acres/AUY)—Eastern Edwards.**

| | | Program Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Brush Type / Category | Brush Control | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Heavy Cedar | Control (Mech) | 60.0 | 50.0 | 40.0 | 28.6 | 28.6 | 28.6 | 28.6 | 25.0 | 25.0 | 25.0 |
| | No Control | 60.0 | 60.1 | 60.1 | 60.2 | 60.3 | 60.3 | 60.4 | 60.5 | 60.5 | 60.6 |
| Heavy Mesquite | Control (Chem) | 35.0 | 30.0 | 25.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| | Control (Mech) | 35.0 | 30.0 | 25.0 | 19.0 | 19.0 | 19.0 | 19.0 | 16.7 | 16.7 | 16.7 |
| | No Control | 35.0 | 35.0 | 35.1 | 35.1 | 35.2 | 35.2 | 35.2 | 35.3 | 35.3 | 35.4 |
| Heavy Mixed Brush | Control (Mech) | 45.0 | 38.2 | 31.6 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | No Control | 45.0 | 45.1 | 45.1 | 45.2 | 45.2 | 45.3 | 45.3 | 45.4 | 45.4 | 45.5 |
| Moderate Cedar | Control (Mech) | 45.0 | 40.0 | 35.0 | 28.6 | 28.6 | 28.6 | 28.6 | 25.0 | 25.0 | 25.0 |
| | No Control | 45.0 | 45.3 | 45.5 | 45.8 | 46.0 | 46.3 | 46.5 | 46.8 | 47.0 | 47.3 |
| Moderate Mesquite | Control (Chem) | 25.0 | 23.2 | 21.6 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| | Control (Mech) | 25.0 | 23.2 | 21.6 | 19.0 | 19.0 | 19.0 | 19.0 | 16.7 | 16.7 | 16.7 |
| | No Control | 25.0 | 25.1 | 25.3 | 25.4 | 25.6 | 25.7 | 25.8 | 26.0 | 26.1 | 26.3 |
| Moderate Mixed Brush | Control (Mech) | 35.0 | 31.6 | 28.3 | 23.8 | 23.8 | 23.8 | 23.8 | 20.8 | 20.8 | 20.8 |
| | No Control | 35.0 | 35.2 | 35.4 | 35.6 | 35.8 | 36.0 | 36.2 | 36.4 | 36.6 | 36.8 |

**Table 2.3a. Economic Evaluation Variables—Twin Buttes.**

| Livestock Composition | |
|---|---|
| Cattle Percentage | 60% |
| Meat Goat Percentage | 10% |
| Sheep Percentage | 30% |

| Discount Rate | 6% |
|---|---|
| Ranch Size (Acres) | 1000 |

| Cattle Enterprise | |
|---|---|
| Cow Animal Unit Equivalent | 1.00 |
| Bull Animal Unit Equivalent | 1.25 |
| Number of Cows per Bull | 25.00 |
| Birthing Rate | 90% |
| Calf Weaning Weight (pounds) | 525 |
| Calf Price per Pound | $0.77 |
| Cow Salvage Price | $400.00 |
| Variable Cost per Cow/Calf | $130.09 |
| Cow Purchase Price | $700.00 |
| Bull Purchase Price | $1,500.00 |
| Bull Salvage Value | $625.00 |
| Death Loss | 2.50% |
| Cow Useful Life (years) | 9 |
| Bull Useful Life (years) | 6 |

| Meat Goat Enterprise | |
|---|---|
| Nannie Animal Unit Equivalent | 0.17 |
| Billy Animal Unit Equivalent | 0.21 |
| Number of Nannies per Billy | 33.00 |
| Birthing Rate | 80% |
| Price per Kid | $50.00 |
| Nannie Salvage Price | $20.00 |
| Variable Cost per Nannie/Kid | $21.42 |
| Nannie Purchase Price | $60.00 |
| Billy Purchase Price | $250.00 |
| Billy Salvage Value | $50.00 |
| Death Loss | 2.50% |
| Nanny Useful Life (years) | 6 |
| Billy Useful Life (years) | 4 |

| Sheep Enterprise | |
|---|---|
| Ewe Animal Unit Equivalent | 0.20 |
| Ram Animal Unit Equivalent | 0.25 |
| Number of Ewes per Ram | 33.00 |
| Birthing Rate | 75% |
| Wool produced per Ewe or Ram (lbs) | 8.00 |
| Lamb Weaning Weight (pounds) | 70 |
| Lamb Price per Pound | $0.85 |
| Ewe Salvage Price | $20.00 |
| Variable Cost per Ewe/Lamb | $27.72 |
| Ewe Purchase Price | $70.00 |
| Wool Price Per Pound | $1.00 |
| Ram Purchase Price | $250.00 |
| Ram Salvage Value | $50.00 |
| Death Loss | 2.50% |
| Ewe Useful Life (years) | 6 |
| Billy Useful Life (years) | 4 |

| Wildlife Enterprise | |
|---|---|
| Increase in Per Acre Revenue From Controlling Heavy Brush. | $0.50 |
| Increase in Per Acre Revenue From Controlling Moderate Brush. | $0.00 |

**Table 2.3b. Economic Evaluation Variables—Western Edwards.**

| Livestock Composition | |
|---|---|
| Cattle Percentage | 20% |
| Meat Goat Percentage | 50% |
| Sheep Percentage | 30% |

| Discount Rate | 6% |
|---|---|
| Ranch Size (Acres) | 1000 |

| Cattle Enterprise | |
|---|---|
| Cow Animal Unit Equivalent | 1.00 |
| Bull Animal Unit Equivalent | 1.25 |
| Number of Cows per Bull | 25.00 |
| Birthing Rate | 90% |
| Calf Weaning Weight (lbs) | 450 |
| Calf Price Per Pound | $0.95 |
| Cow Salvage Price | $400.00 |
| Variable Cost per Cow / Calf | $133.69 |
| Cow Purchase Price | $700.00 |
| Bull Purchase Price | $1,500.00 |
| Bull Salvage Value | $625.00 |
| Death Loss | 2.50% |
| Cow Useful Life (years) | 9 |
| Bull Useful Life (years) | 6 |

| Meat Goat Enterprise | |
|---|---|
| Nanny Animal Unit Equivalent | 0.17 |
| Billy Animal Unit Equivalent | 0.21 |
| Number of Nannys per Billy | 33.00 |
| Birthing Rate | 135% |
| Nanny Weaning Weight (lbs) | 50 |
| Nanny Price Per Pound | $0.85 |
| Nanny Salvage Price | $20.00 |
| Variable Cost per Nanny / Kid | $22.21 |
| Nanny Purchase Price | $70.00 |
| Billy Purchase Price | $250.00 |
| Billy Salvage Value | $40.00 |
| Death Loss | 2.50% |
| Nanny Useful Life (years) | 6 |
| Billy Useful Life (years) | 4 |

| Sheep Enterprise | |
|---|---|
| Ewe Animal Unit Equivalent | 0.20 |
| Ram Animal Unit Equivalent | 0.25 |
| Number of Ewes per Ram | 33.00 |
| Birthing Rate | 65% |
| Wool produced per Ewe or Ram (lbs) | 8.00 |
| Lamb Weaning Weight (pounds) | 65 |
| Lamb Price per Pound | $0.85 |
| Ewe Salvage Price | $20.00 |
| Variable Cost per Ewe / Lamb | $26.74 |
| Ewe Purchase Price | $70.00 |
| Wool Price Per Pound | $1.00 |
| Ram Purchase Price | $250.00 |
| Ram Salvage Value | $40.00 |
| Death Loss | 2.50% |
| Ewe Useful Life (years) | 6 |
| Billy Useful Life (years) | 4 |

| Wildlife Enterprise | |
|---|---|
| Increase in Per Acre Revenue From Controlling Heavy Brush. | $1.75 |
| Increase in Per Acre Revenue From Controlling Moderate Brush. | $0.00 |

**Table 2.3c. Economic Evaluation Variables—Eastern Edwards.**

| Livestock Composition | |
|---|---|
| Cattle Percentage | 80% |
| Meat Goat Percentage | 20% |
| Sheep Percentage | 0% |

| | |
|---|---|
| Discount Rate | 6% |
| Ranch Size (Acres) | 1000 |

| Cattle Enterprise | |
|---|---|
| Cow Animal Unit Equivalent | 1.00 |
| Bull Animal Unit Equivalent | 1.25 |
| Number of Cows per Bull | 25.00 |
| Birthing Rate | 90% |
| Calf Weaning Weight (lbs) | 450 |
| Calf Price Per Pound | $0.95 |
| Cow Salvage Price | $400.00 |
| Variable Cost per Cow / Calf | $127.09 |
| Cow Purchase Price | $700.00 |
| Bull Purchase Price | $1,500.00 |
| Bull Salvage Value | $625.00 |
| Death Loss | 2.50% |
| Cow Useful Life (years) | 9 |
| Bull Useful Life (years) | 6 |

| Meat Goat Enterprise | |
|---|---|
| Nanny Animal Unit Equivalent | 0.17 |
| Billy Animal Unit Equivalent | 0.21 |
| Number of Nannys per Billy | 33.00 |
| Birthing Rate | 115% |
| Nanny Weaning Weight (lbs) | 50 |
| Nanny Price Per Pound | $0.85 |
| Nanny Salvage Price | $20.00 |
| Variable Cost per Nanny / Kid | $21.94 |
| Nanny Purchase Price | $70.00 |
| Billy Purchase Price | $250.00 |
| Billy Salvage Value | $40.00 |
| Death Loss | 2.50% |
| Nanny Useful Life (years) | 6 |
| Billy Useful Life (years) | 4 |

| Sheep Enterprise | |
|---|---|
| Ewe Animal Unit Equivalent | 0.20 |
| Ram Animal Unit Equivalent | 0.25 |
| Number of Ewes per Ram | 33.00 |
| Birthing Rate | 65% |
| Wool produced per Ewe or Ram (lbs) | 8.00 |
| Lamb Weaning Weight (pounds) | 65 |
| Lamb Price per Pound | $0.85 |
| Ewe Salvage Price | $20.00 |
| Variable Cost per Ewe / Lamb | $26.74 |
| Ewe Purchase Price | $70.00 |
| Wool Price Per Pound | $1.00 |
| Ram Purchase Price | $250.00 |
| Ram Salvage Value | $40.00 |
| Death Loss | 2.50% |
| Ewe Useful Life (years) | 6 |
| Billy Useful Life (years) | 4 |

| Wildlife Enterprise | |
|---|---|
| Increase in Per Acre Revenue From Controlling Heavy Brush. | $1.75 |
| Increase in Per Acre Revenue From Controlling Moderate Brush. | $0.00 |

*Scenario Analysis*

Using Landsat photography data, the Blackland Research Center provided data on brush types and density. Brush was dividing into four brush types (cedar, mesquite, mixed brush, oak) and three density categories (light, moderate, heavy). The Blackland Research Center also quantified the amount of treated acres for each scenario. Treated brush type-density categories included heavy cedar, moderate cedar, heavy mesquite, moderate mesquite, heavy mixed brush, and moderate mixed brush. Under all three brush management scenarios, cedar and mesquite brush type density categories were treated with initial and follow-up treatments to reduce canopy cover to 3 to 8 percent and maintain it at that level for 10 years. For mixed brush, post-treatment canopy cover would vary from 10% to 33%. Oak was not treated in our analyses due to its wildlife value and landowner concerns about effects on property values. All categories of light brush were not treated in any scenario. An important difference between brush management under the three scenarios and the one assumed for the TAES study (2000) is that, in this study, no brush occurring on land slopes greater than 15% was treated because mechanical control in these areas would be dangerous to equipment operators, and soil erosion losses would increase. In addition, restoration treatments such as rangeland reseeding, grazing deferments, and implementation of improved grazing management systems through additional cross fencing and water sources was used in addition to initial and follow-up brush removal practices.

Under Scenario I, the least restrictive scenario, all acres of brush classified in one of the six targeted brush-type density categories was treated. However, brush in these categories occurring on slopes greater than 15 percent was not controlled. The difference between the amount of brush controlled under this scenario and the brush management occurring under the TAES study (2000) was due to this slope constraint. For the Twin Buttes and Edwards, the amounts of moderate and heavy brush occurring on slopes greater than 15 percent were not controlled. Scenario II is identical to Scenario I except that all brush occurring within 75 meters of a mapped stream course was not targeted for treatment. Because of the importance of riparian areas to wildlife, this scenario is designated as more wildlife-friendly than Scenario I.

Brush management Scenario III has the same slope constraint as Scenarios I and II as well as the same 150 meter riparian buffer as Scenario II. In contrast to these two, Scenario III requires that residual brush levels following brush removal be 40 percent of the total land area for each subbasin within the five Edwards and three Twin Buttes watersheds. In subbasins where the amount of brush controlled must be reduced from Scenario II, each of the six targeted brush type-densities is reduced by an equal percentage to arrive at the 40 percent residual brush cover threshold. This scenario is considered the most wildlife-friendly of the three due to the protection of riparian area vegetation and the requirement that residual levels of brush for all subbasins be 40 percent of total land cover.

Scenario IV is the base for comparison. The assumption is that the watershed will essentially remain unchanged over time. A last scenario not included in the range/economics analysis is one in which continued increasing infestation of brush is assumed over time (Scenario V).
While the amount and cost of brush controlled differs for each scenario, the methodology used to calculate total society costs and society costs of additional water yield for each scenario are identical.

## Results and Discussion

*Society and Landowner Cost Shares*

**Twin Buttes**

Present values of the total cost of brush control and ecological restoration treatments for the six brush type-density categories range from $143.42 per acre for mechanical control of heavy mesquite to $59.31 per acre for chemical control of moderate mesquite (Table 2.4). The highest rancher share expressed as a percentage of the total treatment cost was 25.63 percent for chemical control of heavy mesquite while the lowest was 8.15 percent for moderate mixed brush. The highest society share, also expressed as a percentage of total treatment cost, was 91.85 percent for mechanical control of moderate mixed brush. The lowest society share was 74.37 percent for chemical control of heavy mesquite.

**Western Edwards**

As mentioned previously, geographic differences between the Eastern and Western portions of the Edwards Aquifer recharge zone necessitated the use of separate carrying capacity, brush treatments and costs, and livestock enterprise assumptions. These different assumptions yielded different landowner/society cost shares for each region.

For the Western Edwards, present values of the total cost of brush management/restoration treatments range from $270.32 per acre for rootplowing with pre-doze treatments of heavy mesquite to $91.99 for chemical treatments of heavy and moderate mesquite (Table 2.5). The highest and lowest rancher shares expressed as a percentage of total treatment costs were 30.30 and 8.83 percent for chemical control of heavy mesquite and mechanical control of moderate mesquite, respectively. For society cost share, the highest percentage, 91.17 percent, was for mechanical control of moderate mesquite, and the lowest percent, 69.7 percent, was found for chemical control of heavy mesquite.

**Eastern Edwards**

The most expensive brush type-density to treat was rootplowing with pre-dozing of heavy mesquite at $274.85 per acre; the least expensive was chemical control of moderate and heavy mesquite at $91.99 (Table 2.6). The highest and lowest rancher shares were 36.88 and 7.88 percent for chemical control of heavy mesquite and mechanical control of moderate cedar, respectively. Society shares ranged from 92.12 percent for mechanical control of moderate cedar and 63.12 percent for chemical control of heavy mesquite.

**Table 2.4. Twin Buttes Landowner/Society Cost Shares of Brush Control (60% Cattle—10% Meat Goat—30% Sheep.**

| Brush Type / Category | Control Practice | PV of Total Cost ($/Acre) | Rancher Share ($/Acre) | Rancher Percent | Society Share ($/Acre) | Society Percent |
|---|---|---|---|---|---|---|
| **Heavy Cedar** | Doze or Shear | 142.21 | 14.44 | 10.15% | 127.77 | 89.85% |
| **Heavy Mesquite** | Chemical | 51.78 | 13.27 | 25.63% | 38.51 | 74.37% |
| | Mechanical Choice | 143.42 | 15.00 | 10.46% | 128.42 | 89.54% |
| **Heavy Mixed Brush** | Mechanical Choice | 127.78 | 14.30 | 11.19% | 113.48 | 88.81% |
| **Moderate Cedar** | Mechanical Choice | 97.71 | 8.87 | 9.08% | 88.84 | 90.92% |
| **Moderate Mesquite** | Chemical | 59.31 | 6.28 | 10.59% | 53.03 | 89.41% |
| | Mechanical Choice | 106.43 | 8.89 | 8.35% | 97.54 | 91.65% |
| **Moderate Mixed Brush** | Mechanical Choice | 98.28 | 8.01 | 8.15% | 90.27 | 91.85% |

**Table 2.5. Western Edwards Landowner / Society Cost Shares of Brush Control (20% Cattle—50% Meat Goat—30% Sheep).**

| Brush Type / Category | Control Practice | PV of Total Cost ($/Acre) | Rancher Share ($/Acre) | Rancher Percent | Society Share ($/Acre) | Society Percent |
|---|---|---|---|---|---|---|
| **Heavy Cedar** | Two Way Chain | 178.99 | 26.66 | 14.89% | 152.33 | 85.11% |
| | Tree Doze | 233.99 | 26.66 | 11.39% | 207.33 | 88.61% |
| | Tree Shear or Flat Cutting | 218.99 | 26.66 | 12.17% | 192.33 | 87.83% |
| **Heavy Mesquite** | Chemical | 91.99 | 27.87 | 30.30% | 64.12 | 69.70% |
| | Rootplow | 245.32 | 30.79 | 12.55% | 214.53 | 87.45% |
| | Rootplow with Pre-doze | 270.32 | 30.79 | 11.39% | 239.53 | 88.61% |
| **Heavy Mixed Brush** | Tree Doze | 234.49 | 28.88 | 12.32% | 205.61 | 87.68% |
| **Moderate Cedar** | Tree Doze | 169.49 | 15.23 | 8.99% | 154.26 | 91.01% |
| | Tree Shear or Flat Cutting | 149.49 | 15.23 | 10.19% | 134.26 | 89.81% |
| **Moderate Mesquite** | Chemical | 91.99 | 9.01 | 9.79% | 82.98 | 90.21% |
| | Mechanical Choice | 135.99 | 12.01 | 8.83% | 123.98 | 91.17% |
| **Moderate Mixed Brush** | Mechanical Choice | 134.85 | 12.20 | 9.05% | 122.65 | 90.95% |

**Table 2.6. Eastern Edwards Landowner / Society Cost Shares of Brush Control (80% Cow/Calf—20% Meat Goat).**

| Brush Type / Category | Control Practice | PV of Total Cost ($/Acre) | Rancher Share ($/Acre) | Rancher Percent | Society Share ($/Acre) | Society Percent |
|---|---|---|---|---|---|---|
| Heavy Cedar | Doze or Shear | 253.66 | 31.89 | 12.57% | 221.77 | 87.43% |
| Heavy Mesquite | Chemical | 91.99 | 33.93 | 36.88% | 58.06 | 63.12% |
| | Rootplow | 249.85 | 38.37 | 15.36% | 211.48 | 84.64% |
| | Rootplow with Pre-doze | 274.85 | 38.37 | 13.96% | 236.48 | 86.04% |
| Heavy Mixed Brush | Rootplow | 234.21 | 33.97 | 14.50% | 200.24 | 85.50% |
| | Rootplow with Pre-doze | 259.21 | 33.97 | 13.11% | 225.24 | 86.89% |
| Moderate Cedar | Doze or Shear | 174.21 | 13.72 | 7.88% | 160.49 | 92.12% |
| Moderate Mesquite | Chemical | 91.99 | 10.43 | 11.34% | 81.56 | 88.66% |
| | Mechanical Choice | 135.99 | 13.64 | 10.03% | 122.35 | 89.97% |
| Moderate Mixed Brush | Mechanical Choice | 134.85 | 14.25 | 10.57% | 120.60 | 89.43% |

*Society Cost of Added Water*

**Twin Buttes**

**Middle Concho.** Total society costs for implementing Scenarios I, II, and III were $45.1M, $42.9M, and $16.0M, respectively (Tables 2.7a, 2.7b and 2.7c). Scenario I is 181 percent more costly than Scenario III—the largest percentage increase between Scenarios I and III for the watersheds within the Twin Buttes. Society's costs per acre-foot of additional water yielded were $158—Scenario I, $159—Scenario II, and $135—Scenario III.

**South Concho.** Total society costs for Scenarios I, II, and III (Tables 2.8a, 2.8band 2.8c), were $15.1M, $14.3M, and $5.9M, respectively. Society cost per acre-foot of additional water yielded was $63 for all scenarios.

**Spring-Dove Creek.** For Scenarios I, II, and III, total society costs were $24.7M, $23.4M and $9.8M respectively (Tables 2.9a, 2.9b and 2.9c). Society costs per acre-foot of additional water were $83 for Scenarios I and II and $82 for Scenario III.

In summary, total society costs differed very slightly between Scenarios I and II in all watersheds (Fig. 2.1). In contrast, total society costs between Scenarios I/II and Scenario III are quite large, indicating substantially more brush is being treated in the first two brush management/restoration plans. Society costs per acre-foot of added water are relatively constant between different scenarios in individual watersheds. However, these costs range from $159 for Scenario II in the Middle Concho to $63 for all scenarios in the South Concho (Figure 2.2). As one might expect, great variation exists in the per acre cost of added water between sub-basins within watersheds. From an economic efficiency perspective, brush management and restoration is most attractive in the South Concho watershed.

**Edwards**

**Frio.** For the three scenarios, society costs of implementing brush management and restoration practices were $12.6M, $10.0M, and $9.4M (Tables 2.10a, 2.10b and 2.10c). Society's costs per acre-foot of additional water yielded are $51 for Scenarios I and II and $49 for Scenario III.

**Hondo.** Total society costs in the watershed for Scenario I were $3.9M, $3.3M for Scenario II, and $3.3M for Scenario III (Tables 2.11a, 2.11b and 2.11c). Cost per acre-foot of additional water yielded were $32 for Scenarios I and II, and $33 for Scenario III.

**Medina.** Total society costs for implementing the three different brush management/restoration scenarios were $27.2M, $23.1M, and $22.1M (Tables 2.12a, 2.12b and 2.12c). Society cost per acre-foot of additional water were $35 for Scenario I and $36 for Scenarios II and III.

**Sabinal.** For Scenarios I, II, and III, total society costs are $7.2M, $6.0M, and $5.7M (Tables 2.13a, 2.13b and 2.13c). . Per acre-foot cost of additional water for society were $45 for Scenarios I and III and $46 for Scenario II.

**Seco.** Total society Costs for the three scenarios were $1.6M, $1.4M, and $1.4M for the three scenarios (Tables 2.14a, 2.14b and 2.14c). Society cost per acre-foot of additional water were an identical $46 for all scenarios.

Table 2.7a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).

| Middle Concho—Scenario 1 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 0 | 0 | 0 | 0 | - |
| 2 | 388,750 | 91,371,364 | 280 | 2,187 | 178 |
| 3 | 0 | 0 | 0 | 0 | - |
| 4 | 0 | 0 | 0 | 0 | - |
| 5 | 367,473 | 81,755,341 | 251 | 1,957 | 188 |
| 6 | 0 | 0 | 0 | 0 | - |
| 7 | 1,455,667 | 223,419,230 | 686 | 5,348 | 272 |
| 8 | 131,176 | 32,402,626 | 99 | 776 | 169 |
| 9 | 1,470,107 | 299,250,690 | 918 | 7,164 | 205 |
| 10 | 56,914 | 11,913,576 | 37 | 285 | 200 |
| 11 | 0 | 0 | 0 | 0 | - |
| 12 | 1,693,792 | 301,341,356 | 925 | 7,214 | 235 |
| 13 | 1,512,840 | 370,477,910 | 1,137 | 8,869 | 171 |
| 14 | 755,414 | 198,688,706 | 610 | 4,756 | 159 |
| 15 | 497,907 | 123,721,212 | 380 | 2,962 | 168 |
| 16 | 3,660,528 | 842,880,196 | 2,586 | 20,178 | 181 |
| 17 | 2,038,873 | 570,178,502 | 1,750 | 13,649 | 149 |
| 18 | 2,897,486 | 726,704,216 | 2,230 | 17,397 | 167 |
| 19 | 750,152 | 193,778,098 | 595 | 4,639 | 162 |
| 20 | 91,467 | 23,945,607 | 73 | 573 | 160 |
| 21 | 2,523,777 | 594,765,659 | 1,825 | 14,238 | 177 |
| 22 | 1,648,321 | 475,090,810 | 1,458 | 11,373 | 145 |
| 23 | 5,072,115 | 1,722,451,068 | 5,285 | 41,234 | 123 |
| 24 | 3,007,399 | 946,281,140 | 2,904 | 22,653 | 133 |
| 25 | 3,427,003 | 1,051,778,398 | 3,227 | 25,178 | 136 |
| 26 | 4,218,490 | 1,158,992,704 | 3,556 | 27,745 | 152 |
| 27 | 5,052,259 | 1,336,623,831 | 4,101 | 31,997 | 158 |
| 28 | 2,346,399 | 534,052,403 | 1,639 | 12,785 | 184 |
| **Total** | **45,064,307** | | | **285,157** | **158** |

**Table 2.7b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| **Middle Concho—Scenario 2** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 0 | 0 | 0 | 0 | - |
| 2 | 378,738 | 88,557,647 | 272 | 2,120 | 179 |
| 3 | 0 | 0 | 0 | 0 | - |
| 4 | 0 | 0 | 0 | 0 | - |
| 5 | 340,691 | 75,140,439 | 231 | 1,799 | 189 |
| 6 | 0 | 0 | 0 | 0 | - |
| 7 | 1,372,545 | 209,399,223 | 643 | 5,013 | 274 |
| 8 | 114,635 | 29,308,982 | 90 | 702 | 163 |
| 9 | 1,401,529 | 279,524,263 | 858 | 6,692 | 209 |
| 10 | 52,661 | 11,999,008 | 37 | 287 | 183 |
| 11 | 0 | 0 | 0 | 0 | - |
| 12 | 1,637,637 | 282,373,163 | 866 | 6,760 | 242 |
| 13 | 1,405,618 | 339,474,264 | 1,042 | 8,127 | 173 |
| 14 | 691,542 | 180,372,534 | 553 | 4,318 | 160 |
| 15 | 472,336 | 117,245,591 | 360 | 2,807 | 168 |
| 16 | 3,472,977 | 805,759,130 | 2,472 | 19,289 | 180 |
| 17 | 1,953,768 | 547,573,838 | 1,680 | 13,108 | 149 |
| 18 | 2,753,592 | 683,536,070 | 2,097 | 16,363 | 168 |
| 19 | 700,335 | 180,676,019 | 554 | 4,325 | 162 |
| 20 | 88,086 | 22,984,786 | 71 | 550 | 160 |
| 21 | 2,434,984 | 570,809,580 | 1,751 | 13,665 | 178 |
| 22 | 1,591,476 | 461,625,349 | 1,416 | 11,051 | 144 |
| 23 | 4,850,224 | 1,665,624,936 | 5,111 | 39,873 | 122 |
| 24 | 2,861,372 | 892,989,955 | 2,740 | 21,377 | 134 |
| 25 | 3,232,261 | 988,256,018 | 3,032 | 23,658 | 137 |
| 26 | 4,044,096 | 1,103,388,621 | 3,386 | 26,414 | 153 |
| 27 | 4,806,438 | 1,266,327,999 | 3,886 | 30,315 | 159 |
| 28 | 2,237,796 | 501,190,114 | 1,538 | 11,998 | 187 |
| **Total** | **42,895,336** | | | **270,609** | **159** |

**Table 2.7c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Middle Concho—Scenario 3 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 0 | 0 | 0 | 0 | - |
| 2 | 145,304 | 35,112,688 | 108 | 841 | 173 |
| 3 | 0 | 0 | 0 | 0 | - |
| 4 | 0 | 0 | 0 | 0 | - |
| 5 | 0 | 0 | 0 | 0 | - |
| 6 | 0 | 0 | 0 | 0 | - |
| 7 | 0 | 0 | 0 | 0 | - |
| 8 | 0 | 0 | 0 | 0 | - |
| 9 | 0 | 0 | 0 | 0 | - |
| 10 | 0 | 0 | 0 | 0 | - |
| 11 | 0 | 0 | 0 | 0 | - |
| 12 | 445,200 | 87,000,778 | 267 | 2,083 | 214 |
| 13 | 781,230 | 212,954,335 | 653 | 5,098 | 153 |
| 14 | 335,092 | 97,457,549 | 299 | 2,333 | 144 |
| 15 | 15,147 | 5,159,438 | 16 | 124 | 123 |
| 16 | 0 | 0 | 0 | 0 | - |
| 17 | 870,534 | 264,918,935 | 813 | 6,342 | 137 |
| 18 | 1,130,424 | 317,758,785 | 975 | 7,607 | 149 |
| 19 | 290,752 | 80,669,006 | 248 | 1,931 | 151 |
| 20 | 40,703 | 10,887,432 | 33 | 261 | 156 |
| 21 | 664,657 | 166,083,987 | 510 | 3,976 | 167 |
| 22 | 626,381 | 190,582,942 | 585 | 4,562 | 137 |
| 23 | 2,314,092 | 881,715,726 | 2,705 | 21,107 | 110 |
| 24 | 1,620,719 | 559,393,687 | 1,716 | 13,391 | 121 |
| 25 | 1,659,320 | 542,779,712 | 1,665 | 12,994 | 128 |
| 26 | 1,958,594 | 616,657,109 | 1,892 | 14,762 | 133 |
| 27 | 2,453,103 | 709,979,540 | 2,179 | 16,996 | 144 |
| 28 | 681,865 | 168,760,988 | 518 | 4,040 | 169 |
| **Total** | **16,033,118** | | | **118,447** | **135** |

**Table 2.8a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| South Concho—Scenario 1 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 783,601 | 639,082,182 | 1,961 | 15,299 | 51 |
| 2 | 332,005 | 263,924,552 | 810 | 6,318 | 53 |
| 3 | 991,965 | 780,796,011 | 2,396 | 18,691 | 53 |
| 4 | 737,987 | 501,821,432 | 1,540 | 12,013 | 61 |
| 5 | 686,979 | 471,468,078 | 1,447 | 11,286 | 61 |
| 6 | 122,874 | 63,513,968 | 195 | 1,520 | 81 |
| 7 | 547,864 | 398,048,022 | 1,221 | 9,529 | 57 |
| 8 | 482,185 | 348,997,154 | 1,071 | 8,355 | 58 |
| 9 | 551,439 | 325,741,603 | 1,000 | 7,798 | 71 |
| 10 | 692,716 | 389,732,444 | 1,196 | 9,330 | 74 |
| 11 | 2,082,796 | 1,620,683,900 | 4,973 | 38,797 | 54 |
| 12 | 751,582 | 492,924,195 | 1,513 | 11,800 | 64 |
| 13 | 2,289,124 | 1,238,790,172 | 3,801 | 29,655 | 77 |
| 14 | 56,342 | 40,064,266 | 123 | 959 | 59 |
| 15 | 1,225,486 | 801,860,118 | 2,460 | 19,196 | 64 |
| 16 | 1,354,411 | 845,734,663 | 2,595 | 20,246 | 67 |
| 17 | 1,100,096 | 659,718,577 | 2,024 | 15,793 | 70 |
| 18 | 299,160 | 77,450,465 | 238 | 1,854 | 161 |
| **Total** | **15,088,612** | | | **238,440** | **63** |

**Table 2.8b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| South Concho—Scenario 2 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 724,718 | 598,961,040 | 1,838 | 14,338 | 51 |
| 2 | 318,924 | 254,471,687 | 781 | 6,092 | 52 |
| 3 | 960,066 | 763,866,554 | 2,344 | 18,286 | 53 |
| 4 | 707,321 | 486,914,198 | 1,494 | 11,656 | 61 |
| 5 | 632,366 | 441,565,269 | 1,355 | 10,571 | 60 |
| 6 | 121,227 | 62,703,385 | 192 | 1,501 | 81 |
| 7 | 506,201 | 372,899,956 | 1,144 | 8,927 | 57 |
| 8 | 461,155 | 336,871,727 | 1,034 | 8,064 | 57 |
| 9 | 524,237 | 310,829,681 | 954 | 7,441 | 70 |
| 10 | 641,199 | 365,822,898 | 1,123 | 8,757 | 73 |
| 11 | 2,002,511 | 1,574,829,042 | 4,832 | 37,700 | 53 |
| 12 | 721,900 | 477,061,384 | 1,464 | 11,420 | 63 |
| 13 | 2,170,864 | 1,184,195,959 | 3,634 | 28,348 | 77 |
| 14 | 48,699 | 35,550,868 | 109 | 851 | 57 |
| 15 | 1,173,335 | 775,219,423 | 2,379 | 18,558 | 63 |
| 16 | 1,277,918 | 813,793,215 | 2,497 | 19,481 | 66 |
| 17 | 1,051,542 | 635,716,079 | 1,951 | 15,218 | 69 |
| 18 | 286,688 | 68,625,815 | 211 | 1,643 | 175 |
| **Total** | **14,330,871** | | | **228,854** | **63** |

**Table 2.8c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| South Concho—Scenario 3 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 0 | 0 | 0 | 0 | #DIV/0! |
| 2 | 0 | 0 | 0 | 0 | #DIV/0! |
| 3 | 247,476 | 197,292,290 | 605 | 4,723 | 52 |
| 4 | 252,297 | 177,572,447 | 545 | 4,251 | 59 |
| 5 | 235,069 | 169,202,732 | 519 | 4,051 | 58 |
| 6 | 59,208 | 31,234,879 | 96 | 748 | 79 |
| 7 | 33,742 | 22,714,382 | 70 | 544 | 62 |
| 8 | 105,097 | 78,350,790 | 240 | 1,876 | 56 |
| 9 | 256,031 | 154,412,946 | 474 | 3,696 | 69 |
| 10 | 346,393 | 201,054,441 | 617 | 4,813 | 72 |
| 11 | 933,418 | 764,926,085 | 2,347 | 18,312 | 51 |
| 12 | 352,287 | 239,242,397 | 734 | 5,727 | 62 |
| 13 | 1,088,645 | 617,334,557 | 1,894 | 14,778 | 74 |
| 14 | 33,350 | 24,651,101 | 76 | 590 | 57 |
| 15 | 640,185 | 435,341,897 | 1,336 | 10,422 | 61 |
| 16 | 691,796 | 451,228,529 | 1,385 | 10,802 | 64 |
| 17 | 531,105 | 333,778,659 | 1,024 | 7,990 | 66 |
| 18 | 107,888 | 26,101,404 | 80 | 625 | 173 |
| **Total** | **5,913,987** | | | **93,947** | **63** |

**Table 2.9a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| **Spring/Dove Creeks—Scenario 1** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 2,832,021 | 1,139,275,790 | 3,496 | 27,273 | 104 |
| 2 | 1,759,978 | 1,177,504,360 | 3,613 | 28,188 | 62 |
| 3 | 2,366,236 | 1,627,881,605 | 4,995 | 38,970 | 61 |
| 4 | 765,254 | 608,994,620 | 1,869 | 14,579 | 52 |
| 5 | 16,504 | 10,289,249 | 32 | 246 | 67 |
| 6 | 925,991 | 486,517,053 | 1,493 | 11,647 | 80 |
| 7 | 1,143,199 | 569,392,446 | 1,747 | 13,631 | 84 |
| 8 | 450,397 | 209,210,688 | 642 | 5,008 | 90 |
| 9 | 936,215 | 388,611,003 | 1,192 | 9,303 | 101 |
| 10 | 959,787 | 401,731,255 | 1,233 | 9,617 | 100 |
| 11 | 1,518,470 | 767,222,827 | 2,354 | 18,366 | 83 |
| 12 | 1,703,706 | 929,601,019 | 2,852 | 22,254 | 77 |
| 13 | 833,600 | 538,965,486 | 1,654 | 12,902 | 65 |
| 14 | 1,266,090 | 676,787,667 | 2,077 | 16,202 | 78 |
| 15 | 1,200,346 | 512,761,426 | 1,573 | 12,275 | 98 |
| 16 | 1,178,762 | 453,366,900 | 1,391 | 10,853 | 109 |
| 17 | 926,790 | 365,215,282 | 1,121 | 8,743 | 106 |
| 18 | 784,547 | 303,884,575 | 932 | 7,275 | 108 |
| 19 | 137,822 | 50,554,173 | 155 | 1,210 | 114 |
| 20 | 1,336,029 | 519,001,715 | 1,593 | 12,424 | 108 |
| 21 | 1,012,154 | 501,000,017 | 1,537 | 11,993 | 84 |
| 22 | 122,398 | 38,216,962 | 117 | 915 | 134 |
| 23 | 520,376 | 193,445,641 | 594 | 4,631 | 112 |
| **Total** | **24,696,670** | | | **298,505** | **83** |

**Table 2.9b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Spring/Dove Creeks—Scenario 2 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 2,652,849 | 1,078,093,029 | 3,308 | 25,808 | 103 |
| 2 | 1,679,866 | 1,137,098,018 | 3,489 | 27,221 | 62 |
| 3 | 2,255,889 | 1,566,354,514 | 4,806 | 37,497 | 60 |
| 4 | 719,795 | 577,955,724 | 1,773 | 13,836 | 52 |
| 5 | 14,340 | 8,684,638 | 27 | 208 | 69 |
| 6 | 901,070 | 474,048,833 | 1,455 | 11,348 | 79 |
| 7 | 1,089,991 | 543,269,391 | 1,667 | 13,005 | 84 |
| 8 | 411,844 | 188,783,873 | 579 | 4,519 | 91 |
| 9 | 872,680 | 360,996,295 | 1,108 | 8,642 | 101 |
| 10 | 921,745 | 383,918,859 | 1,178 | 9,191 | 100 |
| 11 | 1,437,831 | 727,117,530 | 2,231 | 17,406 | 83 |
| 12 | 1,622,793 | 882,521,827 | 2,708 | 21,127 | 77 |
| 13 | 779,427 | 511,075,905 | 1,568 | 12,235 | 64 |
| 14 | 1,224,521 | 654,644,816 | 2,009 | 15,671 | 78 |
| 15 | 1,184,362 | 505,756,903 | 1,552 | 12,107 | 98 |
| 16 | 1,125,918 | 431,938,574 | 1,325 | 10,340 | 109 |
| 17 | 882,753 | 348,417,670 | 1,069 | 8,341 | 106 |
| 18 | 757,700 | 293,841,069 | 902 | 7,034 | 108 |
| 19 | 130,937 | 46,950,211 | 144 | 1,124 | 116 |
| 20 | 1,259,003 | 485,104,253 | 1,489 | 11,613 | 108 |
| 21 | 951,304 | 474,493,958 | 1,456 | 11,359 | 84 |
| 22 | 115,973 | 34,738,471 | 107 | 832 | 139 |
| 23 | 483,637 | 169,700,752 | 521 | 4,062 | 119 |
| **Total** | **23,476,228** | | | **284,526** | **83** |

**Table 2.9c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Spring/Dove Creeks—Scenario 3 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 908,131 | 378,572,171 | 1,162 | 9,063 | 100 |
| 2 | 322,910 | 224,005,495 | 687 | 5,362 | 60 |
| 3 | 232,577 | 159,194,543 | 488 | 3,811 | 61 |
| 4 | 415,240 | 339,236,444 | 1,041 | 8,121 | 51 |
| 5 | 6,758 | 4,162,712 | 13 | 100 | 68 |
| 6 | 477,340 | 258,897,236 | 794 | 6,198 | 77 |
| 7 | 538,543 | 278,395,515 | 854 | 6,664 | 81 |
| 8 | 156,048 | 74,235,764 | 228 | 1,777 | 88 |
| 9 | 257,314 | 112,503,630 | 345 | 2,693 | 96 |
| 10 | 430,477 | 188,698,649 | 579 | 4,517 | 95 |
| 11 | 761,244 | 399,586,648 | 1,226 | 9,566 | 80 |
| 12 | 964,621 | 542,662,251 | 1,665 | 12,991 | 74 |
| 13 | 462,245 | 310,901,541 | 954 | 7,443 | 62 |
| 14 | 593,896 | 329,743,594 | 1,012 | 7,894 | 75 |
| 15 | 556,505 | 252,856,766 | 776 | 6,053 | 92 |
| 16 | 653,522 | 266,990,297 | 819 | 6,391 | 102 |
| 17 | 530,515 | 221,471,332 | 680 | 5,302 | 100 |
| 18 | 377,918 | 153,107,384 | 470 | 3,665 | 103 |
| 19 | 63,789 | 23,132,172 | 71 | 554 | 115 |
| 20 | 471,240 | 190,155,158 | 583 | 4,552 | 104 |
| 21 | 408,812 | 210,386,011 | 646 | 5,036 | 81 |
| 22 | 0 | 21,107 | 0 | 1 | 0 |
| 23 | 196,976 | 69,981,336 | 215 | 1,675 | 118 |
| **Total** | **9,786,621** | | | **119,429** | **82** |

**Table 2.10a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Frio—Scenario 1 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,439,481 | 1,124,918,882 | 3,452 | 26,929 | 53 |
| 2 | 922,060 | 756,154,712 | 2,320 | 18,102 | 51 |
| 3 | 546,776 | 429,544,080 | 1,318 | 10,283 | 53 |
| 4 | 645,042 | 501,789,672 | 1,540 | 12,012 | 54 |
| 5 | 299,355 | 263,627,913 | 809 | 6,311 | 47 |
| 6 | 240,464 | 194,723,517 | 597 | 4,661 | 52 |
| 7 | 304,771 | 282,057,145 | 865 | 6,752 | 45 |
| 8 | 602,519 | 523,017,756 | 1,605 | 12,520 | 48 |
| 9 | 544,506 | 422,817,099 | 1,297 | 10,122 | 54 |
| 10 | 774,341 | 652,055,947 | 2,001 | 15,610 | 50 |
| 11 | 103,004 | 82,596,566 | 253 | 1,977 | 52 |
| 12 | 311,401 | 236,023,641 | 724 | 5,650 | 55 |
| 13 | 613,273 | 560,528,784 | 1,720 | 13,418 | 46 |
| 14 | 358,051 | 375,113,803 | 1,151 | 8,980 | 40 |
| 15 | 206,303 | 171,270,477 | 526 | 4,100 | 50 |
| 16 | 180,516 | 181,630,576 | 557 | 4,348 | 42 |
| 17 | 587,653 | 668,383,291 | 2,051 | 16,000 | 37 |
| 18 | 559,093 | 512,411,750 | 1,572 | 12,267 | 46 |
| 19 | 197,479 | 196,417,566 | 603 | 4,702 | 42 |
| 20 | 130,545 | 141,755,303 | 435 | 3,393 | 38 |
| 21 | 262,135 | 251,464,137 | 772 | 6,020 | 44 |
| 22 | 494,083 | 311,159,198 | 955 | 7,449 | 66 |
| 23 | 401,508 | 295,053,022 | 905 | 7,063 | 57 |
| 24 | 473,997 | 313,875,942 | 963 | 7,514 | 63 |
| 25 | 801,995 | 564,173,364 | 1,731 | 13,506 | 59 |
| 26 | 598,363 | 397,332,104 | 1,219 | 9,512 | 63 |
| **Total** | **12,598,715** | | | **249,202** | **51** |

**Table 2.10b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Frio—Scenario 2 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,280,400 | 993,747,761 | 3,049 | 23,789 | 54 |
| 2 | 787,310 | 642,336,279 | 1,971 | 15,377 | 51 |
| 3 | 382,564 | 295,626,757 | 907 | 7,077 | 54 |
| 4 | 483,495 | 372,311,349 | 1,142 | 8,913 | 54 |
| 5 | 231,115 | 198,671,857 | 610 | 4,756 | 49 |
| 6 | 173,174 | 137,175,094 | 421 | 3,284 | 53 |
| 7 | 245,692 | 225,041,564 | 691 | 5,387 | 46 |
| 8 | 553,975 | 475,642,141 | 1,459 | 11,386 | 49 |
| 9 | 492,706 | 374,891,345 | 1,150 | 8,974 | 55 |
| 10 | 569,916 | 478,079,745 | 1,467 | 11,445 | 50 |
| 11 | 66,652 | 53,132,441 | 163 | 1,272 | 52 |
| 12 | 214,907 | 155,872,124 | 478 | 3,731 | 58 |
| 13 | 404,839 | 371,757,207 | 1,141 | 8,899 | 45 |
| 14 | 320,684 | 333,347,074 | 1,023 | 7,980 | 40 |
| 15 | 129,751 | 104,789,824 | 322 | 2,509 | 52 |
| 16 | 143,065 | 144,550,541 | 444 | 3,460 | 41 |
| 17 | 525,051 | 593,470,085 | 1,821 | 14,207 | 37 |
| 18 | 432,313 | 383,484,533 | 1,177 | 9,180 | 47 |
| 19 | 149,649 | 145,121,723 | 445 | 3,474 | 43 |
| 20 | 102,515 | 113,910,096 | 350 | 2,727 | 38 |
| 21 | 196,797 | 182,696,422 | 561 | 4,374 | 45 |
| 22 | 398,456 | 248,227,007 | 762 | 5,942 | 67 |
| 23 | 270,962 | 189,677,616 | 582 | 4,541 | 60 |
| 24 | 362,461 | 237,166,355 | 728 | 5,678 | 64 |
| 25 | 631,465 | 439,292,694 | 1,348 | 10,516 | 60 |
| 26 | 476,830 | 312,342,334 | 958 | 7,477 | 64 |
| **Total** | **10,026,745** | | | **196,356** | **51** |

**Table 2.10c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| **Frio—Scenario 3** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,381,342 | 835,249,117 | 2,563 | 19,995 | 69 |
| 2 | 961,279 | 583,116,558 | 1,789 | 13,959 | 69 |
| 3 | 548,013 | 305,134,261 | 936 | 7,305 | 75 |
| 4 | 634,569 | 383,437,149 | 1,177 | 9,179 | 69 |
| 5 | 291,960 | 205,453,452 | 630 | 4,918 | 59 |
| 6 | 226,632 | 141,324,820 | 434 | 3,383 | 67 |
| 7 | 313,466 | 232,775,761 | 714 | 5,572 | 56 |
| 8 | 535,396 | 363,206,296 | 1,114 | 8,695 | 62 |
| 9 | 511,132 | 283,507,274 | 870 | 6,787 | 75 |
| 10 | 811,805 | 491,409,053 | 1,508 | 11,764 | 69 |
| 11 | 90,211 | 54,917,624 | 169 | 1,315 | 69 |
| 12 | 287,012 | 160,042,828 | 491 | 3,831 | 75 |
| 13 | 588,611 | 384,256,591 | 1,179 | 9,199 | 64 |
| 14 | 393,497 | 344,788,729 | 1,058 | 8,254 | 48 |
| 15 | 176,951 | 108,151,588 | 332 | 2,589 | 68 |
| 16 | 209,138 | 149,408,964 | 458 | 3,577 | 58 |
| 17 | 632,463 | 611,904,665 | 1,878 | 14,648 | 43 |
| 18 | 578,795 | 395,765,572 | 1,214 | 9,474 | 61 |
| 19 | 190,286 | 149,751,843 | 460 | 3,585 | 53 |
| 20 | 144,242 | 117,495,332 | 361 | 2,813 | 51 |
| 21 | 270,897 | 188,982,573 | 580 | 4,524 | 60 |
| 22 | 513,321 | 259,157,763 | 795 | 6,204 | 83 |
| 23 | 376,682 | 196,276,006 | 602 | 4,699 | 80 |
| 24 | 474,934 | 246,448,445 | 756 | 5,900 | 81 |
| 25 | 807,032 | 454,822,313 | 1,396 | 10,888 | 74 |
| 26 | 613,309 | 324,890,070 | 997 | 7,778 | 79 |
| **Total** | **12,562,974** | | | **190,833** | **66** |

**Table 2.11a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| **Hondo—Scenario 1** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 291,473 | 370,006,778 | 1,135 | 8,858 | 33 |
| 2 | 165,148 | 172,794,881 | 530 | 4,137 | 40 |
| 3 | 333,236 | 480,414,993 | 1,474 | 11,501 | 29 |
| 4 | 384,933 | 554,277,913 | 1,701 | 13,269 | 29 |
| 5 | 302,726 | 356,580,660 | 1,094 | 8,536 | 35 |
| 6 | 137,917 | 248,835,338 | 764 | 5,957 | 23 |
| 7 | 788,763 | 1,129,570,631 | 3,466 | 27,041 | 29 |
| 8 | 431,129 | 520,435,227 | 1,597 | 12,459 | 35 |
| 9 | 644,373 | 814,949,703 | 2,501 | 19,509 | 33 |
| 10 | 457,234 | 535,762,158 | 1,644 | 12,826 | 36 |
| **Total** | **3,936,934** | | | **124,090** | **32** |

Table 2.11b. **Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| **Hondo—Scenario 2** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 240,813 | 299,697,220 | 920 | 7,174 | 34 |
| 2 | 121,929 | 129,337,919 | 397 | 3,096 | 39 |
| 3 | 291,292 | 415,609,256 | 1,275 | 9,949 | 29 |
| 4 | 316,184 | 428,786,401 | 1,316 | 10,265 | 31 |
| 5 | 222,617 | 257,661,586 | 791 | 6,168 | 36 |
| 6 | 127,485 | 233,445,728 | 716 | 5,588 | 23 |
| 7 | 703,643 | 970,987,965 | 2,979 | 23,244 | 30 |
| 8 | 367,734 | 440,726,057 | 1,352 | 10,551 | 35 |
| 9 | 589,500 | 738,988,447 | 2,268 | 17,691 | 33 |
| 10 | 383,459 | 427,637,116 | 1,312 | 10,237 | 37 |
| **Total** | **3,364,655** | | | **103,964** | **32** |

Table 2.11c. **Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| **Hondo—Scenario 3** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 240,813 | 299,697,220 | 920 | 7,174 | 34 |
| 2 | 121,929 | 129,337,919 | 397 | 3,096 | 39 |
| 3 | 291,292 | 415,609,256 | 1,275 | 9,949 | 29 |
| 4 | 316,184 | 428,786,401 | 1,316 | 10,265 | 31 |
| 5 | 222,617 | 257,661,586 | 791 | 6,168 | 36 |
| 6 | 60,957 | 111,947,278 | 344 | 2,680 | 23 |
| 7 | 703,643 | 970,987,965 | 2,979 | 23,244 | 30 |
| 8 | 367,734 | 440,726,057 | 1,352 | 10,551 | 35 |
| 9 | 589,500 | 738,988,447 | 2,268 | 17,691 | 33 |
| 10 | 383,459 | 427,637,116 | 1,312 | 10,237 | 37 |
| **Total** | **3,298,127** | | | **101,055** | **33** |

**Table 2.12a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Medina—Scenario 1 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,517,604 | 1,240,285,929 | 3,806 | 29,691 | 51 |
| 2 | 959,234 | 856,727,922 | 2,629 | 20,509 | 47 |
| 3 | 1,786,039 | 1,601,630,177 | 4,914 | 38,341 | 47 |
| 4 | 797,254 | 702,259,299 | 2,155 | 16,811 | 47 |
| 5 | 503,826 | 713,854,314 | 2,190 | 17,089 | 29 |
| 6 | 1,740,368 | 1,970,601,190 | 6,047 | 47,174 | 37 |
| 7 | 712,072 | 978,515,879 | 3,003 | 23,425 | 30 |
| 8 | 959,182 | 1,368,142,016 | 4,198 | 32,752 | 29 |
| 9 | 826,299 | 1,107,042,464 | 3,397 | 26,501 | 31 |
| 10 | 544,324 | 772,960,958 | 2,372 | 18,504 | 29 |
| 11 | 519,426 | 755,710,343 | 2,319 | 18,091 | 29 |
| 12 | 803,705 | 1,014,423,964 | 3,113 | 24,284 | 33 |
| 13 | 1,372,481 | 1,691,342,357 | 5,190 | 40,489 | 34 |
| 14 | 1,140,600 | 1,720,670,286 | 5,280 | 41,191 | 28 |
| 15 | 237,890 | 365,130,693 | 1,120 | 8,741 | 27 |
| 16 | 1,033,233 | 1,391,676,356 | 4,270 | 33,315 | 31 |
| 17 | 736,960 | 859,434,157 | 2,637 | 20,574 | 36 |
| 18 | 694,607 | 809,780,049 | 2,485 | 19,385 | 36 |
| 19 | 428,412 | 518,455,666 | 1,591 | 12,411 | 35 |
| 20 | 3,057,210 | 3,815,469,918 | 11,707 | 91,338 | 33 |
| 21 | 1,074,041 | 1,244,297,132 | 3,818 | 29,787 | 36 |
| 22 | 757,458 | 983,554,897 | 3,018 | 23,545 | 32 |
| 23 | 582,367 | 624,275,031 | 1,916 | 14,944 | 39 |
| 24 | 511,768 | 661,989,906 | 2,031 | 15,847 | 32 |
| 25 | 793,765 | 911,397,797 | 2,797 | 21,818 | 36 |
| 26 | 624,963 | 649,699,033 | 1,994 | 15,553 | 40 |
| 27 | 705,292 | 952,201,922 | 2,922 | 22,795 | 31 |
| 28 | 942,502 | 947,357,319 | 2,907 | 22,679 | 42 |
| 29 | 462,572 | 371,223,723 | 1,139 | 8,887 | 52 |
| 30 | 82,268 | 95,122,278 | 292 | 2,277 | 36 |
| 31 | 128,312 | 134,535,398 | 413 | 3,221 | 40 |
| 32 | 165,634 | 590,477,557 | 1,812 | 14,135 | 12 |
| **Total** | **27,201,668** | | | **776,105** | **35** |

**Table 2.12b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Medina – Scenario 2 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,285,838 | 1,049,035,495 | 3,219 | 25,113 | 51 |
| 2 | 775,525 | 688,762,673 | 2,113 | 16,488 | 47 |
| 3 | 1,336,019 | 1,126,386,688 | 3,456 | 26,964 | 50 |
| 4 | 591,654 | 500,282,238 | 1,535 | 11,976 | 49 |
| 5 | 440,646 | 621,706,130 | 1,908 | 14,883 | 30 |
| 6 | 1,284,632 | 1,396,666,006 | 4,286 | 33,435 | 38 |
| 7 | 598,911 | 801,913,165 | 2,461 | 19,197 | 31 |
| 8 | 786,365 | 1,071,079,174 | 3,287 | 25,640 | 31 |
| 9 | 695,101 | 890,682,429 | 2,733 | 21,322 | 33 |
| 10 | 451,109 | 634,258,100 | 1,946 | 15,183 | 30 |
| 11 | 452,335 | 636,863,550 | 1,954 | 15,246 | 30 |
| 12 | 695,920 | 871,043,791 | 2,673 | 20,852 | 33 |
| 13 | 1,199,517 | 1,412,119,188 | 4,333 | 33,805 | 35 |
| 14 | 989,766 | 1,437,272,258 | 4,410 | 34,407 | 29 |
| 15 | 198,824 | 305,916,628 | 939 | 7,323 | 27 |
| 16 | 895,667 | 1,193,573,568 | 3,662 | 28,573 | 31 |
| 17 | 650,810 | 755,469,025 | 2,318 | 18,085 | 36 |
| 18 | 569,449 | 673,780,472 | 2,067 | 16,130 | 35 |
| 19 | 378,422 | 453,574,395 | 1,392 | 10,858 | 35 |
| 20 | 2,750,319 | 3,373,054,349 | 10,350 | 80,747 | 34 |
| 21 | 962,248 | 1,126,649,341 | 3,457 | 26,971 | 36 |
| 22 | 686,786 | 885,596,177 | 2,717 | 21,200 | 32 |
| 23 | 497,312 | 518,803,539 | 1,592 | 12,420 | 40 |
| 24 | 416,552 | 523,857,310 | 1,607 | 12,541 | 33 |
| 25 | 671,345 | 749,127,626 | 2,299 | 17,933 | 37 |
| 26 | 519,078 | 510,632,109 | 1,567 | 12,224 | 42 |
| 27 | 662,246 | 885,421,339 | 2,717 | 21,196 | 31 |
| 28 | 915,520 | 924,076,908 | 2,835 | 22,121 | 41 |
| 29 | 425,472 | 339,976,967 | 1,043 | 8,139 | 52 |
| 30 | 80,403 | 93,135,712 | 286 | 2,230 | 36 |
| 31 | 107,246 | 110,880,472 | 340 | 2,654 | 40 |
| 32 | 127,282 | 443,382,713 | 1,360 | 10,614 | 12 |
| **Total** | **23,098,316** | | | **646,470** | **36** |

**Table 2.12c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Medina—Scenario 3 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,285,838 | 1,049,035,495 | 3,219 | 25,113 | 51 |
| 2 | 775,525 | 688,762,673 | 2,113 | 16,488 | 47 |
| 3 | 1,336,019 | 1,126,386,688 | 3,456 | 26,964 | 50 |
| 4 | 591,654 | 500,282,238 | 1,535 | 11,976 | 49 |
| 5 | 440,646 | 621,706,130 | 1,908 | 14,883 | 30 |
| 6 | 1,284,632 | 1,396,666,006 | 4,286 | 33,435 | 38 |
| 7 | 598,911 | 801,913,165 | 2,461 | 19,197 | 31 |
| 8 | 786,365 | 1,071,079,174 | 3,287 | 25,640 | 31 |
| 9 | 695,101 | 890,682,429 | 2,733 | 21,322 | 33 |
| 10 | 342,663 | 493,463,124 | 1,514 | 11,813 | 29 |
| 11 | 452,335 | 636,863,550 | 1,954 | 15,246 | 30 |
| 12 | 615,408 | 788,683,337 | 2,420 | 18,880 | 33 |
| 13 | 1,199,517 | 1,412,119,188 | 4,333 | 33,805 | 35 |
| 14 | 908,333 | 1,346,453,230 | 4,131 | 32,233 | 28 |
| 15 | 103,700 | 163,375,677 | 501 | 3,911 | 27 |
| 16 | 821,503 | 1,117,309,667 | 3,428 | 26,747 | 31 |
| 17 | 650,810 | 755,469,025 | 2,318 | 18,085 | 36 |
| 18 | 569,449 | 673,780,472 | 2,067 | 16,130 | 35 |
| 19 | 344,645 | 422,511,727 | 1,296 | 10,114 | 34 |
| 20 | 2,750,319 | 3,373,054,349 | 10,350 | 80,747 | 34 |
| 21 | 802,496 | 960,957,978 | 2,949 | 23,004 | 35 |
| 22 | 590,118 | 778,411,742 | 2,388 | 18,634 | 32 |
| 23 | 473,944 | 506,332,189 | 1,554 | 12,121 | 39 |
| 24 | 416,552 | 523,857,310 | 1,607 | 12,541 | 33 |
| 25 | 671,345 | 749,127,626 | 2,299 | 17,933 | 37 |
| 26 | 519,078 | 510,632,109 | 1,567 | 12,224 | 42 |
| 27 | 561,807 | 767,301,360 | 2,354 | 18,368 | 31 |
| 28 | 791,985 | 815,437,619 | 2,502 | 19,521 | 41 |
| 29 | 425,472 | 339,976,967 | 1,043 | 8,139 | 52 |
| 30 | 80,403 | 93,135,712 | 286 | 2,230 | 36 |
| 31 | 107,246 | 110,880,472 | 340 | 2,654 | 40 |
| 32 | 127,282 | 443,382,713 | 1,360 | 10,614 | 12 |
| **Total** | **22,121,098** | | | **620,713** | **36** |

**Table 2.13a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Sabinal – Scenario 1 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 763,855 | 620,294,101 | 1,903 | 14,849 | 51 |
| 2 | 173,872 | 164,912,889 | 506 | 3,948 | 44 |
| 3 | 396,934 | 363,637,102 | 1,116 | 8,705 | 46 |
| 4 | 1,022,319 | 1,172,952,384 | 3,599 | 28,079 | 36 |
| 5 | 912,591 | 951,652,492 | 2,920 | 22,782 | 40 |
| 6 | 324,519 | 427,995,636 | 1,313 | 10,246 | 32 |
| 7 | 118,201 | 87,195,434 | 268 | 2,087 | 57 |
| 8 | 525,886 | 633,729,304 | 1,945 | 15,171 | 35 |
| 9 | 1,500,024 | 1,207,881,481 | 3,706 | 28,915 | 52 |
| 10 | 355,388 | 356,253,040 | 1,093 | 8,528 | 42 |
| 11 | 879,274 | 602,376,681 | 1,848 | 14,420 | 61 |
| 12 | 267,152 | 170,112,994 | 522 | 4,072 | 66 |
| **Total** | **7,240,015** | | | **161,803** | **45** |

**Table 2.13b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Sabinal—Scenario 2 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 551,325 | 446,689,576 | 1,371 | 10,693 | 52 |
| 2 | 113,847 | 105,290,583 | 323 | 2,521 | 45 |
| 3 | 271,001 | 241,107,277 | 740 | 5,772 | 47 |
| 4 | 858,318 | 987,179,110 | 3,029 | 23,632 | 36 |
| 5 | 741,316 | 760,240,821 | 2,333 | 18,199 | 41 |
| 6 | 275,223 | 356,720,371 | 1,095 | 8,539 | 32 |
| 7 | 110,767 | 74,440,755 | 228 | 1,782 | 62 |
| 8 | 487,984 | 573,271,967 | 1,759 | 13,724 | 36 |
| 9 | 1,318,878 | 1,017,060,451 | 3,121 | 24,347 | 54 |
| 10 | 314,138 | 304,732,214 | 935 | 7,295 | 43 |
| 11 | 756,534 | 514,125,566 | 1,578 | 12,308 | 61 |
| 12 | 204,479 | 127,126,119 | 390 | 3,043 | 67 |
| **Total** | **6,003,809** | | | **131,855** | **46** |

**Table 2.13c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Sabinal—Scenario 3 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 551,325 | 458,463,614 | 1,407 | 10,975 | 50 |
| 2 | 113,847 | 107,450,484 | 330 | 2,572 | 44 |
| 3 | 271,001 | 248,062,817 | 761 | 5,938 | 46 |
| 4 | 858,318 | 1,004,584,207 | 3,082 | 24,049 | 36 |
| 5 | 741,316 | 775,416,609 | 2,379 | 18,563 | 40 |
| 6 | 275,223 | 364,338,044 | 1,118 | 8,722 | 32 |
| 7 | 89,966 | 62,341,557 | 191 | 1,492 | 60 |
| 8 | 274,998 | 331,900,708 | 1,018 | 7,945 | 35 |
| 9 | 1,318,878 | 1,036,435,284 | 3,180 | 24,811 | 53 |
| 10 | 266,796 | 266,298,000 | 817 | 6,375 | 42 |
| 11 | 756,534 | 528,818,380 | 1,623 | 12,659 | 60 |
| 12 | 204,479 | 130,962,007 | 402 | 3,135 | 65 |
| **Total** | **5,722,680** | | | **127,237** | **45** |

**Table 2.14a. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Seco—Scenario 1 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 160,018 | 127,971,059 | 393 | 3,063 | 52 |
| 2 | 167,910 | 162,078,729 | 497 | 3,880 | 43 |
| 3 | 117,498 | 111,600,732 | 342 | 2,672 | 44 |
| 4 | 72,858 | 57,819,991 | 177 | 1,384 | 53 |
| 5 | 480,178 | 348,656,130 | 1,070 | 8,346 | 58 |
| 6 | 112,323 | 87,730,748 | 269 | 2,100 | 53 |
| 7 | 139,916 | 80,630,741 | 247 | 1,930 | 72 |
| 8 | 83,813 | 55,871,648 | 171 | 1,338 | 63 |
| 9 | 142,060 | 102,521,086 | 315 | 2,454 | 58 |
| 10 | 42,258 | 28,663,653 | 88 | 686 | 62 |
| 11 | 106,289 | 76,997,959 | 236 | 1,843 | 58 |
| 12 | 50,388 | 34,998,135 | 107 | 838 | 60 |
| **Total** | **1,675,509** | | | **30,535** | **55** |

**Table 2.14b. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Seco—Scenario 2 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 128,963 | 114,843,246 | 352 | 2,749 | 47 |
| 2 | 132,399 | 128,118,572 | 393 | 3,067 | 43 |
| 3 | 75,004 | 75,848,332 | 233 | 1,816 | 41 |
| 4 | 59,436 | 53,339,468 | 164 | 1,277 | 47 |
| 5 | 439,280 | 391,662,334 | 1,202 | 9,376 | 47 |
| 6 | 88,477 | 72,408,344 | 222 | 1,733 | 51 |
| 7 | 104,514 | 89,656,937 | 275 | 2,146 | 49 |
| 8 | 76,685 | 90,464,468 | 278 | 2,166 | 35 |
| 9 | 103,935 | 95,427,779 | 293 | 2,284 | 45 |
| 10 | 35,745 | 37,690,257 | 116 | 902 | 40 |
| 11 | 76,899 | 57,414,774 | 176 | 1,374 | 56 |
| 12 | 42,681 | 43,647,482 | 134 | 1,045 | 41 |
| **Total** | **1,364,019** | | | **29,936** | **46** |

**Table 2.14c. Total Society Cost and Cost of Added Water from Brush Control by Sub-Basin (acre-foot).**

| Seco—Scenario 3 | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 128,919 | 114,843,246 | 352 | 2,749 | 47 |
| 2 | 132,399 | 128,118,572 | 393 | 3,067 | 43 |
| 3 | 75,004 | 75,848,332 | 233 | 1,816 | 41 |
| 4 | 59,436 | 53,339,468 | 164 | 1,277 | 47 |
| 5 | 439,280 | 391,662,334 | 1,202 | 9,376 | 47 |
| 6 | 88,477 | 72,408,344 | 222 | 1,733 | 51 |
| 7 | 104,514 | 89,656,937 | 275 | 2,146 | 49 |
| 8 | 76,685 | 90,464,468 | 278 | 2,166 | 35 |
| 9 | 103,935 | 95,427,779 | 293 | 2,284 | 45 |
| 10 | 35,745 | 37,690,257 | 116 | 902 | 40 |
| 11 | 76,899 | 57,414,774 | 176 | 1,374 | 56 |
| 12 | 42,681 | 43,647,482 | 134 | 1,045 | 41 |
| **Total** | **1,363,974** | | | **29,936** | **46** |

For the Edwards' watersheds as a whole, total society costs for implementing Scenario I in each watershed ranged from 17 percent (Hondo) to 26 percent (Frio) greater than the costs for implementing Scenario II. Total costs between Scenarios II and III were similar in all watersheds because the slope constraint, riparian constraint, and amount of oak in the Edwards come close to satisfying the 40 percent residual cover requirement. The trend of larger differences between Scenario I and II than between Scenario II and III existed for all watersheds within the Edwards. Society costs per acre-foot of additional water varied from $32 (Hondo, Scenarios I and II) to $51 (Frio, Scenarios I and II). Like the Twin Buttes, sub-basins within the Edwards' watersheds exhibited great variability in the per acre cost of added water. To achieve the least expensive additional water provided by the three Scenarios, brush management/restoration efforts should be concentrated on the Hondo and Medina watersheds.

*Ecological Restoration*

Considering the rangeland component, this study focuses on rangeland activities but there are opportunities for improved management of the riparian zone. Appendix A provides insight related to riparian management practices that complement this analysis. In addition to providing increased off-site water yield, brush control coupled with appropriate grazing management can restore rangeland vegetation towards a more historic climax plant community. In Texas, the encroachment of woody species such as honey mesquite (Archer et al., 1994) and juniper, or cedar, (redberry juniper in Twin Buttes region, ashe juniper in the Edwards Aquifer Recharge Zone) in native grassland savannas has become pronounced over the last 50-80 years (Ansley et al., 1995; Smeins et al., 1997). It is thought that brush species in the Twin Buttes region, a former grassland savanna, began to dominate in the late 1800s (Upper Colorado River Authority, 2000). Much of the Edwards Plateau region, in which the Edwards Aquifer Recharge Zone is wholly contained, became dominated by woody plants during the 20th century (Smeins et al., 1997). Causes of the invasion of brush species include suppression of fire, overgrazing by livestock, dissemination of seed by livestock (mesquite), and possibly increases in the levels of atmospheric carbon dioxide (Ansley et al., 1996).

As mentioned previously, a distinct difference between this study and the TAES study (2000), and a very important aspect of this research, is the incorporation of restoration practices in addition to initial and follow-up brush control treatments. These additional restoration practices will enable the rangelands of the Twin Buttes and Edwards to become closer to historic climax plant communities with respect to vegetative composition. Specifically, the types of change one could expect from the chosen brush management/restoration treatments would be the recovery of many climax plant community grasses and forbs, reduced abundance of mesquite and juniper, and resulting improvements in hydrologic functioning and wildlife habitat.

Initial brush control treatments for this project are the same mechanical and chemical treatments used in the TAES study (2000). Mechanical treatments include such practices as tree dozing, rootplowing, rootplowing with pre-doze, tree shearing, tree shearing with stump spray, and individual plant excavation or grubbing. Chemical treatments include herbicide applied aerially or through individual plant treatments.

Where mechanical treatments are used, rangeland reseeding will follow. Though average rainfall differences between the two watersheds do exist, grass species to be planted are fairly similar for each study area. The native mix to be planted includes such climax grass species as sideoats gramma, little bluestem, Indian grass, and switchgrass. In many areas within both watersheds, the abundance of climax grasses has decreased markedly due to over-grazing and the concomitant increase in brush due to causes cited previously,

To improve the chances of successful reseedings, full year grazing deferments will be performed in the first year on seeded rangelands. Not only will the grazing deferments help in the establishment of seeded plants, they will help climax grasses and forbs, which are generally preferred plants by livestock, become more abundant and robust.

In addition to initial brush control treatments and reseeding (where mechanical treatments are used), infrastructure will be built in the first year to enable ranchers to improve their grazing systems. Our model calls for the installation of an additional cross fence and water source to enable ranchers to rotate livestock into more pastures, increasing the efficiency of grazing. In addition to helping vegetative composition improve, the existence of an additional pasture will facilitate the accumulating of fine fuel loads for prescribed burns.

Follow-up treatments, occurring in years 3 and 7, are designed to keep brush canopy levels between 3 and 8 percent for mesquite and juniper brush categories during the 10-year horizon. For mixed brush, post-treatment canopy levels would be between 10 and 33%. Types of follow-up treatments are prescribed burns or individual plant treatments of herbicides.

**Twin Buttes**

**Middle Concho.** Total acres restored under Scenarios I, II, and III are 506,529, 481,744, and 179,212, respectively (Figure 2.5).

**South Concho.** Acres restored under Scenario I were 171,258, 162,854 for Scenario II, and 67,232 for Scenario III (Figure 2.5).

**Spring-Dove Creek.** For this watershed, 272,611 acres were restored under Scenario I, 258,941 acres were controlled for Scenario II, and 106,981 acres are controlled under Scenario III (Figure 2.5).

To summarize, acres of treated and restored rangelands differ very little between Scenario I and Scenario II in the Twin Buttes' watersheds. Very large differences in restored rangelands existed between Scenario I/II and Scenario III for all three watersheds. In fact, compared with Scenario III, Scenario I treated over 150 percent more acres.

**Edwards**

**Frio.** Total acres restored under Scenarios I, II, and III were 74,998, 60,267, and 56,194, respectively (Figure 2.5).

**Hondo.** Acres restored under Scenario I were 21,294, 18,210 for Scenario II, and 17,786 for Scenario III (Figure 2.5).

**Medina.** For this watershed, 145,948 acres were restored under Scenario I, 123,908 acres were restored under Scenario II, and 118,560 acres were restored under Scenario III (Figure 2.5).

**Sabinal.** Restored acreages under Scenarios I, II, and III are 42,323, 35,233, and 33,537, respectively (Figure 2.5).

**Seco.** Scenario I called for the restoration of 8,734 acres while both Scenarios II and III restored 7,106 acres (Figure 2.5).

In the Edwards study area, the amount of restored rangeland was very similar, if not the same, for Scenarios II and III in all watersheds. The largest differences in the amount of restored land for all five watersheds was between Scenario I and Scenario II.

**Comparison Across Watersheds**

Because of slope differences and rocky terrain, treatment costs for the six targeted brush type-density categories were higher in the Eastern and Western portions of the Edwards than they were in the Twin Buttes.

With few exceptions, total society costs for the three different brush management/restoration scenarios were higher for the Twin Buttes' watersheds than those for the Edwards (Figure 2.1). This is due to the larger watershed sizes and acres of brush treated. The watersheds of the Twin Buttes showed much larger differences in total society costs between Scenarios I/II and Scenario III than those of the Edwards.

When total society costs for all watersheds within their respective study area were combined, cost differences for the Edwards between the most expensive and least expensive Scenarios, Scenarios I and III, were roughly 26 percent (Figure 2.3). For the entire Twin Buttes, Scenario I is 167 percent more costly than Scenario III (Figure 2.4). When the five Edwards' watersheds are combined and compared with the combined watersheds of the Twin Buttes, implementation of Scenarios I and II are less costly on a total society cost basis for the Edwards while Scenario III is cheaper for the Twin Buttes.

Cost of added water is less expensive for the Edwards than the Twin Buttes for all watersheds and scenarios (Figure 2.2). The most expensive watershed on a cost per acre-foot of added water basis was the Middle Concho. Costs were roughly double those of the next highest watershed. While cost of added water varied between watersheds and study areas, all watersheds displayed a pattern of similar costs of added water between brush management/restoration scenarios.

Compared with the Edwards, cost of added water for the entire Twin Buttes study area were 163 percent higher for Scenario I, 160 percent higher for Scenario II, and 144 percent higher for Scenario III (Figures 2.3 and 2.4). Cost of added water were similar for all scenarios for all of the Edwards' watersheds, while Scenario III had slightly lower cost of added water than Scenarios I and II for the combined Twin Buttes' watersheds.

For the three brush management/restoration scenarios, the amount of restored acres for all of the Twin Buttes' watersheds was higher than the Edwards, with the exception of Scenario III for the

South Concho and Spring-Dove Creeks, which treated less brush than Scenarios I, II, and III for the Medina (Figure 2.5). By far, the watershed with the most restored acres under the three brush management/restoration scenarios was the Middle Concho.

Restored acres for the whole Twin Buttes were higher for all scenarios than the combined Edwards' watersheds (Figure 2.6). The percentage increases in restored acres for the Twin Buttes compared with the entire Edwards were 224 percent for Scenario I, 269 percent for Scenario II, and 52 percent for Scenario III.

**Conclusions**

By integrating data from hydrologic modeling, focus groups, and range scientists, an economic model was used to study the economic feasibility of three different brush management/restoration scenarios in the Edwards and Twin Buttes. Total treatment costs, landowner costs, and society cost of the six targeted brush type-density categories were reported. Overall, treatment costs per treated acre were higher for the Edwards than the Twin Buttes.

Three brush management/restoration scenarios were analyzed. The scenarios differ in the amount and location of residual brush cover. Highest levels of brush are removed under Scenario I followed by Scenario II and then Scenario III.

The Edwards' watersheds showed small differences in the total society cost for each scenario, with Scenarios I and II showing larger differences than Scenarios II and III. Acres of brush removed were close for all scenarios. With one exception, the Hondo, the watersheds within the Edwards showed very similar cost for acre-foot of added water for the three scenarios.

Watersheds of the Twin Buttes had minor cost differences between Scenarios I and II and substantial differences between Scenarios I/II and Scenario III. These differences reflect the different levels of brush removed. For each watershed except for the Middle Concho, society cost for added water was nearly identical for all Scenarios.

Total cost for Scenarios I and II were generally higher for the Twin Buttes' watersheds than for the Edwards'. This trend was caused by the size of the watersheds and corresponding increase in brush removed. When watersheds from each study area are combined, the Twin Buttes has significantly higher costs for Scenarios I and II while being slightly less expensive for Scenario III. If watersheds within their respective study area are combined, the Edwards experienced much lower cost for added water than the Twin Buttes.

Amounts of restored acres were much higher for the Twin Buttes' watersheds than those of the Edwards in almost all instances. The Twin Buttes' watersheds showed largest differences between Scenarios I/II and Scenario III while the Edwards' watersheds had their largest differences in restored acres between Scenario I and II. When combining all watersheds into their respective study area, restored acres were significantly higher for the Twin Buttes than the Edwards in Scenarios I and II, while the difference for Scenario III was not quite as dramatic.

**Additional Considerations.**

Success of each brush management/restoration scenario in improving off-site water yield and restoring rangelands depends on the willingness of landowners in the two study areas to participate. One reason why landowners may be reluctant to participate in the three scenarios is the perceived impacts to hunting enterprises, especially deer hunting. These impacts could include loss of wildlife habitat due to fragmentation, loss of thermal and/or escape cover, loss of wildlife diversity, and a potential loss of food sources (Rollins, 2000). Scenario III may be a more satisfactory option for landowners with this concern than Scenarios I and II because of the residual brush requirement. In the Twin Buttes area, however, these same negative impacts on deer habitat may enhance habitat for quail.

Another reason why brush management/restoration programs may cause landowners to be reluctant is the importance of brush to property values. The top motives for the purchase of the majority of landholdings throughout the state are recreation followed by the desire for rural homesites (Wilkins et al., 2000). Agriculture production, which generally benefits from decreased levels of brush, is not the driving force behind property purchases that it once was.

One cost not incorporated into the economic model is the transaction costs associated with implementing any cost-share program. These include costs associated with contract development, monitoring, and any public hearings. Contract development and monitoring costs would be most expensive for scenarios calling for increased brush control.

In order for brush management/restoration programs to work, the public must be willing to enroll their land in such a program. Landowner surveys conducted by the TAES (Narayanan, et al., 2002) indicate that landowners in the Edwards would include only 49 percent of their moderate cover and 53 percent of their heavy cover in a brush management program. In the Twin Buttes, landowners were willing to include 59 percent of their moderate cover and 64 percent of their heavy cover into a brush management program. With respect to Scenarios II and III, 26.5 percent of survey respondents in the Edwards said that requiring a 75 yard riparian buffer zone would either "reduce interest" or "prevent participation" in a program with that restriction. 15.1 percent of survey respondents in the Twin Buttes said that the riparian buffer restriction would either "reduce interest" or "prevent participation." Obviously, there are big differences in landowner attitudes regarding the desirability of various aspects of a brush control program. It is important to note, however, that a good majority of all the landowner s surveyed in both watersheds were willing to participate to some degree in a brush control restoration program.

Finally, some aspects of the expected changes in ecosystem health and services provided by brush management and restoration treatments can be extremely difficult or impossible to economically quantify. Improvements in ecosystem stability and resilience, changes in non-game animal composition and abundance, and alterations of carbon sequestration capacity, all important concepts from an ecological viewpoint, are not included in this model because of logistic reasons. Obviously, there are big differences in landowner attitudes regarding land use and the desirability of various aspects of a brush control program. It is important to note, however, that a good majority of all the landowners surveyed in both watersheds were willing to participate to some degree in a brush control restoration program.

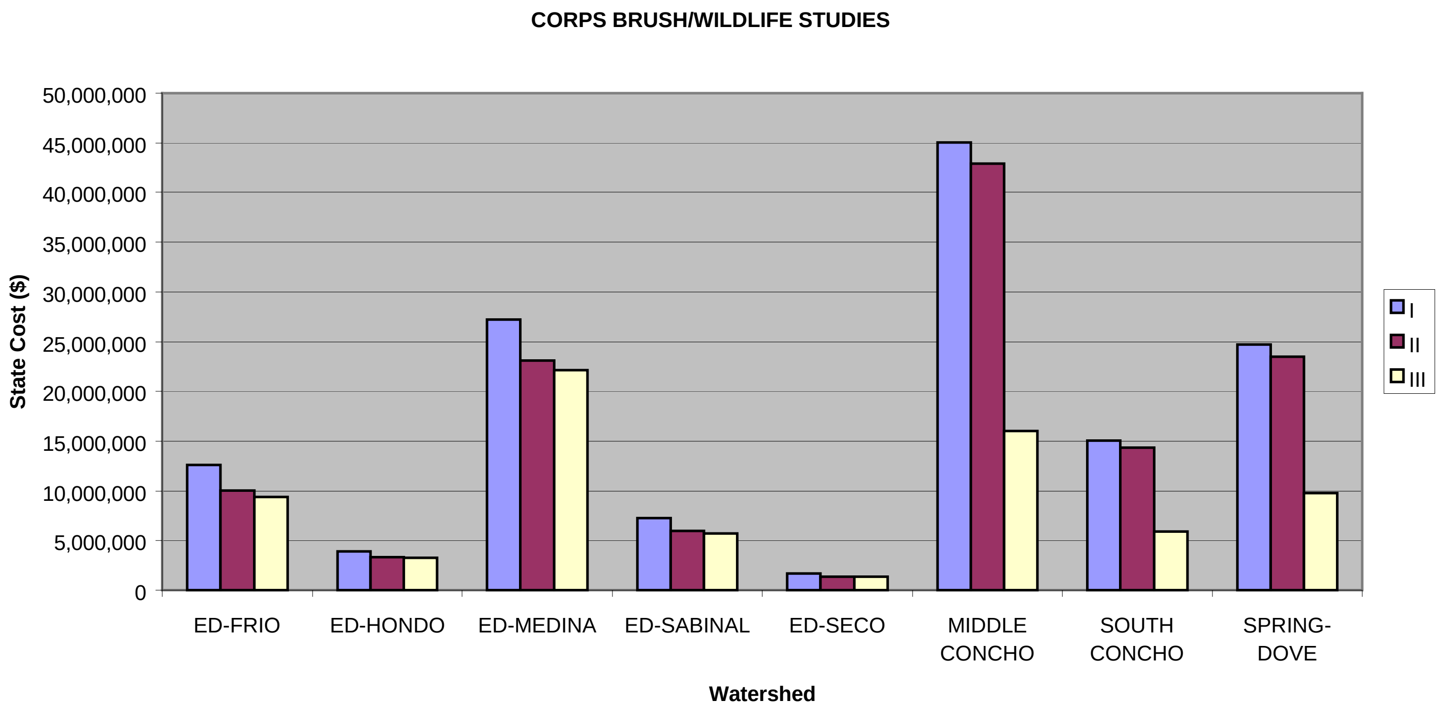


**Figure 2.1. Comparison of Society costs for restoration, Scenarios I, II and III.**

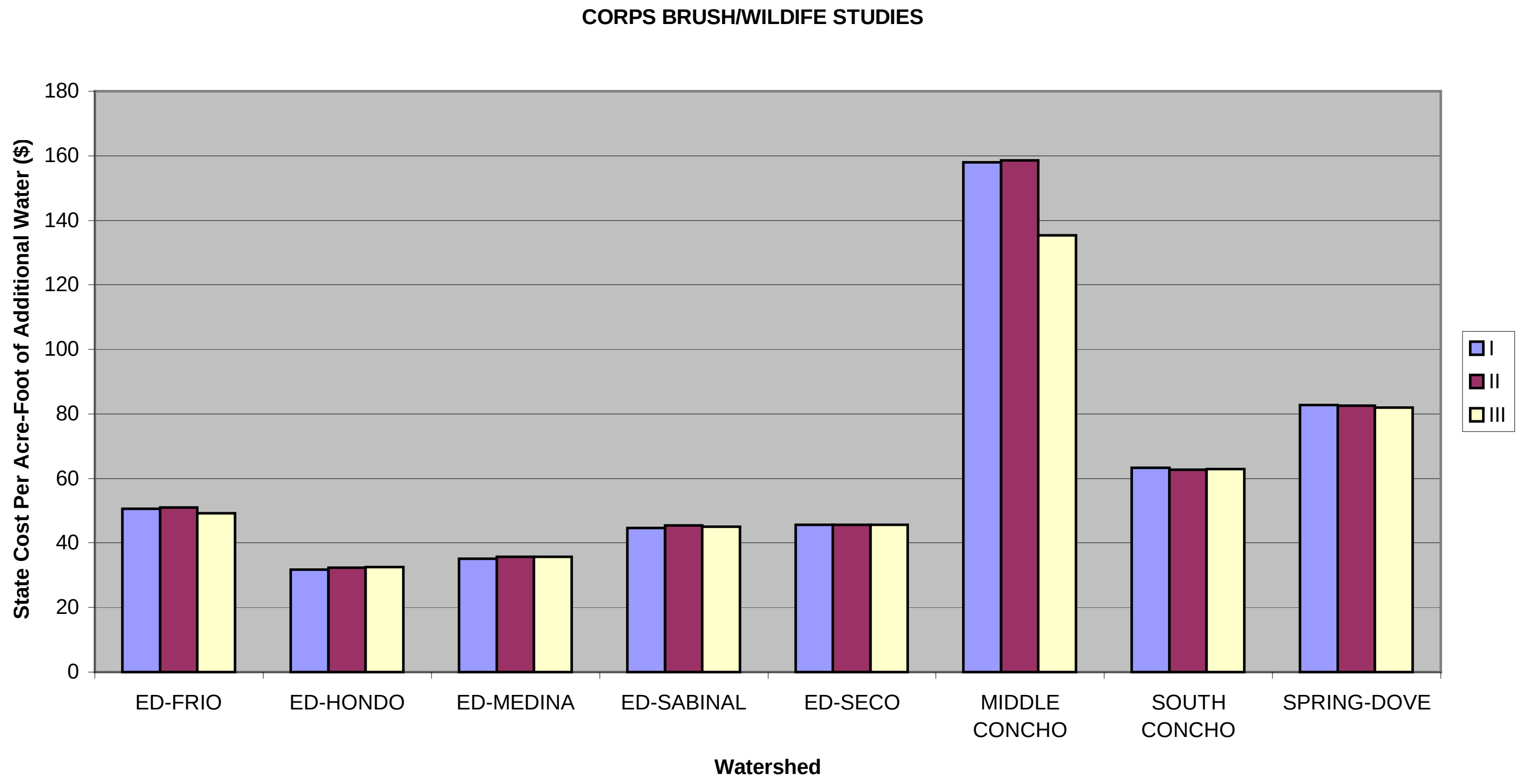


**Figure 2.2 Comparison of Society Costs per Acre-Foot of Water Saved, by Watershed.**

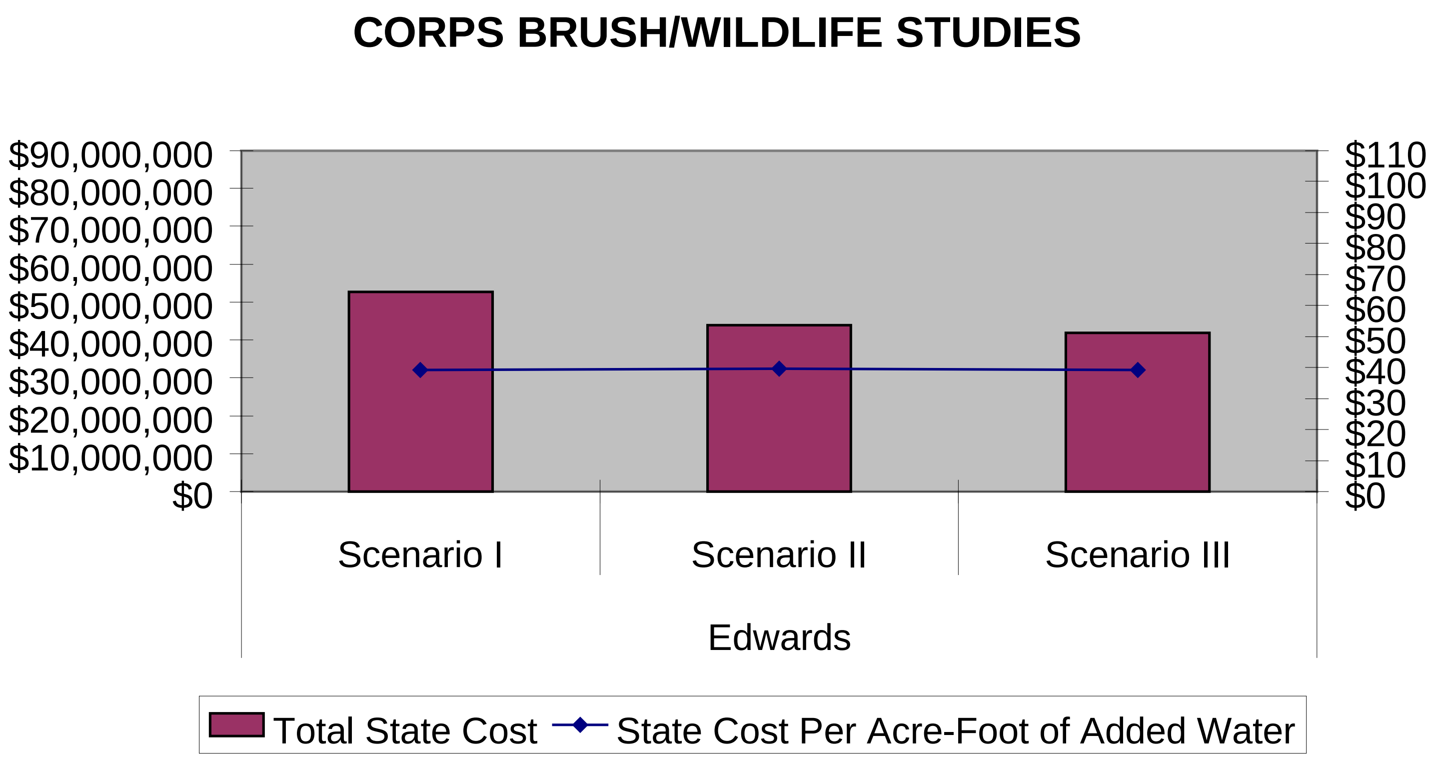


**Figure 2.3. Comparison of Society Costs by Scenario, Edwards.**

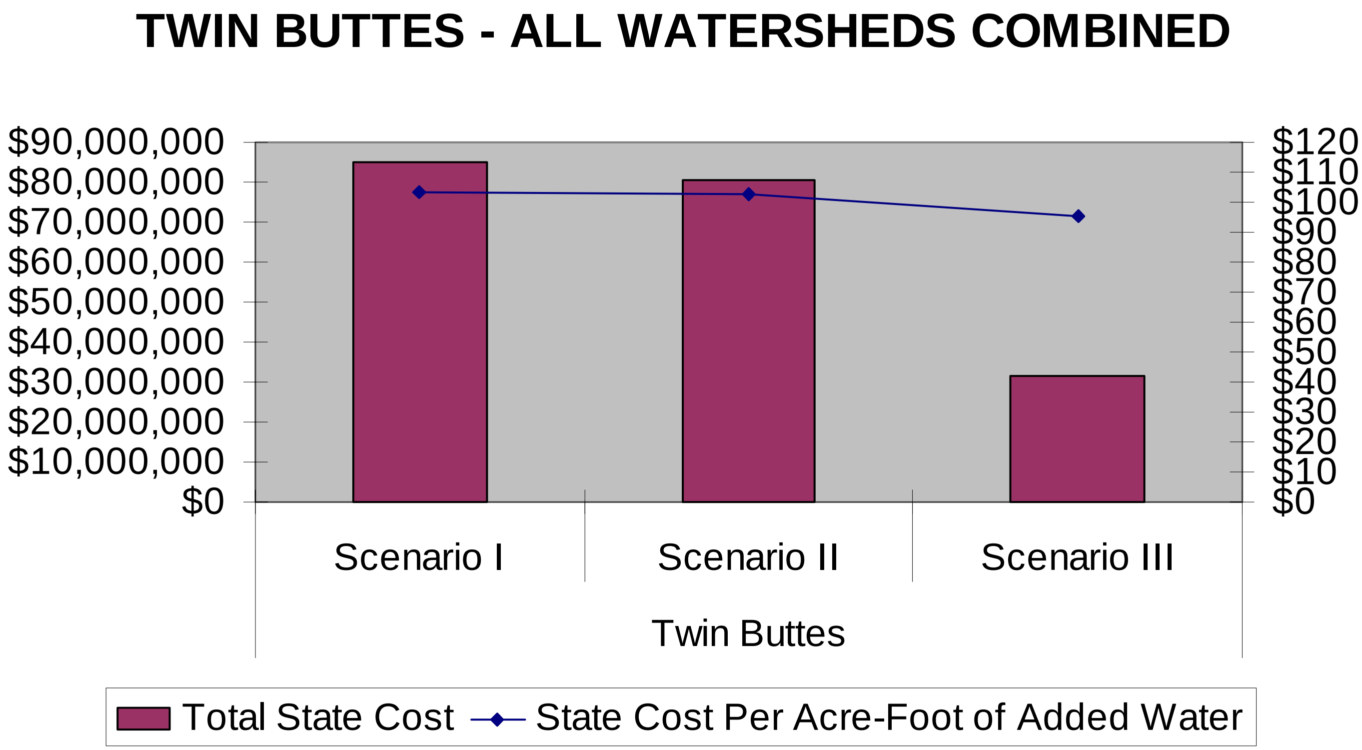


**Figure 2.4. Comparison of Society Costs by Scenario, Twin Buttes.**

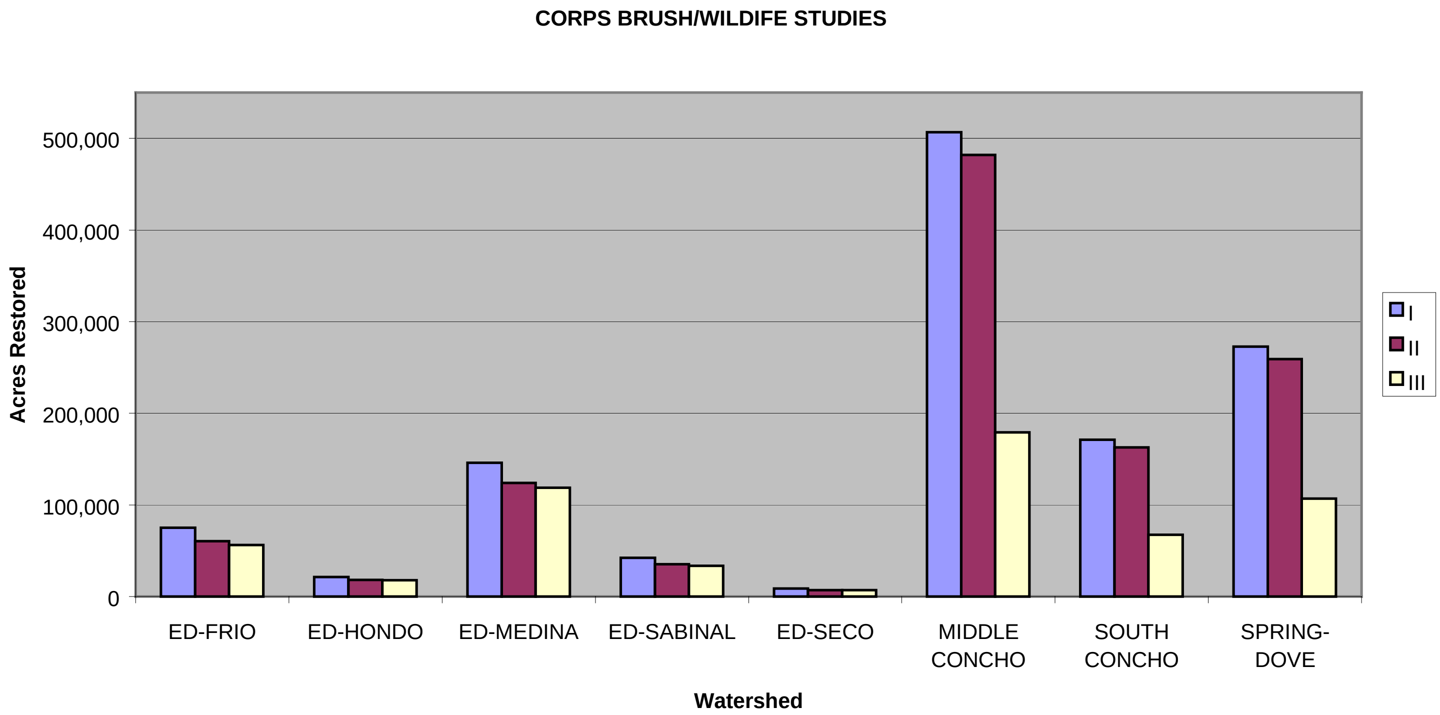


**Figure 2.5. Rangeland restoration, by watershed.**

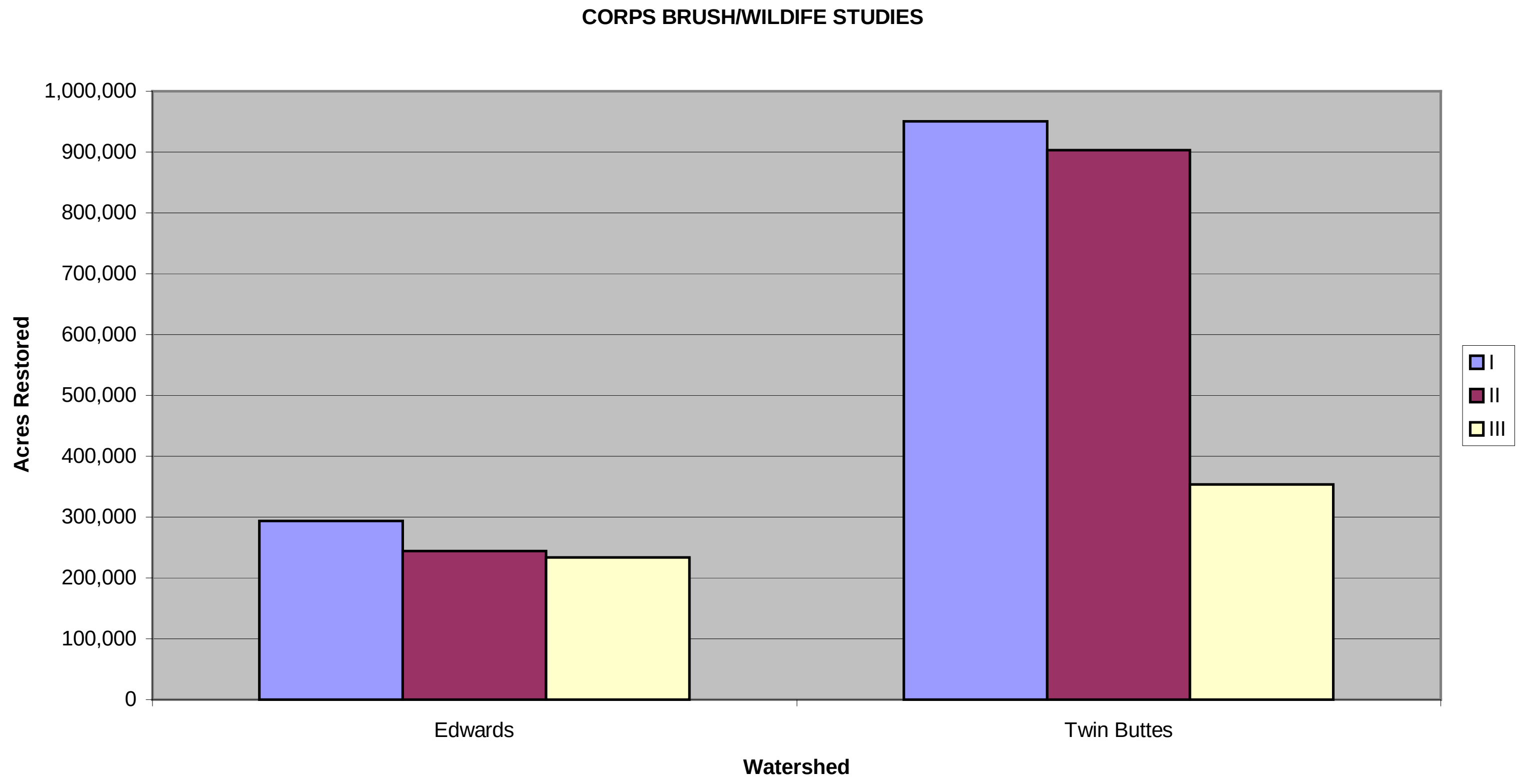


**Figure 2.6. Comparison of rangeland restoration, Edwards versus Twin Buttes.**

# Section. 3 Wildlife Response to Brush Management Scenarios

**Participants**

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**Introduction**

Within the past 150 years, rangeland vegetation has undergone a large-scale conversion from grasslands and savannas to woodlands (Scholes and Archer 1997). This shift is termed brush encroachment because the brush species that have always existed within the landscape have increased in number and cover. Continuous grazing by domestic livestock and exclusion from fire are identified as major contributors to brush encroachment (Van Auken 2000). In Texas, the loss of native grassland habitats has been substantial; e.g., Samson and Knopf (1994) report a 90 percent reduction of tallgrass prairie, a 30 percent reduction of mixed grass prairie, and a 80 percent reduction of shortgrass prairie since European settlement. For many grassland-associated species, this habitat loss is likely made worse by brush encroachment.

An unsurprising consequence of losing grassland habitat is the decline of grassland-associated wildlife. In fact, grassland bird species show more declining trends than any other avian species group in North America (Peterjohn and Sauer 1999). Texas rangelands provide breeding and wintering habitat for many species that require grasslands (obligate species) as well as those species that prefer grassland habitats (facultative species) (Vickery et al. 1999). Presumably, these species have declined on rangelands in the Edward's Plateau. However, the Edwards Plateau also provides habitat for many brush or woodland associated species. The federally endangered Golden-cheeked Warbler (*Dendroica chrysoparia*), for example, breeds in forested or brushy habitats on the Edwards Plateau (Kroll 1980).

A landscape-scale brush management program may provide a unique opportunity to restore grassland habitats on the Edwards Plateau. Although grassland species could benefit from changing brush dominated areas to grasslands, careful planning may be required to ensure that results will mimic historical landscape patterns as much as possible. Observations from the 1860's indicate that the Edwards Plateau was a mosaic of grasslands, savannas, and scrub forest (Weniger 1988). In order to meet objectives of restoring ecological function, properly designed brush management plans should account for the habitat requirements needed to maintain viable populations of brush or woodland associated species while improving habitat for grassland-associated species. However, as there is with any change in habitat, any brush management strategy implemented across the landscape will result in a shift in the wildlife community resulting in gains or losses for particular species, depending on changes in habitat.

This report summarizes the current association of bird species and bird-guilds with brush species and brush cover in the Twin Buttes and Edwards watersheds, and predicts changes in habitat occupancy under five brush management scenarios. We chose to use bird guilds as landscape indicators of ecological condition, as did O'Connell et al. (2000) for the U. S. Environmental Protection Agency's Environmental Monitoring and Assessment Program. Because of variability in species composition and abundance within communities, O'Connell et al. suggested that bird data should be grouped at an ecologically relevant higher order of organization than the species' level to use as a measure of ecological condition. A response guild, a group of species that require similar habitat, food, or other elements for survival (Verner 1984, Szaro 1986), was that appropriate level. O'Connell et al. successfully used the bird-guild approach across a region to reflect the overall structure, function, and composition of ecosystems, the three primary attributes of biodiversity according to Noss (1990). Noss also suggested monitoring at more than one level of hierarchical organization. We monitored two levels. We examined individual species' responses to vegetation patterns in addition to guild response patterns. In addition to analyzing bird occupancy patterns, we more fully described the composition of these watersheds by summarizing the diversity of wildlife found in these areas. We reviewed the scientific literature and records from these two watersheds for all wildlife species. We created a list of wildlife species likely to occur in each watershed and described the habitat association for each species.

**Methods**

*Site Selection*

Rancher participation limited the selection of survey sites. We used the existing, private roads (paved, gravel, and 2-track) to set up and access the sites. Survey sites were separated by at least 800 m in the Twin Buttes study area and at least 400m in the Edwards study area. The first site was placed near the entrance of the ranch. Each site was displaced from the road by walking a random distance (50 to 100m) and azimuth from the road. The second site was placed at a randomly assigned distance from the first site using a Global Positioning System (GPS) and was also displaced from the road. This process continued until the minimum distance requirement could no longer be met. We entered the location of each site into a GPS unit and downloaded it into Arc View. Fore these analyses, we considered each site to be an independent observation.

*Survey Protocol*

**Spring Bird Surveys**

Two observers sampled breeding birds with the fixed-radius point count method (Hutto et al. 1986) so the relative abundance between different survey areas could be compared. Two observers sampled Twin Buttes in 2001 and Edwards in 2002. A primary observer recorded the distance of each bird from plot center in five intervals (<25 m, 26-50 m, 51-75 m, 76-100 m, and >100 m) to determine which fixed-radius to use., The primary observer was the same at every survey site. The observers conducted point counts for 10 minutes (Dettmers et al. 1999) and recorded three detection time intervals (0-3 minutes, 3-5 minutes, and 5-10 minutes), so potential density biases from movement could be examined (Granholm 1983), and for comparison with different studies. Point counts were conducted between 15 minutes after sunrise until 11 am when wind conditions were less than 18 km per hour. The observers visited each site one time during the breeding season (April to June). Although detection changes throughout the breeding season, we decided on one count per year because of the benefits associated with a larger sample size (Ralph et al. 1993). We attempted to sample each habitat type throughout the breeding season so that the effects of detection differences would be minimized. The Twin Buttes study area had 295 survey sites and the Edwards study area had 201 survey sites (Figures 3.1 and 3.2).

## Winter Bird Surveys

Two observers ran a 100m transect through each survey point along one of three randomly chosen azimuths (0, 120, or 240 degrees). The observers systematically searched five meters on both sides of the centerline to detect secretive grassland species. A primary observer recorded the perpendicular distance of each bird from the centerline in six intervals (<5 m, 6-25 m, 26-50 m, 51-75 m, 76-100 m, and >100 m). The primary observer was the same at every survey site. The primary observer also recorded the search time dedicated to each transect. Surveys were conducted between 30 minutes after sunrise until 2 pm when wind conditions were less than 18 km per hour. We visited each site one time during the winter season (January to March 2002). In winter, 135 of the 295 spring sites were surveyed in the Twin Buttes study area and 147 of the 201 spring sites were surveyed in the Edwards study area (Figure 3.1 and 3.2).

*Habitat Use Models*

We defined a landscape as the 50.24 ha area encompassed by a 400-m radius around each survey site in the Twin Buttes study area (Canterbury et al. 2000) and as the 12.97 ha area encompassed by a 200-m radius around each survey site in the Edwards study area. The 295 landscapes in the Twin Buttes study area and the 201 landscapes in the Edwards study area were used to build logistic regression models to predict the probability of occupancy of bird species and guilds. Each landscape was clipped out of the brush cover type layer and the computer program, FRAGSTATS (McGarigal and Marks 1995), was used to calculate the percent of the landscape (PLAND) occupied by each brush cover type (Figure 3.3).

The PLAND of the 15 brush cover types in the Twin Buttes study area were combined into four variables representing the average percent cover of the major brush types in each landscape using the following equations:

Equation 1: Juniper Percent Cover = (PLAND hvy juniper * 0.65) + (PLAND mod juniper * 0.20) + (PLAND lgt juniper *0.05)

Equation 2: Mesquite Percent Cover = (PLAND hvy mesquite 0.65) + (PLAND mod mesquite *0.20) + (PLAND lgt mesquite * 0.05)

Equation 3: Mix Percent Cover = (PLAND hvy mix *0.65) + (PLAND mod mix *0.20) + (PLAND lgt mix *0.05)

Equation 4: Oak Percent Cover = (PLAND hvy oak *0.65) + (PLAND mod oak * 0.20)

The heavy cover types are multiplied by 0.65 because it is the mid-point between 0.3 and 1.0; the range of the heavy cover type. The moderate cover types are multiplied by 0.2, the mid-point of the moderate cover type, and the light cover types are multiplied by 0.05, the mid-point of the light cover type. These four variables are the independent variables in the logistic regressions for the Twin Buttes study area. All four variables were transformed by the natural log (y+1) to normalize the data.

In a similar manner, the PLAND of the 18 brush cover types in the Edwards study area were combined into four variables representing the average percent cover of the major brush types in each landscapes using the following equations:

Equation 5: Cedar Percent Cover = (PLAND hvy cedar * 0.65) + (PLAND hvy cedar_hvy oak * 0.325) + (PLAND hvy cedar_mod oak * 0.45) + (PLAND mod cedar_mod oak * 0.1) + (PLAND mod cedar * 0.2) + (lgt cedar * 0.05)

Equation 6: Oak Percent Cover = (PLAND hvy oak * 0.65) + (PLAND hvy cedar_hvy oak * 0.325) + (PLAND hvy cedar_mod oak * 0.2) + (PLAND mod cedar_mod oak * 0.1) + (PLAND mod oak * 0.2) + (PLAND lgt oak * 0.05)

Equation 7: Mix Percent Cover = (PLAND hvy mix * 0.65) + (PLAND mod mix * 0.2) + (PLAND lgt mix * 0.05)

Equation 8: Mesquite Percent Cover = (PLAND hvy mesquite * 0.65) + (PLAND mod mesquite * 0.2) + (PLAND lgt mix * 0.05)

The mid-point of the heavy cover types and moderate cover types are the same as the Twin Buttes equations. The brush cover type, hvy cedar_hvy oak, was multiplied by 0.325 for the cedar and oak equations because it was assumed that both vegetation types equally contributed to the average heavy multiplier of 0.65. Similarly, the 0.65 multiplier of the brush cover type, hvy cedar_mod oak, was broken into 0.45 for the cedar cover and 0.2 for the oak cover. The 0.2 multiplier of the brush cover type, mod cedar_mod oak, was broken into a 0.1 multiplier for cedar and a 0.1 for oak. These four variables are the independent variables used in the logistic regressions for the Edwards study area. Juniper, oak, and mesquite cover were transformed by taking the natural log (y+1).

The dependent variable in a logistic regression analysis is binary. In this case, the dependent variable takes on the value of 0 (bird or guild absent) and one (bird or guild present). Logistic regressions build a model similar to a linear model, except the model predicts the values of y in a range between 0 and 1 instead of negative infinity and positive infinity. The logit model is:

Equation 9: $y = \exp(Xb + e) / [1 + \exp(Xb + e)]$

Rearranging the terms and logging both sides makes:

Equation 10: $\log [y/(1-y)] = Xb + e = \beta_o + \beta_j x_{ij} + e_i$ for all $i = 1,\ldots, n$

The probability of a bird or guild being present is represented as:

Equation 11: $Prob(Y_{ij} = 1 | x_{ij}) = e^{\beta_0 + \beta_j x_{ij}} / 1 + e^{\beta_0 + \beta_j x_{ij}}$

This equation can be used to predict the presence or absence of individual species and guilds across an entire study areas for the different scenarios.

Logistic regression models were built for every bird species detected at 15 or more survey sites. Species were grouped into breeding habitat guilds for spring surveys and foraging guilds for winter surveys (Ehrlich et al. 1988). In addition, grassland-associated species were placing into a grassland obligate or a grassland facultative group (Vickery et al. 1999). Breeding birds associated with riparian areas were also grouped (Ehrlich et al. 1988).

*Scenario Analyses*

In order to relate landscape variables to particular locations, we centered a template of a given radius at each of several thousand equally spaced grid points across each watershed – this termed a “moving window.” At each grid point, the variables of interest were calculated from the surrounding landscape within the “window.” See figure 3.3 for an example of a window template. The result was a dataset with variables assigned to each grid point. A moving window analysis was used to calculate the percent of the landscape (PLAND) covered by each brush cover type for the both study areas. We used FRAGSTATS to place a “moving window” over each grid in steps equal to the column width of the land use grid. The window size was a 400-m radius circle in the Twin Buttes study area and a 200-m radius circle in the Edwards study area so as to conform to the landscape of consideration in building the logistic models. At each step (18,337 locations on the Twin Buttes, and 8,494 locations on the Edwards) the PLAND for each brush cover type was calculated for the surrounding window. As a result we built a new grid for all 15 vegetation types in Twin Buttes and all 18 brush cover types in the Edwards. In the process, every 31 x 31m pixel was assigned the average percent of the landscape calculated using every window including that pixel. Three separate moving window analysis were run for each study area to cover all the vegetation changes in the five brush scenarios. First, a moving window analysis was run over all the brush cover type pixels in the entire study area. Second, a moving window analysis was run where only areas with a 15 or greater percent slope had brush cover type pixels and the rest of the study area was blank. Third, a moving window was run where only areas with the slope over 15 percent or within the 75 m stream buffers had brush cover type pixels and the rest of the study area was blank. The moving window PLAND grids were aggregated by a factor of 20 using the mean to create new grids with 620 X 620 m pixel size. The x coordinate, y coordinate, and PLAND value for all the pixels in these grids were then exported into Microsoft Excel spreadsheets.

The 45 excel spreadsheets for the Twin Buttes were linked together in Microsoft Access by their common x and y coordinates. The 54 Excel spreadsheets for the Edwards were also linked together. The Twin Buttes study area, excluding the upper Middle Concho sub-basins, had 18,337 locations and the Edwards study area had 8,494 locations. The PLAND for each of the brush cover type variables at each location (over the entire study area, on slope over 15 percent and on slopes over 15 percent and within the stream buffers) were used to calculate the four independent variables used in the logistic regressions for each scenario.

Equations 1 to 8 were used to calculate the independent variables for the logistic regression models for every location across the study areas. The PLAND of the brush cover variables for Scenario I were adjusted by changing the treatable cover types outside of the greater than 15 percent slope areas to their post treatment cover types while not changing the treatable cover types within the 15 percent slope areas. The PLAND of the brush cover variables for Scenario II were calculated by changing the treatable cover types within the stream buffered or the greater than 15 percent slope areas to their post treatment cover types while not changing the treatable cover types within these areas. The PLAND of the brush cover variables for Scenario III were calculated the same way as Scenario II. If the moderate and heavy cover types left after changing the treatable cover types were less than 40 percent, treatable heavy and moderate cover types outside of the untreated area would be left untreated until the 40 percent requirement was met. The brush cover types taken to meet the 40 percent requirement were chosen based on the proportion available. If not enough heavy or moderate cover types were available to meet the 40 percent requirement, then all treatable brush types were left untreated. The PLAND of the brush variables for Scenario IV were calculated by leaving all the brush cover types untreated. The PLAND of the brush cover type variables for Scenario V were calculated by changing every moderate brush cover type to heavy and every light brush cover type to moderate.

The independent variables calculated for each scenario were used in Equation 11 for each bird or guild model. The probability a bird species or guild would be present at each location across the study area was calculated for each scenario.

*Species Composition*

To create the list of bird species likely to occur in each watershed, we used bird field checklists from three state parks (Garner, Lost Maples, San Angelo), one region (Concho Valley region), one chamber of commerce (Uvalde: Nature quest), and one camp (H. E. Butt foundation). To create the amphibian, reptile, and mammal lists, we used distribution maps in Dixon (2000) and Davis and Schmidly (1994). We used field guides to describe the habitat associations of each species.

**Results and Discussion**

*Brush Cover*

**Twin Buttes**

The total brush cover on the Twin Buttes was estimated at 23.7 percent, most of which was mesquite and juniper (Table 3.1). Concentrations of juniper were aggregated in the more central portions of the study area, whereas concentrations of mesquite were more widely distributed (Figure 3.4). Scenario I was projected to reduce total brush cover by 73 percent. The exclusion of riparian areas from brush removal in Scenario II resulted in a modest effect on overall brush cover. However, the 40 percent retention constraints of Scenario III resulted in only a 32.1 percent reduction of total brush cover (Table 3.1). If in fact, the changes projected under future Scenario V were to occur (i.e., continued brush encroachment), then we projected total brush cover to almost double, much of the increase coming from expansion of juniper.

**Edwards**

The total brush cover on the Twin Buttes was estimated at 48.7 percent, most of which was juniper and oak, as well as mixed brush which is primarily a juniper/oak mix. (Table 3.2). With the exception of scattered aggregations of more open country in major drainage bottoms, the concentrations of juniper, oak and mixed brush were well distributed across the area (Figure 3.5). Because the present condition includes heavy concentrations of juniper on slopes >15 percent (where mechanical brush management is not feasible), the differences among Scenarios I, II, and III were only slight; resulting a in a 24.4 to 22.4 percent decrease in total brush cover. Continued brush encroachment under Scenario V was projected to result in a 32.6 percent increase in total brush cover with 64.6 percent of the total landscape dominated by one or more species of brush (Table 3.2).

**Table 3.1. Changes in the average brush percent cover by scenario over the Twin Buttes study area.**

| Brush Type | Scenario I | II | III | IV | V |
|---|---|---|---|---|---|
| | -----------------------% Cover----------------------- | | | | |
| Juniper | 1.9 | 2.3 | 5.9 | 9 | 21.3 |
| Mesquite | 2.1 | 3.1 | 7.5 | 11.8 | 19.1 |
| Mixed | 0.8 | 0.9 | 1.1 | 1.3 | 3 |
| Oak | 1.6 | 1.6 | 1.6 | 1.6 | 1.8 |
| Total | **6.4** | **7.9** | **16.1** | **23.7** | **45.2** |
| %Change[a] | **-73.0** | **-66.7** | **-32.1** | **0.0** | **90.7** |

[a] %Change represents the percent increase / decrease in total estimated brush cover when compared to Scenario IV (the present condition).

**Table 3.2. Changes in the average brush percent cover by scenario over the Edwards study area.**

| Brush Type | Scenario I | II | III | IV | V |
|---|---|---|---|---|---|
| | -----------------------% Cover----------------------- | | | | |
| Juniper | 7.3 | 7.9 | 7.9 | 14 | 16.1 |
| Mesquite | 1.5 | 1.7 | 1.7 | 2.6 | 4.7 |
| Mixed | 13.6 | 14.1 | 14.1 | 20 | 26.5 |
| Oak | 14.4 | 14.1 | 14.1 | 12.1 | 17.3 |
| Total | 36.8 | 37.8 | 37.8 | 48.7 | 64.6 |
| %Change | -24.4 | -22.4 | -22.4 | 0.0 | 32.6 |

[a] %Change represents the percent increase / decrease in total estimated brush cover when compared to Scenario IV (the present condition).

*Survey Summaries*[1]

**Twin Buttes**

During the spring surveys we detected 3,874 individuals of 76 species within the 100-m sampling radius of 295 sample locations (Appendix B1). On average, we detected 8.8 species at each location (SE = 0.2, SD = 2.7). The maximum number of species detected at a sample site was 19. The most common species recorded was the Northern Mockingbird; and greater than 63 percent of total individuals detected were represented by only 12 species.

During the winter surveys, we detected 2,702 individuals of 69 species within a 100m area along each transect at 135 sample locations (Appendix B2). On average, 4.7 species were detected at each location (SE = 0.3, SD = 3.0).The maximum number of species detected at a sample site was 16. The most common species recorded was the Western Meadowlark; yet the white-crowned sparrow was detected at the most sites. Greater than 56 percent of total individuals detected were represented by seven species.

**Edwards.**

During the spring surveys, we detected 2,941 individuals of 79 species within the 100-m sampling radius of 201 sample locations (Appendix C1). On average, we detected 9.8 species at each location (SE = 0.2, SD = 3.0). The maximum number of species detected at a sample site was 19. The most common species was the Tufted Titmouse; and greater than 43 percent of total individuals were represented by eight species.

During the winter surveys, we detected 2,177 individuals of 56 species within a 100m area along each transect at 147 sample locations (Appendix C2). On average, 5.6 species were detected at each location (SE = 0.2, SD = 2.6). The maximum number of species detected at a sample site was 13. The most common species recorded was the Chipping Sparrow; yet northern cardinals were detected at the most sites. Greater than 57 percent of total individuals were represented by five species.

*Model Results.*

The focus was on the breeding birds detected in the spring surveys when building the logistic regression models. Breeding birds are likely to have stronger habitat ties than wintering birds because they are confined to a breeding territory while nesting. Breeding and wintering bird guilds are listed in Appendices D1-4.

**Twin Buttes**

Logistic regression models were built for the seven guilds, the grassland obligate group, the grassland facultative group, and the riparian group (Appendix B3). The sample size (N) and McFadden's rho-squared (Rho$^2$) were used to evaluate the models. Rho-squared is similar to an R-squared and always falls between 0 and 1. As the rho-squared value increases, the fit of the model increases. A rho-squared value between 0.2 and 0.4 is considered very satisfactory

[1] For reporting efficiency, the larger volumes of summary data for bird surveys are presented in Appendices B (Twin Buttes) and C (Edwards).

(Hensher and Johnson 1981). A cut-off of 0.1 was used to decide which models are sufficient to model across the scenarios.

The grassland obligate group and brush guild have the strongest models. The grassland obligates are negatively associated with all brush types (Table 3.3). Juniper and oak are the most significant variables in the model. The brush guild is positively associated with all brush types, and juniper and oak are the most significant variables in the model (Table 3.3). The deciduous group had an insufficient sample size and the grassland facultative group and grassland guild are present at nearly every site. Although these models did not have a sufficient rho-squared, it is notable that woodland guild had a significant positive association with oak cover and the scrub guild had a significant positive association with juniper cover. The riparian guild also had a significant positive association with oak cover, the brush cover type that represents the mixed deciduous forests associated with streams with year round water.

**Table 3.3. Logistic regression model relationships for breeding birds on the Twin Buttes study area. Sign (+/-) represents the direction of response (i.e., change in habitat occupancy) predicted from an increase in that brush type. Specific model terms are presented in Appendix IE.**

| Species / Group | Juniper | Mesquite | Mixed | Oak |
|---|---|---|---|---|
| Grassland Obligates | **-***[a]** | - | - | **-*** ** |
| Brush Guild | **+*** ** | + | + | **+*** ** |
| Black-chinned Hummingbird | + | - | + | **+*** ** |
| Tufted Titmouse | + | **-* ** | **+*** ** | **+*** ** |
| Western Scrub Jay | **+*** ** | + | + | - |
| Yellow-billed Cuckoo | - | - | - | **+*** ** |
| Cassin's Sparrow | **-** ** | + | - | **-*** ** |
| Lark Sparrow | **-** ** | - | - | **-*** ** |
| Western Meadowlark | **-*** ** | + | - | - |

[a] statistical significance, *** = p<0.01, ** = p<0.05, * = p<0.1.

Logistic regression models were built for the 36 species that were present at 15 or more survey sites (Appendix B4). Seven species have sufficient models. The three grassland-associated species, Cassin's Sparrow, Lark Sparrow, and Western Meadowlark, have significant negative associations with juniper cover (Table 3.3). Cassin's Sparrow and Lark Sparrow also have a significant negative association with oak cover (Table 3.3). Mesquite cover did not seem to affect the presence or absence of these grassland-associated species. This could be due to mesquite's association with deeper soils types that produce more grass cover. Black-chinned Hummingbird, Tufted Titmouse, and Yellow-billed Cuckoo have significant positive associations with oak cover. Tufted Titmouse and Yellow-billed Cuckoo glean insects off of deciduous tree leaves and nest in deciduous trees. Oak probably provides the best surface area for this type of foraging technique and may offer superior nest sites. Western Scrub Jay has a significant positive association with juniper cover. This relationship may be attributed to this species affinity towards nesting in stands of dense brush.

**Edwards**

Logistic regression models were built for the seven guilds, the grassland obligate group, the grassland facultative group, and the riparian group (Appendix C3). The grassland guild had the strongest model. The grassland guild had a significant negative relationship with all four brush cover types (Table 3.4). The grassland facultative group was present at nearly every site and the grassland obligate group did not have a large enough sample size to build sufficient models. The other guilds' models did not meet the minimum rho-squared requirement. However, it is notable that the savanna guild had significant negative association with cedar and significant positive relationships with both oak cover and mesquite cover, the two brush species associated with grassland savannas. The deciduous guild had a significant positive association with oak cover and mix cover. Many deciduous guild species forage on the leaves and bark of the trees represented in the oak and mix brush cover types.

**Table 3.4. Logistic regression model relationships for Edwards breeding birds. Sign (+/-) represents the direction of response (i.e., change in habitat occupancy) predicted from an increase in that brush type. Specific model terms are presented in Appendix IIE.**

| Species / Group | Juniper | Mesquite | Mixed | Oak |
|---|---|---|---|---|
| Grassland Guild | - *** | - * | - *** | - * |
| Golden-cheeked Warbler | + *** | - | + *** | + *** |
| Northern Mockingbird | -** | - | -*** | + |
| Scissortail Flycatcher | - | - | - *** | - |
| Vermillion Flycatcher | - * | - | - ** | - ** |
| Lark Sparrow | - ** | - | - *** | - |
| Black-and-white Warbler | + *** | - | + ** | + *** |
| Northern Bobwhite | - *** | - | + | - |
| Red-eyed Vireo | +** | +* | +* | +** |
| Canyon Wren | + | - | +* | +** |

| | | | | |
|---|---|---|---|---|
| Western Scrub Jay | **+*** ** | **-** | + | **-** |
| White-eyed Vireo | **+ *** | + | **+ ***** | + |
| Blue-gray Gnatcatcher | + | + | **+**** | **+***** |
| Lesser Goldfinch | **- **** | + | **-** | **+ *** |

[a] statistical significance, *** = $p<0.01$, ** = $p<0.05$, * = $p<0.1$.

Logistic regression models were built for the 35 species that were present at 15 or more survey sites (Appendix C4). Thirteen species had sufficient models (Table 3.4). The endangered Golden-cheeked Warbler, the Black-and-white Warbler, and the Red-eyed Vireo had significant positive relationships with juniper cover, oak cover, and mix cover. Golden-cheeked Warblers forage on deciduous trees and use the bark of mature juniper to build their nests. The grassland-associated Lark Sparrow and Scissor-tailed Flycatcher have significant negative relationships with mix cover, but the grassland-associated Northern Bobwhite has no significant relationship to mix cover. However, Lark Sparrow and Northern Bobwhite have significant negative relationships to juniper cover. These grassland-associated species have no significant relationships to oak cover and were often present in oak savanna habitat. The Vermillion flycatcher has significant negative relationships with juniper cover, oak cover, and mix cover. Good summer habitat is widely spaced junipers and oaks (Oberholser 1974). The Lesser Goldfinch has a significant negative association with juniper cover and a significant positive relationship with oak cover, which they use for foraging. Lesser Goldfinches use lightly wooded areas in Texas (Oberholser 1974). As in Twin Buttes, the Western Scrub Jay has a significant positive relationship with juniper cover. Scrub Jays feed on cedar berries and nest in dense shrubs. Oberholser (1974:589) noted that "Texas Scrub Jays seem almost as tied to juniper on rough ground as is the Golden-cheeked Warbler". The Northern Mockingbird, often associated with edges (Oberholser 1974), has a significant negative relationship with juniper cover and mix cover. Associated with tangled thickets and thick undergrowth (Oberholser 1974), the White-eyed Vireo has a significant positive relationship with juniper cover and mix cover. Canyon Wren and Blue-gray Gnatcatcher have significant positive relationships with oak cover and mix cover. Blue-gray Gnatcatchers forage on deciduous leaves and are known to favor oaks in the breeding season (Oberholser 1974). Canyon Wrens are present only in areas with predominant limestone outcrops or cliffs on which they nest.

*Scenarios*

**Twin Buttes**

The logistic regression models for the two guilds and seven species that were sufficient were applied across the study area for each scenario using the intercept and slope estimates (Appendix B5). The average probability of the guild or species being an index of habitat quality under each scenario (Table 3.5). The scenarios represent a gradient in the amount brush cover with Scenario I having the least juniper, mesquite, and mix cover and Scenario V having the most juniper, mesquite, and mix cover (Table 3.1). Oak stays the same in Scenario I, II, III, and IV because it is not a treatable brush cover type, but slightly increases in Scenario V as the moderate oak cover type changed to a heavy oak cover type.

As the brush cover increased, the probability of occurrence for grassland obligates decreased from 0.824 in Scenario I to 0.594 in Scenario V. The brush guild had the opposite trend with probability of occurrence increasing from 0.546 in Scenario I to 0.924 in Scenario V.

The grassland-associated Cassin's Sparrow, Lark Sparrow, and Western Meadowlark all followed the same trend as the grassland obligate group and had a decreasing probability of occurrence from Scenario I to Scenario V. The probability of occurrence of the Western Scrub Jay increased from 0.003 in Scenario I to 0.254 in Scenario V as the juniper cover increased. The probability of occurrence of species that had significant relationships with oak cover was driven by the other variables. These relationships are complex because the magnitude of any variable's influence is dependent on the size of the slope estimate for that variable. For example, the Yellow-billed Cuckoo's insignificant negative associations with juniper, mesquite, and mix cover caused the probability of occurrence to increase from 0.068 in Scenario IV to 0.117 in Scenario I. These negative associations offset the positive association of increasing the oak cover in Scenario V, so the probability of occurrence dropped to 0.049. The probability of occurrence of the Tufted Titmouse is another example, but here lowering the cover of juniper, mix, and mesquite had the same effect as increasing all the brush cover types. The increase in oak cover makes the probability of occurrence in Scenario V almost equal to the probability of occurrence in Scenario I.

**Edwards**

The logistic regression models for the grassland guild and the 13 species were applied across the study area for every scenario using each model's intercept and slope estimates (Appendix C5). The average probability of the guild or species being present across the study area changed for each scenario (Table 3.5). The scenarios in the Edwards also represent a gradient in the amount of brush cover (Table 3.2). Cedar, mix, and mesquite cover increased along the gradient with the lowest covers in Scenario I and the highest covers in Scenario V. Oak cover increases from the value in Scenario IV with the treatments in scenarios I, II and III because many of the treatable brush cover types are changed to an oak cover type after treatment. Oak also increases in Scenario V as the moderate oak cover type changes to a heavy oak cover type and the light oak cover type changes to a moderate oak cover type.

The probability of occurrence of the grassland guild decreased from 0.319 in Scenario I to 0.028 in Scenario V. The probability of occurrence of the Golden-cheeked warbler, Black-and-white Warbler, Red-eyed Vireo, Western Scrub Jay, and White-eyed Vireo all increased from Scenario I to Scenario V. The probability of occurrence of the Northern Mockingbird, Scissortailed Flycatcher, Vermillion Flycatcher, Lark Sparrow, Northern Bobwhite, and Lesser Goldfinch all decreased from Scenario I to Scenario V. The probability of occurrence of the Canyon Wren and Blue-gray Gnatcatcher stayed the same for Scenario I through 4, but increase in Scenario V. These models do not work equally well for all species. Some species (e.g., Golden-cheeked Warbler) have unique needs that are not represented in these analyses. Golden-cheeked Warblers nest in mature, closed-canopy juniper on slopes. Our model suggests that the amount of warbler habitat would decrease precipitously in Scenarios I-III (Tables 3.5 and 3.6). That is not likely. Because most of the warblers nest on slopes, and none of the treatments would occur on slopes, warbler habitat should remain the same after treatments. Similarly, if no treatments occur (Scenario V), warbler habitat is not likely to increase because juniper-oak communities already occupy most slope habitat and any increase in brush cover is not necessarily the mature brush cover preferred by Golden-cheeked Warblers.

*Implications*

The two grassland guilds appear to be among the most responsive of the bird groups we modeled. Likewise, they are probably the best indicator groups for the gauging the restoration of grassland ecosystems. While each of the component species are likely to respond to habitat changes not accounted for here, they do appear to genuinely respond to changes in landscape level brush concentrations.

As applied to the Twin Buttes, the difference in level of response of grassland obligates to the various scenarios was modest when viewing the landscape in its entirety (Tables 3.5 and 3.6). However, when spatial variability is considered, the relative importance of landscape changes due to scenario treatments reveals a set of patterns that may guide management (Figure 3.6). For example, when comparing the present condition to Scenario III, several local areas of high priority for treatment are revealed (Figure 3.7). Likewise, areas where concentrated brush treatments are not likely to result in measurable habitat improvements at the landscape scale can be identified.

For the grassland guild on the Edwards study area, the differences between scenarios I-III are slight. However, the predicted improvement for a grassland guild resulting from any of the scenarios is substantial. When comparing the present condition to Scenario III, the mean likelihood of occurrence increases by 79 percent (Table 3.5), and the percent of the study area with a likelihood of >0.5 would more than double (Table 3.6, Figure 3.8). Because much of the Edwards area has slopes >15 percent, much of the brush is not treatable under our scenarios. However, treating those areas that are accessible should result in a substantial percentage increase in grassland restoration (Figure 3.9).

*Species Composition.*

A listing of the breeding bird guilds from the winter and summer surveys in Twin Buttes is presented in Appendix D1 and D2, and for the Edwards in Appendix D3 and D4. There were 254 bird species recorded in Edwards and 329 in Twin Buttes watersheds (Appendix E1). Distribution maps indicate that 95 amphibian and reptile species occur in Edwards and 93 in Twin Buttes (Appendix E2) and that 62 mammal species occur in Edwards and 62 in Twin Buttes watersheds (Appendix E3).

Therefore, we sampled a good proportion of the total bird fauna (37 percent). Excluding nocturnal raptors, waterbirds, and shorebirds, we sampled approximately 53 percent of the terrestrial bird species, those birds most expected to be affected by brush management. By examining the guild and species levels, we discovered how brush management is likely to affect wildlife species within the Edwards and Twin Buttes watersheds.

**Table 3.5. Average probability of occurrence of guilds and species across the study areas by scenario. Estimated probability of occurrence at any one site ranges from 0 to 1. Numerical values represent an average score from the accumulation of all "moving windows" sites across each study area.**

| Study Area | Species/Group | Scenario I | Scenario II | Scenario III | Scenario IV | Scenario V |
|---|---|---|---|---|---|---|
| Twin Buttes | Grassland Obligates | 0.824 | 0.812 | 0.74 | 0.699 | 0.594 |
| | Brush Guild | 0.546 | 0.584 | 0.763 | 0.809 | 0.924 |
| | Black-chinned Hummingbird | 0.064 | 0.054 | 0.035 | 0.026 | 0.02 |
| | Tufted Titmouse | 0.263 | 0.251 | 0.212 | 0.199 | 0.254 |
| | Western Scrub Jay | 0.003 | 0.005 | 0.032 | 0.092 | 0.254 |
| | Yellow-billed Cuckoo | 0.117 | 0.108 | 0.081 | 0.068 | 0.049 |
| | Cassin's Sparrow | 0.76 | 0.754 | 0.712 | 0.691 | 0.625 |
| | Lark Sparrow | 0.866 | 0.848 | 0.759 | 0.702 | 0.533 |
| | Western Meadowlark | 0.116 | 0.103 | 0.043 | 0.033 | 0.009 |
| Edwards | Grassland Guild | 0.319 | 0.293 | 0.292 | 0.163 | 0.028 |
| | Golden-cheecked Warbler | 0.225 | 0.239 | 0.239 | 0.414 | 0.698 |
| | Northern Mockingbird | 0.263 | 0.243 | 0.243 | 0.119 | 0.031 |
| | Scissor-tailed Flycatcher | 0.096 | 0.087 | 0.087 | 0.044 | 0.005 |
| | Vermillion Flycatcher | 0.104 | 0.098 | 0.098 | 0.066 | 0.009 |
| | Lark Sparrow | 0.259 | 0.242 | 0.242 | 0.145 | 0.031 |
| | Black-and-white Warbler | 0.2 | 0.204 | 0.204 | 0.273 | 0.474 |
| | Northern Bobwhite | 0.062 | 0.054 | 0.053 | 0.027 | 0.008 |
| | Red-eyed Vireo | 0.09 | 0.097 | 0.097 | 0.176 | 0.446 |
| | Canyon Wren | 0.089 | 0.087 | 0.087 | 0.088 | 0.185 |
| | Western Scrub Jay | 0.16 | 0.17 | 0.17 | 0.28 | 0.29 |
| | White-eyed Vireo | 0.236 | 0.246 | 0.246 | 0.359 | 0.545 |
| | Blue-grey Gnatcatcher | 0.275 | 0.273 | 0.273 | 0.273 | 0.523 |

**Mean Probability of Occurrence**

| | | | | | |
|---|---|---|---|---|---|
| 0.0-0.10 | 0.10-0.25 | 0.25-0.50 | 0.50-0.75 | 0.75-0.90 | 0.9-1.0 |

**Table 3.6. Percent of study area estimated to have a greater than 0.5 probability of occurrence under the various brush management scenarios, for guilds and species across the Twin Buttes and Edwards study areas.**

| Study Area | Species/Group | Scenario I | Scenario II | Scenario III | Scenario IV | Scenario V |
|---|---|---|---|---|---|---|
| Twin Buttes | Grassland Obligates | 96.8 | 95.7 | 90.7 | 85 | 67.8 |
| | Brush Guild | 63.2 | 69.7 | 92 | 92.8 | 99.3 |
| | Black-chinned Hummingbird | 2.1 | 1.5 | 0.8 | 0.5 | 0.3 |
| | Tufted Titmouse | 10.6 | 9.5 | 7 | 6.2 | 11.2 |
| | Western Scrub Jay | 0 | 0 | 0 | 1.3 | 38.5 |
| | Yellow-billed Cuckoo | 2.9 | 2.2 | 1.4 | 0.9 | 0.5 |
| | Cassin's Sparrow | 92.1 | 91.5 | 88.2 | 85.3 | 75 |
| | Lark Sparrow | 99.7 | 98.9 | 95.3 | 87.2 | 60.3 |
| | Western Meadowlark | 0 | 0 | 0.005 | 0.005 | 0 |
| Edwards | Grassland Guild | 21.7 | 18.4 | 18.4 | 8.1 | 0 |
| | Golden-cheecked Warbler | 10.1 | 12 | 12 | 45.8 | 83.9 |
| | Northern Mockingbird | 9.1 | 7.3 | 7.2 | 1.7 | 0 |
| | Scissor-tailed Flycatcher | 0.06 | 0.05 | 0 | 0 | 0 |
| | Vermillion Flycatcher | 1.5 | 1.2 | 1 | 0.3 | 0 |
| | Lark Sparrow | 6.1 | 11.4 | 11.4 | 4.7 | 0 |
| | Black-and-white Warbler | 2 | 4.5 | 4.5 | 10.2 | 50.7 |
| | Northern Bobwhite | 0.08 | 0.08 | 0.06 | 0 | 0 |
| | Red-eyed Vireo | 0.01 | 0.01 | 0.01 | 0.1 | 37.6 |
| | Canyon Wren | 0.1 | 0.09 | 0.09 | 0 | 2 |
| | Western Scrub Jay | 0 | 0 | 0 | 1 | 0.3 |
| | White-eyed Vireo | 0 | 0.04 | 0.04 | 20 | 72.5 |
| | Blue-grey Gnatcatcher | 9.5 | 9 | 9 | 3.3 | 56.3 |

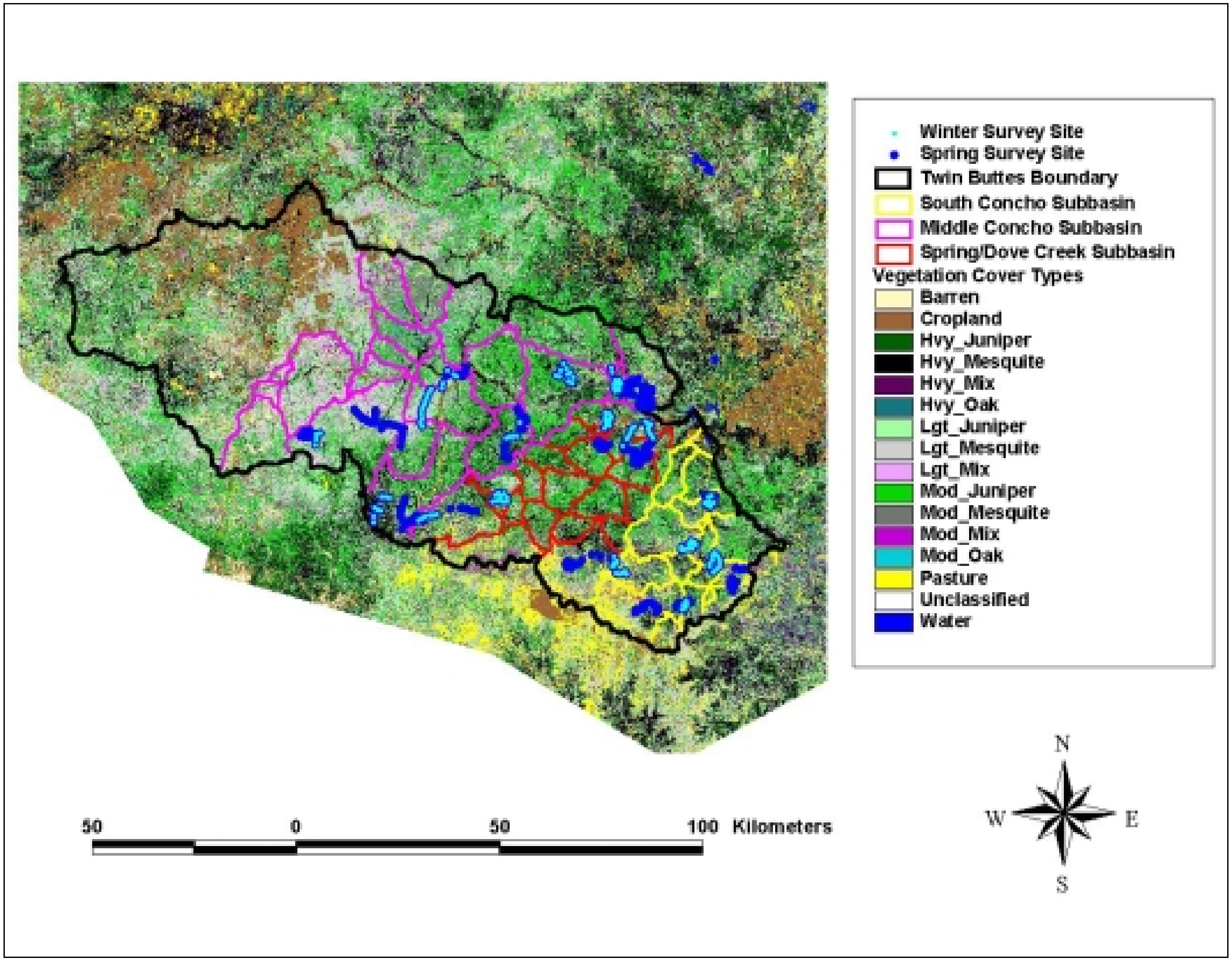


**Figure 3.1 Twin Buttes study area survey sites. Winter survey sites were sampled in winter 2002 and spring 2001. Spring survey sites were sampled in spring 2001.**

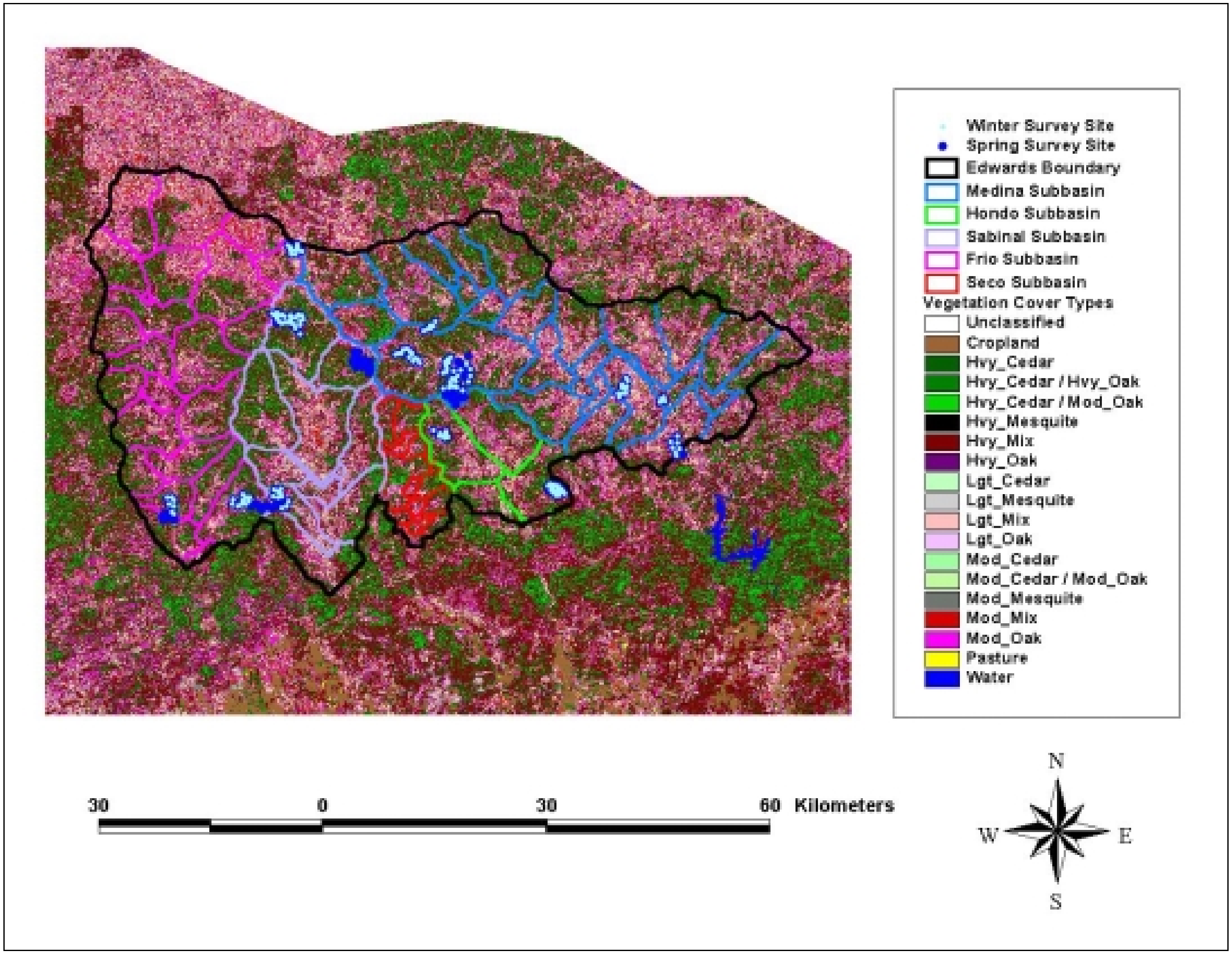


**Figure 3.2. Twin Buttes study area survey sites. Winter survey sites were sampled in winter 2002 and spring 2001. Spring survey sites were sampled in spring 2001.**

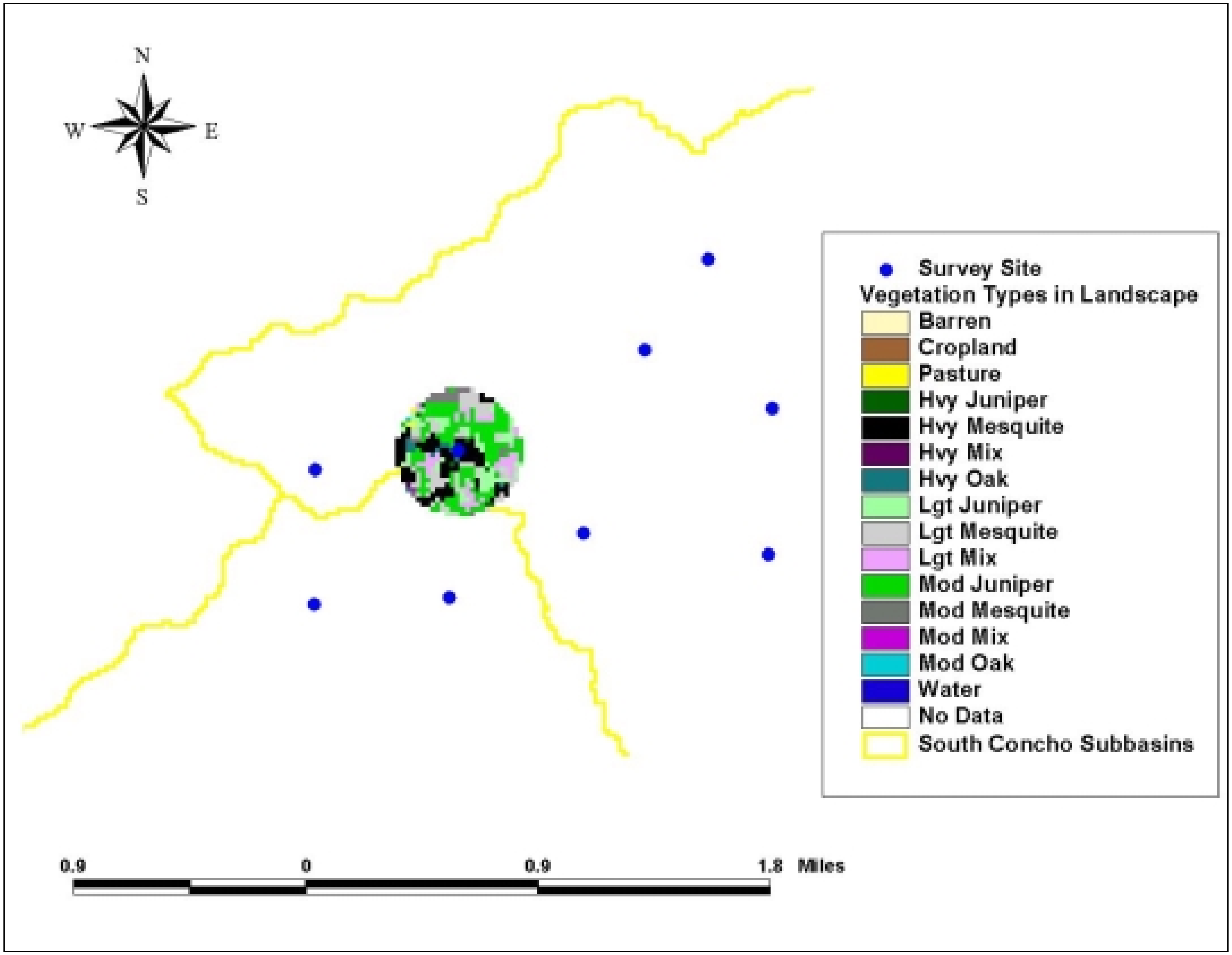


**Figure 3.3. Example of a 400-m-radius landscape in the Twin Buttes study area.**

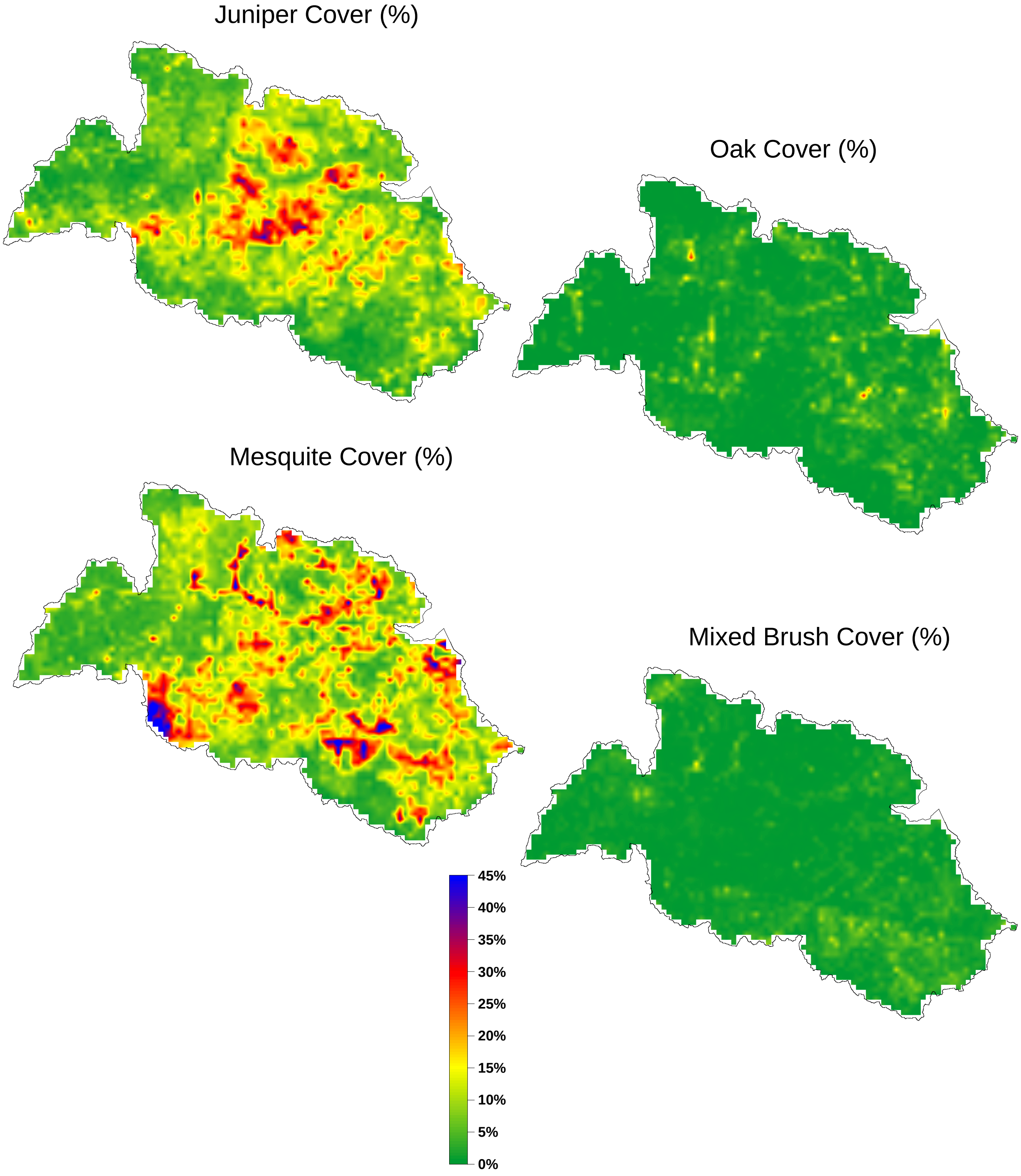


**Figure 3.4. Present condition (Scenario IV) of brush cover variables across the Twin Buttes study area. Brush cover concentrations are represented at a 620m x 620m resolution.**

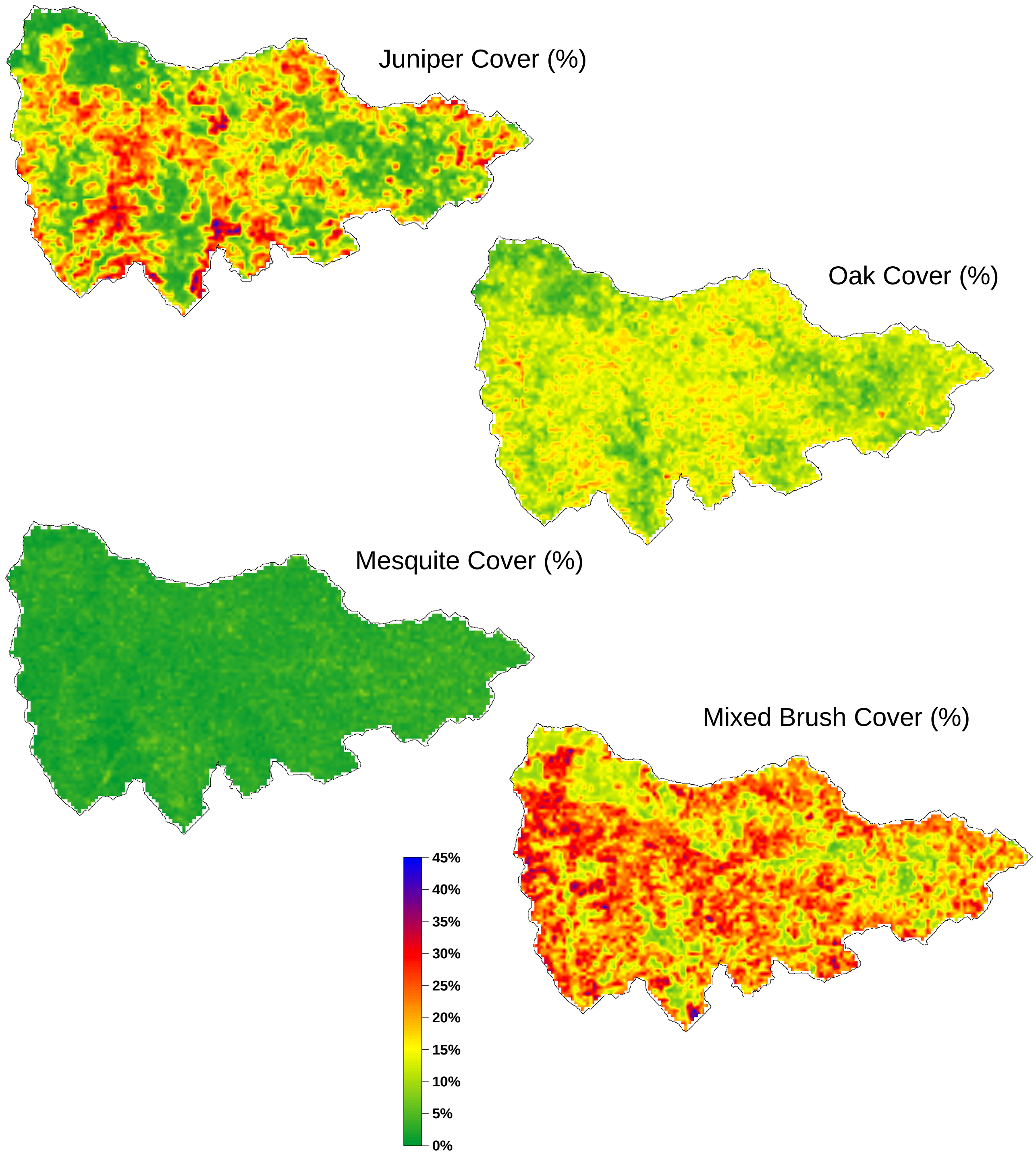


**Figure 3.5. Present condition (Scenario IV) of brush cover variables across the Edwards study area. Brush cover concentrations are represented at a 620m x 620m resolution.**

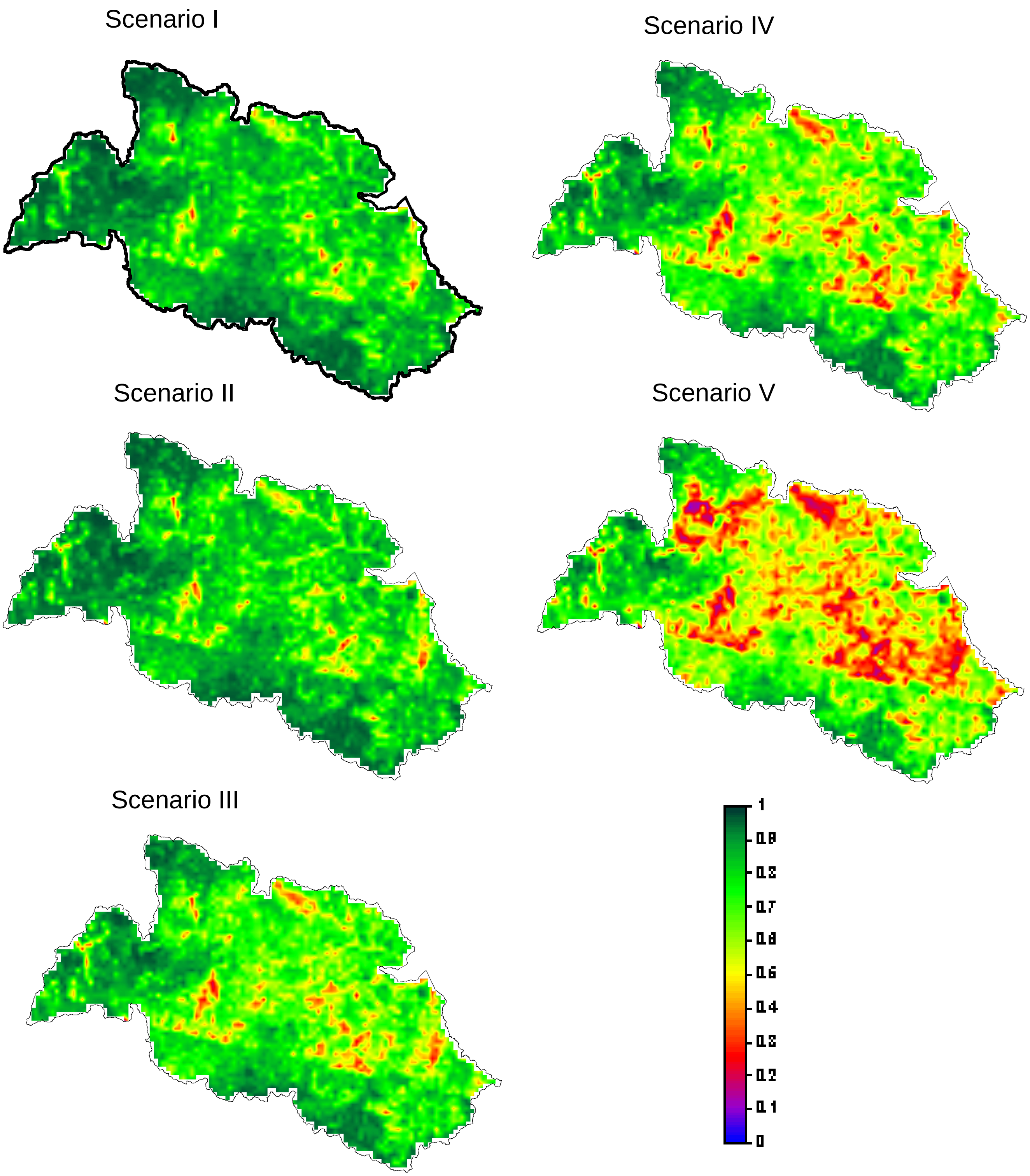


**Figure 3.6. Predicted probability of occupancy by obligate grassland birds during the breeding season for each of five brush management scenarios, Twin Buttes Study Area. Color scale represents probabilities of occurrence estimated by logistic regression model (see text).**

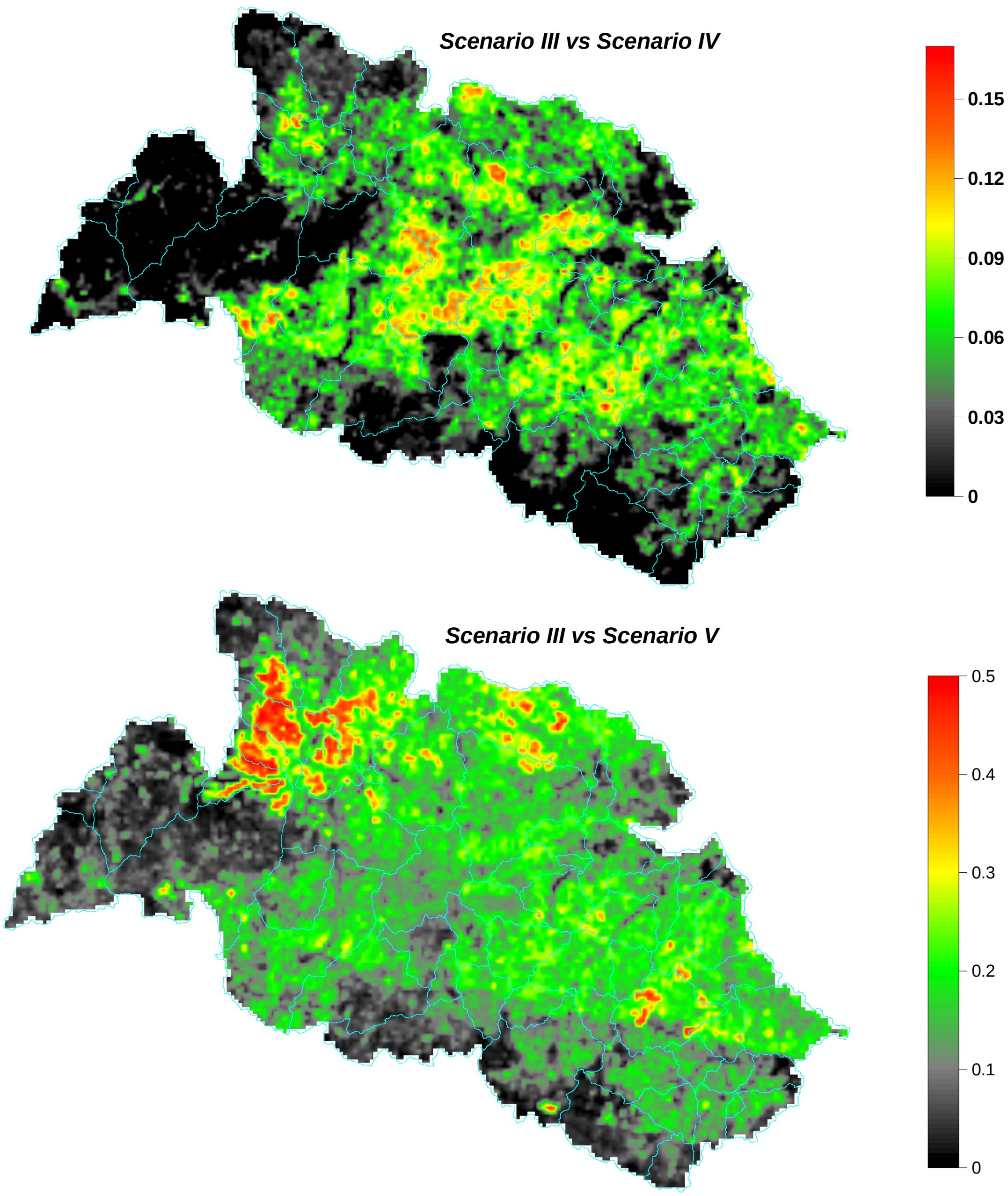


**Figure 3.7. Comparisons of the impact of Scenario III *versus* Scenarios IV and IV on habitat occupancy scores for grassland breeding birds across the Twin Buttes study area. Numerical values represent the estimated increase in the likelihood of occurrence of grassland breeding birds resulting from the localized habitat changes of Scenario III when compared to the present condition (Scenario IV) and a projected future scenario of "no action" (Scenario V).**

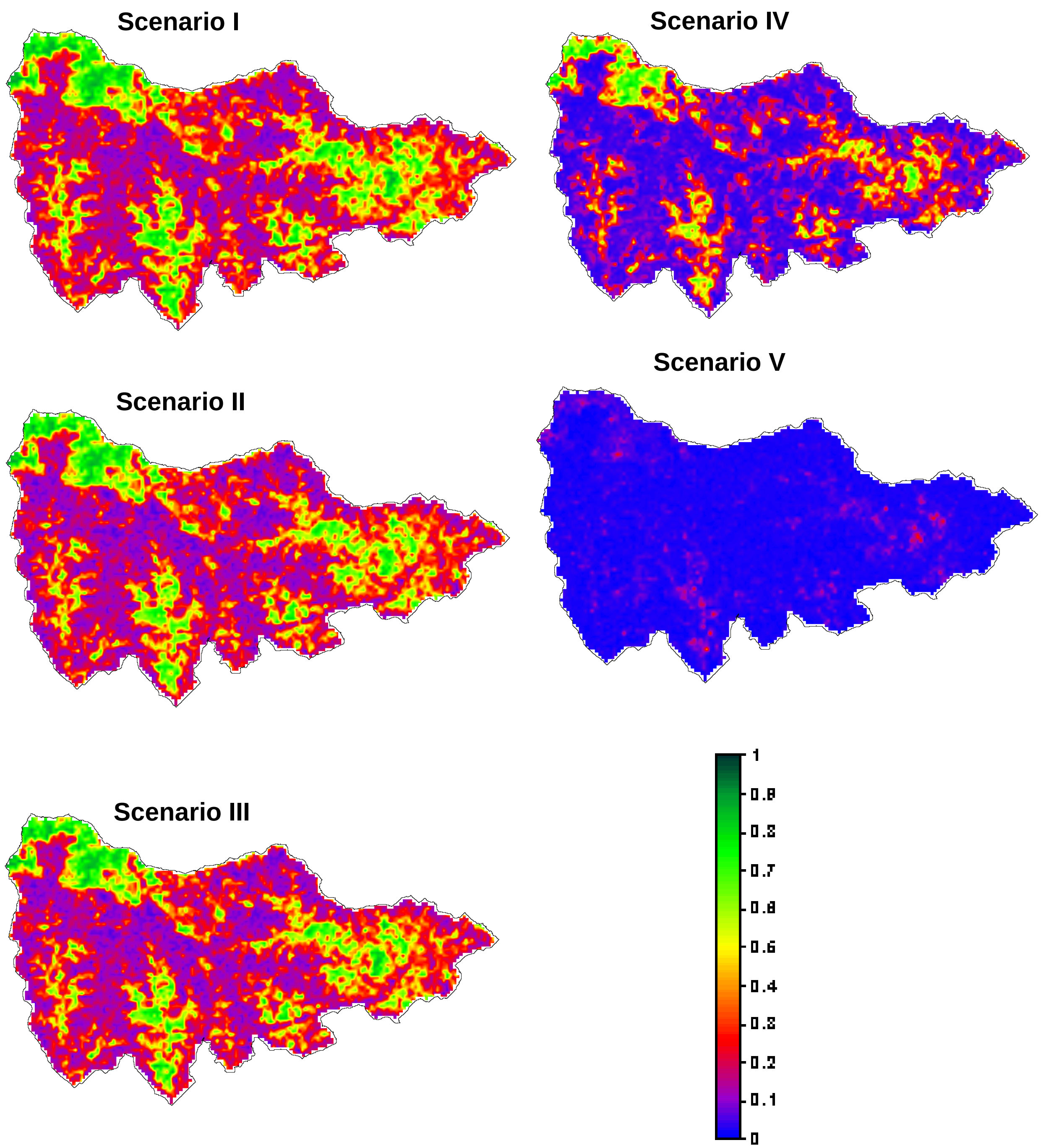


**Figure 3.8. Predicted probability of occupancy by a grassland guild of birds during the breeding season for each of five brush management scenarios, Edwards Study Area. Color scale represents probabilities of occurrence estimated by logistic regression model (see text).**

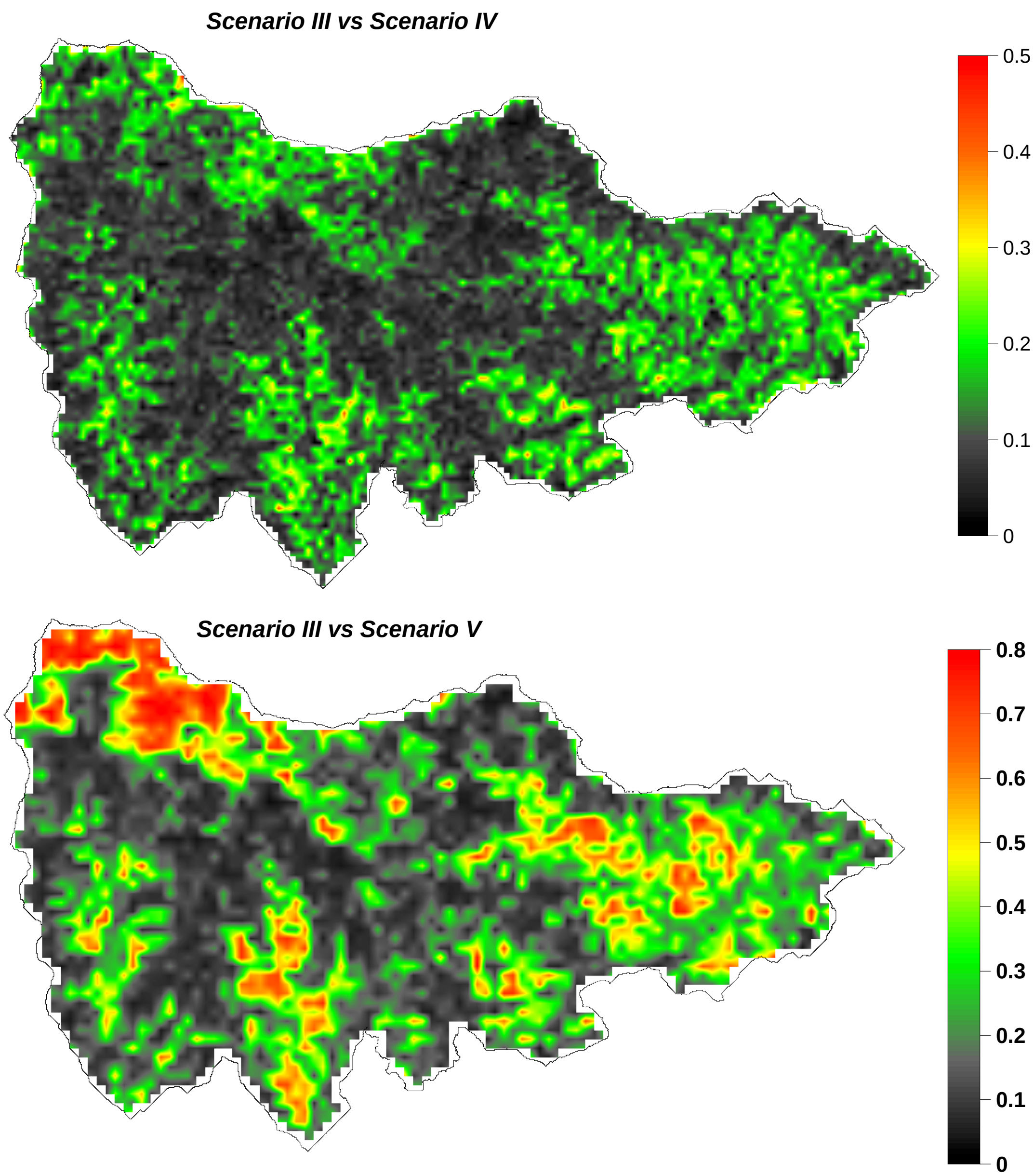


**Figure 3.9. Comparisons of the impact of Scenario III *versus* Scenarios IV and IV on habitat occupancy scores for grassland breeding birds across the Edwards study area. Numerical values represent the estimated increase in the likelihood of occurrence of grassland breeding birds resulting from the localized habitat changes of Scenario III when compared to the present condition (Scenario IV) and a projected future scenario of "no action" (Scenario V).**

# Section 4. Aquatic Biota Responses to Alternative Brush Management Scenarios

## Participants

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## Introduction

The purpose of the aquatic biota project subcomponent is to provide the means for assessing changes in aquatic biological diversity likely to result from alternative brush management scenarios in the Twin Buttes and Edwards aquifer recharge zone watersheds. Specific objectives of this study were (1) to establish baseline conditions characterizing stream habitats and aquatic biota within the project boundaries; (2) to establish baseline relationships between integrative measures of aquatic habitat quality and landscape features (land cover) and hydrologic (discharge) conditions within sampled sub-basins; and (3) to project the likely influence of alternative brush management scenarios on aquatic communities residing in streams within the study watersheds.

## Methods

*Biological Field Surveys*

The Environmental Protection Agency's draft EMAP Guidelines for field monitoring/assessment of biota were used to assess water bodies within the study areas. The Texas Natural Resource Conservation Commission Guidelines for Receiving Water Assessments also were consulted in order to maximize transferability of field methodologies. Appendix F indicates collection sites and environmental data.

In this study of biological indicators of ecological integrity, 131 sites were selected for biological surveys. Sites were nested within watersheds, basins, and sub-basins (Figures 4.1 and 4.2; Tables 4.1 and 4.2). Because our sampling was conducted during prolonged drought conditions, many streambeds, particularly upstream ephemeral reaches, were dry. As a result, aquatic sampling was limited to stream reaches that contained water in areas having points of access. We consulted maps and selected property owners were consulted to determine areas of access. During June-July 2001, field surveys were conducted to obtain baseline data for stream habitats and fish and benthic aquatic macroinvertebrate assemblages.

At each survey location, before biological sampling was initiated, we collected location coordinates using a hand-held global positioning system (GPS), estimated riparian vegetation coverage, characterized general weather conditions and identified the local aquatic habitat as either ‘riffle,’ ‘run’ or ‘pool’. We measured the following parameters at five points (near bank, 1/4 width, 1/2 width, 3/4 width, and near other bank) along three transects perpendicular to the longitudinal axis of the stream channel (from shoreline to shoreline): water depth, water velocity (using a Marsh McBirney digital flowmeter), substrate composition (visual estimates of percentage coverage of categories), percent coverage by woody debris, and percent coverage by aquatic vegetation. At each survey location, we measured the following physicochemical water parameters *in situ*: dissolved oxygen (mg/L), conductivity (µS), and temperature (ºC) using a YSI Model 85 multiparameter meter and probe, and pH using a Hach digital probe.

**Table 4.1. Summary of the number of aquatic survey (sample) locations by watershed, basin, and sub-basin.**

| Watershed | Basin | Sub-basin Number | Number of Aquatic Surveys |
|---|---|---|---|
| Edwards | Frio | 6010101 | 1 |
| Edwards | Frio | 6010301 | 15 |
| Edwards | Frio | 6010501 | 12 |
| Edwards | Frio | 6010503 | 8 |
| Edwards | Frio | 6010801 | 3 |
| Edwards | Hondo | downstream of sub-basin | 6 |
| Edwards | Medina | 2010301 | 4 |
| Edwards | Medina | 2010401 | 1 |
| Edwards | Medina | 2010501 | 2 |
| Edwards | Medina | 2010601 | 3 |
| Edwards | Medina | 2020201 | 1 |
| Edwards | Medina | 2020303 | 5 |
| Edwards | Sabinal | 6060101 | 8 |
| Edwards | Sabinal | 6060201 | 8 |
| Edwards | Sabinal | 6060301 | 6 |
| Edwards | Sabinal | 6060501 | 2 |
| Edwards | Seco | 7060105 | 3 |
| Twin Buttes | Middle Concho | 25 | 5 |
| Twin Buttes | Middle Concho | 27 | 8 |
| Twin Buttes | South Concho | 16 | 12 |
| Twin Buttes | Spring-Dove | 13 | 3 |
| Twin Buttes | Spring-Dove | 15 | 10 |
| Twin Buttes | Spring-Dove | 21 | 5 |

**Table 4.2. Sample location and IBI scores for collected aquatic samples.**

| Sample Number | Fish IBI Score | Invertebrate IBI Score | Drainage | Habitat Classification | Basin | Sub-basin Number |
|---|---|---|---|---|---|---|
| BC-01 | 77 | 21 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-02 | 77 | 25 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-03 | 72 | 23 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-04 | 68 | 29 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-05 | 68 | 25 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-06 | 60 | 23 | Twin Buttes | Riffle | South Concho | 16 |
| BC-07 | 86 | 21 | Twin Buttes | Riffle | South Concho | 16 |
| BC-08 | 78 | 21 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-09 | 68 | 17 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-10 | 68 | 27 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-11 | 52 | 29 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-12 | 73 | 27 | Twin Buttes | Run / Pool | South Concho | 16 |
| BC-13 | 49 | 19 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-14 | 49 | 23 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-15 | 39 | 25 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-16 | 74 | 25 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-17 | 79 | 31 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-18 | 59 | 25 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-19 | 71 | 21 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-20 | 59 | 21 | Twin Buttes | Run / Pool | Middle Concho | 27 |
| BC-21 | 56 | 23 | Twin Buttes | Run / Pool | Middle Concho | 25 |
| BC-22 | 12 | 19 | Twin Buttes | Riffle | Middle Concho | 25 |
| BC-23 | 37 | 21 | Twin Buttes | Run / Pool | Middle Concho | 25 |
| BC-24 | 30 | 21 | Twin Buttes | Run / Pool | Middle Concho | 25 |
| BC-25 | 65 | 23 | Twin Buttes | Run / Pool | Middle Concho | 25 |
| BC-26 | 58 | 27 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-27 | 49 | 23 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-28 | 0 | 23 | Twin Buttes | Riffle | Spring-Dove | 15 |
| BC-29 | 49 | 19 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-30 | 41 | 23 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-31 | 41 | 21 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-32 | 41 | 23 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-33 | 58 | 25 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-34 | 46 | 27 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-35 | 59 | 23 | Twin Buttes | Run / Pool | Spring-Dove | 15 |
| BC-36 | 46 | 15 | Twin Buttes | Run / Pool | Spring-Dove | 13 |
| BC-37 | 32 | 23 | Twin Buttes | Run / Pool | Spring-Dove | 13 |
| BC-38 | 52 | 17 | Twin Buttes | Run / Pool | Spring-Dove | 13 |
| BC-39 | 61 | 25 | Twin Buttes | Run / Pool | Spring-Dove | 21 |
| BC-40 | 56 | 23 | Twin Buttes | Riffle | Spring-Dove | 21 |
| BC-41 | 69 | 21 | Twin Buttes | Run / Pool | Spring-Dove | 21 |
| BC-42 | 58 | 15 | Twin Buttes | Riffle | Spring-Dove | 21 |
| BC-43 | 86 | 21 | Twin Buttes | Run / Pool | Spring-Dove | 21 |
| BC-44 | 62 | 15 | Edwards | Run / Pool | Frio | 6010503 |
| BC-45 | 42 | 21 | Edwards | Run / Pool | Frio | 6010503 |
| BC-46 | 39 | 21 | Edwards | Run / Pool | Frio | 6010503 |
| BC-47 | 57 | 19 | Edwards | Run / Pool | Frio | 6010503 |
| BC-48 | 56 | 27 | Edwards | Run / Pool | Frio | 6010503 |

| Sample Number | Fish IBI Score | Invertebrate IBI Score | Drainage | Habitat Classification | Basin | Sub-basin Number |
|---|---|---|---|---|---|---|
| BC-49 | 75 | 21 | Edwards | Riffle | Frio | 6010503 |
| BC-50 | 66 | 23 | Edwards | Run / Pool | Frio | 6010501 |
| BC-51 | 76 | 33 | Edwards | Run / Pool | Frio | 6010501 |
| BC-52 | 65 | 27 | Edwards | Riffle | Frio | 6010501 |
| BC-53 | 59 | 13 | Edwards | Run / Pool | Frio | 6010501 |
| BC-54 | 61 | 27 | Edwards | Riffle | Frio | 6010501 |
| BC-55 | 82 | § | Edwards | Run / Pool | Frio | 6010501 |
| BC-56 | 62 | § | Edwards | Run / Pool | Frio | 6010501 |
| BC-57 | 59 | 19 | Edwards | Run / Pool | Frio | 6010501 |
| BC-58 | 37 | 23 | Edwards | Riffle | Frio | 6010501 |
| BC-59 | 61 | § | Edwards | Run / Pool | Frio | 6010501 |
| BC-60 | 70 | 15 | Edwards | Riffle | Frio | 6010501 |
| BC-61 | 37 | 21 | Edwards | Riffle | Frio | 6010501 |
| BC-62 | 66 | 17 | Edwards | Riffle | Frio | 6010503 |
| BC-63 | 70 | 27 | Edwards | Run / Pool | Frio | 6010503 |
| BC-64 | 54 | § | Edwards | Run / Pool | Frio | 6010301 |
| BC-65 | 73 | 25 | Edwards | Riffle | Frio | 6010301 |
| BC-66 | 68 | 21 | Edwards | Run / Pool | Frio | 6010301 |
| BC-67 | 73 | 23 | Edwards | Riffle | Frio | 6010301 |
| BC-68 | 70 | 29 | Edwards | Run / Pool | Frio | 6010301 |
| BC-69 | 77 | 23 | Edwards | Run / Pool | Frio | 6010301 |
| BC-70 | 51 | 25 | Edwards | Riffle | Frio | 6010301 |
| BC-71 | 64 | 25 | Edwards | Run / Pool | Frio | 6010301 |
| BC-72 | 65 | § | Edwards | Riffle | Frio | 6010301 |
| BC-73 | 67 | 27 | Edwards | Run / Pool | Frio | 6010301 |
| BC-74 | 79 | 23 | Edwards | Run / Pool | Frio | 6010301 |
| BC-75 | 51 | 19 | Edwards | Run / Pool | Frio | 6010301 |
| BC-76 | 57 | 21 | Edwards | Run / Pool | Frio | 6010301 |
| BC-77 | 56 | 15 | Edwards | Run / Pool | Frio | 6010301 |
| BC-78 | 34 | 25 | Edwards | Run / Pool | Frio | 6010301 |
| BC-79 | 77 | 27 | Edwards | Run / Pool | Frio | 6010101 |
| BC-80 | 70 | 27 | Edwards | Run / Pool | Frio | 6010801 |
| BC-81 | 78 | 23 | Edwards | Riffle | Frio | 6010801 |
| BC-82 | 76 | 23 | Edwards | Run / Pool | Frio | 6010801 |
| BC-83 | 63 | 23 | Edwards | Run / Pool | Sabinal | 6060101 |
| BC-84 | 40 | 23 | Edwards | Riffle | Sabinal | 6060101 |
| BC-85 | 76 | 17 | Edwards | Run / Pool | Sabinal | 6060101 |
| BC-86 | 78 | 21 | Edwards | Run / Pool | Sabinal | 6060101 |
| BC-87 | 74 | 23 | Edwards | Run / Pool | Hondo | † |
| BC-88 | 70 | 15 | Edwards | Riffle | Hondo | † |
| BC-89 | 55 | 25 | Edwards | Run / Pool | Hondo | † |
| BC-90 | 75 | 17 | Edwards | Riffle | Hondo | † |
| BC-91 | 84 | 23 | Edwards | Run / Pool | Hondo | † |
| BC-92 | 75 | 21 | Edwards | Riffle | Hondo | † |
| BC-93 | 85 | 23 | Edwards | Run / Pool | Seco | 7060105 |
| BC-94 | 54 | 23 | Edwards | Run / Pool | Seco | 7060105 |
| BC-95 | 37 | 23 | Edwards | Riffle | Seco | 7060105 |
| BC-96 | 56 | 23 | Edwards | Run / Pool | Sabinal | 6060501 |
| BC-97 | 61 | 23 | Edwards | Riffle | Sabinal | 6060501 |
| BC-98 | 72 | 25 | Edwards | Run / Pool | Sabinal | 6060301 |

| Sample Number | Fish IBI Score | Invertebrate IBI Score | Drainage | Habitat Classification | Basin | Sub-basin Number |
|---|---|---|---|---|---|---|
| BC-99 | 62 | 27 | Edwards | Run / Pool | Sabinal | 6060301 |
| BC-100 | 52 | 21 | Edwards | Run / Pool | Sabinal | 6060301 |
| BC-101 | 64 | 21 | Edwards | Run / Pool | Sabinal | 6060301 |
| BC-102 | 51 | 23 | Edwards | Run / Pool | Sabinal | 6060301 |
| BC-103 | 63 | 25 | Edwards | Run / Pool | Sabinal | 6060301 |
| BC-104 | 84 | 27 | Edwards | Run / Pool | Medina | 2010301 |
| BC-105 | 74 | 23 | Edwards | Run / Pool | Sabinal | 6060101 |
| BC-106 | 56 | 21 | Edwards | Run / Pool | Sabinal | 6060101 |
| BC-107 | 65 | 25 | Edwards | Riffle | Sabinal | 6060101 |
| BC-108 | 66 | 17 | Edwards | Run / Pool | Sabinal | 6060101 |
| BC-109 | 76 | 27 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-110 | 57 | 27 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-111 | 61 | 21 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-112 | § | 27 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-113 | 62 | 19 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-114 | 73 | 23 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-115 | 52 | 21 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-116 | 52 | 25 | Edwards | Run / Pool | Sabinal | 6060201 |
| BC-117 | 60 | 25 | Edwards | Run / Pool | Medina | 2010301 |
| BC-118 | 83 | 23 | Edwards | Riffle | Medina | 2010301 |
| BC-119 | § | 25 | Edwards | Riffle | Medina | 2010301 |
| BC-120 | 60 | 25 | Edwards | Run / Pool | Medina | 2010401 |
| BC-121 | 82 | 27 | Edwards | Run / Pool | Medina | 2010501 |
| BC-122 | 53 | 21 | Edwards | Riffle | Medina | 2010501 |
| BC-123 | 53 | 23 | Edwards | Riffle | Medina | 2010601 |
| BC-124 | 60 | 29 | Edwards | Run / Pool | Medina | 2010601 |
| BC-125 | 79 | 31 | Edwards | Run / Pool | Medina | 2010601 |
| BC-126 | 66 | 23 | Edwards | Run / Pool | Medina | 2020201 |
| BC-127 | 91 | 25 | Edwards | Riffle | Medina | 2020303 |
| BC-128 | 72 | 25 | Edwards | Run / Pool | Medina | 2020303 |
| BC-129 | 78 | 19 | Edwards | Riffle | Medina | 2020303 |
| BC-130 | 79 | 19 | Edwards | Run / Pool | Medina | 2020303 |
| BC-131 | 76 | 25 | Edwards | Run / Pool | Medina | 2020303 |

§ IBI Score not calculated. † Sample collected downstream of southernmost identified sub-basin.

Fish surveys were conducted using a seine net (6.4 m x 1.8 m with 4 mm mesh). At each site, the level of effort was documented to facilitate estimation of catch per unit effort and to allow duplication of the effort at a later time. Collection effort was continued until no additional fish species were collected with additional seine hauls. In some instances, large fish were identified, weighed, and measured in the field, then released alive. Otherwise, all specimens from a given site were preserved in 15 percent formalin as a single sample, labeled, and returned to the lab for identification and measurement. Individual fish were identified to species. After identification and enumeration in the laboratory, these specimens were deposited into Texas A&M University's Texas Cooperative Wildlife Collection (TCWC accession number 1681).

Benthic macroinvertebrate surveys were conducted using a Surber sampler (Merritt and Cummins 1984). Two Surber samples were taken at each survey location. Surber samples were non-randomly positioned within the survey location to encompass variation in benthic habitat characteristics (e.g., cobble, mud, sand, submerged vegetation). Invertebrate samples were preserved in the field in 75 percent EtOH with Rose Bengal added to stain invertebrates. Individual invertebrates were identified to family (Plafkin et al. 1989), except Ephemeroptera that were identified to order, and enumerated. A reference collection of these specimens has been retained in K.O. Winemiller's laboratory at Texas A&M University. Individual Surber samples were processed as distinct and individual samples, however, the benthic macroinvertebrate index of biotic integrity (B-IBI) was calculated based on pooled results from the paired Surber samples at each location (see Development of B-IBI below). Fish species and abundance are presented in Appendix G with aquatic macro invertebrate taxa in Appendix H.

*Development of Fish IBI (F-IBI)*

Karr and Dudley (1981) defined biotic integrity as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." Karr (1981) and his associates (Karr et al. 1986) developed the original index of biotic integrity (IBI) for stream fishes in Indiana and Illinois. Since its original development, the IBI has been modified and adapted for use as an indicator of stream health in other regions of the Midwest (e.g., Lyons 1992, Barbour 1999) and the country (Moyle and Randall 1998, Gamon and Simon 2000).

The fish IBI (F-IBI) score for a stream is calculated from a series of metrics that reflect the essential structural and functional features of the fish community. Metrics employed for the Edward's and Twin Buttes F-IBIs are described in Table 4.3. We modified metrics developed for Texas' Brazos-Navasota River watershed IBI (Winemiller and Gelwick 1998) and other published IBIs (Karr et al. 1986, Lyons 1992). Natural fluvial fish communities of the Edwards and Twin Buttes watersheds differ from the Brazos-Navasota River watershed and Midwestern communities in several respects which had to be taken into account in developing the scoring criteria. The team first searched and databased earlier fish collections from the Edwards and Twin Buttes watersheds that were archived in the Texas Cooperative Wildlife Collection (TCWC – College Station, TX) and the Texas Natural History Collection (TNHC – Austin, TX). Surveys dating from the 1940s to the present were evaluated to assess species ranges, assemblage composition, and interannual variation observed in past collections. Next was development of a distinct scoring criteria for the Edwards and Twin Buttes watersheds (Table 4.3) based on species ranges and characteristic differences between samples from the two distinct watersheds. Furthermore, because fish assemblages sampled from riffles are typically different from run / pool habitats (e.g., different maximum species richness and abundance patterns), a separate set of scoring criteria was developed for riffle and run / pool habitats within each basin. Ten metrics were employed in run / pool F-IBI calculations; however, only six metrics were used in riffle F-IBI calculations. In order to standardize maximum possible F-IBI scores, we, therefore, standardized categorical scores so that the maximum possible score scales to 100 (Table 4.3).

Scoring criteria used for Midwestern streams were modified to allow a relatively high percentage of omnivorous fishes to be associated with a relatively high degree of ecological integrity (reflected in scoring criteria in Table4.3). Like Lyons (1992), this study included madtoms (*Noturus* species) in our tally of darter species at each site. Madtoms are not darters, they occupy habitats and ecological niches similar to darters, and thus are valuable indicators of ecosystem health. Some species were classified as intolerant forms that were not classified as such by Lyons (1992). Because the streams and rivers of our region tend to be warmer (with lower dissolved oxygen concentrations) and more turbid than Wisconsin streams, we used a less restrictive interpretation of intolerance. Thus, in addition to the species listed as intolerant by Lyons, all species of darters were included (Percidae) and the freckled madtom (*Noturus nocturnus*) as intolerant forms. Percentage of green sunfish (*Lepomis cyanellus*) was only used for run / pool F-IBI calculations. Green sunfish are tolerant fish that are good colonizers of disturbed stream habitats, and as a consequence, sites dominated by green sunfish are likely to be degraded. However, the western mosquitofish (*Gambusia affinis*), an efficient colonizer highly tolerant of degraded conditions, was an ideal indicator species for each of the watersheds and both habitat types. Mosquitofish do not naturally occur in Midwestern streams, but they are almost always present and sometimes common in most Texas streams. Therefore, following Winemiller and Gelwick (1998), the percentage of mosquitofish to indicate domination by a tolerant, ubiquitous species under degraded conditions were used. Percentage of omnivores serves as an indicator of altered community trophic structure, with high percentages reflecting a degraded system. Even under pristine conditions, many of the rivers and streams of the Edwards and Twin Buttes watersheds commonly contain two species of omnivorous minnows, red shiners (*Cyprinella lutrensis*) and bullhead minnows (*Pimephales vigilax*). The scoring criteria used for Midwestern streams was modified to allow a relatively high percentage of omnivorous fishes to be associated with a relatively high degree of ecological integrity (reflected in scoring criteria in Table 4.3). Because scoring criteria for the percentage of omnivores had to be adjusted upward for our region, the percentage of invertebrate feeders (invertivores) had to be adjusted downward. Because fish samples from Twin Buttes riffles only contained invertivores, we did not include trophic characterization as a metric for F-IBI scores (Table 4.3).

**Table 4.3. Individual metrics and associated scoring criteria for habitat-specific and basin specific fish IBI calculation. Due to the varying number of metrics used per group, scores vary such that the maximum possible score is scaled to 100 points.**

| | **Riffle IBI Scoring Criteria*** | | | | | **Run/Pool IBI Scoring Criteria**** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **16.6** | **11.6** | **8.3** | **3.3** | **0** | **10** | **7** | **5** | **2** | **0** |
| **Number of native species** | 6+ | 4-5 | 3 | 2 | 1 | 9+ | 7-8 | 5-6 | 3-4 | 0-2 |
| **Number of darter species** | 2 | | 1 | | 0 | 2 | | 1 | | 0 |
| **Number of sunfish species** | 2 | | 1 | | 0 | 4+ | 3 | 2 | 1 | 0 |
| **Number of intolerant species** | 4+ | 3 | 2 | 1 | 0 | 4+ | 3 | 2 | 1 | 0 |
| **Percent tolerant species** | 0-39 | 40-49 | 50-69 | 70-79 | 80-100 | 0-39 | 40-49 | 50-69 | 70-79 | 80-100 |
| **Percent green sunfish** | not used | | | | | 0-1 | 2-9 | 10-19 | 20-29 | 30-100 |
| **Percent mosquitofish** | 0-1 | 2-9 | 10-19 | 20-29 | 30-100 | 0-1 | 2-9 | 10-19 | 20-29 | 30-100 |
| **Percent omnivores** | not used | | | | | 0-9 | 10-19 | 20-29 | 30-39 | 40-100 |
| **Percent invertivores** | not used | | | | | 81-100 | 50-80 | 20-49 | 10-19 | 0-9 |
| **Percent carnivores** | not used | | | | | 7-100 | 4-6 | 2-3 | .1-1 | 0 |

* 6 Metrics Used

* *10 Metrics Used

Unlike Lyons (1992), these F-IBI scores were not adjusted based on the total density of fishes in seine samples. Lyons reasoned that Wisconsin streams with better biological integrity should support more individual fishes. In contrast, some of the least impacted streams in the study regions actually yielded samples with fewer individual fishes. It appears that in central Texas, streams with good integrity can have high fish densities (often unshaded sites with high primary productivity), or they can have low fish densities (highly shaded sites with clear water and little algal production). Furthermore, because streams of the region may naturally be dominated by soft substrates (sand, clay, and mud), the percentage of lithophilous spawning fishes may not be a valid indicator of fish community health. Most of the native fishes of our region are capable of completing their life cycles in systems with little or no clean hard substrates. Therefore, the percentage of lithophils was not employed as an F-IBI metric here.

Species assignments for the species richness metrics are given in Table 4.4, and species assignments for trophic metrics are given in Table 4.5. Refer to Lyons (1992) and Winemiller and Gelwick (1998) for additional justification of the F-IBI metrics and scoring rationale. The criteria used for qualitative assessment of stream biological integrity from F-IBI scores are given in Table 4.6. This numerical scale for scoring integrity categories derives from Lyons (1992).

*Development of Invertebrate IBI (B-IBI)*

In recent years, IBIs have been developed based on benthic invertebrates (e.g., Lenat 1993) rather than fishes as originally proposed by Karr (1981). A rationale for focusing on benthic invertebrates is that many of these taxa are highly sensitive to landscapes impacts that affect streams, such as siltation and poor water quality (Ohio EPA 1988, Fore et al. 1996, Chessman 1999, Whiles et al. 2000). A benthic macroinvertebrate IBI (B-IBI) score was calculated for each site using the pooled Surber samples and a series of metrics that reflect the essential structural and functional features of the invertebrate assemblage. Metrics employed for the Edward's and Twin Buttes B-IBIs are described in Table 4.7. Metrics were selected from previously developed benthic macroinvertebrate IBIs (Kerans and Karr 1994, Barbour et al. 1999, Lammert and Allan 1999). As in these previous efforts, this benthic invertebrate IBI dealt with taxonomy at the family and ordinal scales of resolution. Species-level identification of aquatic invertebrates requires a high degree of systematic expertise, a requirement that reduces the transferability, efficiency, and speed of ecological assessments (i.e., key motivations for IBI development). Preexisting B-IBIs were modified based on the range of values observed in our samples. Again, because different regions and habitats normall support different numbers of species and ecological forms, basin-specific and habitat-specific scoring criteria were employed (Table 4.7).

Seven previously recommended metrics were chosen to be included in the B-IBI. Following Kerans and Karr (1994), dominance was defined as the proportion of individuals in the most abundant taxon. Measures of relative abundance of select taxa have are widely used in B-IBIs (Plafkin et al. 1989, Kerans and Karr 1994, Barbour et al. 1999, Lammert and Allan 1999). The following relative abundance metrics were included: percent unionid muscles, percent corbiculid clams, percent Ephemeroptera, and percent chironomids. Negative anthropogenic impacts on lentic systems are expected to result in increased dominance, percent corbiculid clams, and percent chironomids within benthic macroinvertebrate communities, whereas less impacted systems are expected to have higher proportions of unionid muscles and

Ephemeroptera taxa. We employed two richness measures: trichopteran family richness and total taxonomic richness. Both of these richness measures are expected to decline with anthropogenic impacts to lentic systems (Kerans and Karr 1994, Barbour et al. 1999).

*Multivariate analysis of aquatic assemblages (CCA analyses)*

Canonical correspondence analysis (CCA) was used to evaluate the relationships between species, samples, and environmental conditions at the time of sampling. The input data used to estimate the regression equation are presented in Appendix I for Scenarios IV and V. CCA is a direct gradient analysis technique that constrains the ordering of species and site scores to yield maximum correlation with environmental variables (ter Braak and Šmilauer 1998). In CCA, species abundances are assumed to be a unimodal function of environmental gradients, and environmental factors likely contributing to the observed gradient are measured and included in the analysis. Environmental variables included in these analyses were: mean stream width (wetted portion of channel reach), coefficient of variation in stream width (wetted portion), mean water depth, water depth coefficient of variation, mean water velocity, water velocity coefficient of variation, percentages of substrate composed of sand, mud, clay, pebble, cobble and bedrock, percentage of substrate covered by detritus, water temperature, dissolved oxygen content of water, water pH, and water conductivity. A separate CCA analyses were conducted for fish species collected in seine samples and invertebrate taxa collected in Surber samples. Results from these analyses permit ordination of species and sites in relation to dominant environmental gradients, and reveal the set of environmental factors associated with the structure of fish and invertebrate assemblages among our samples.

Interpretation of the importance of environmental parameters included in the CCA analysis is based upon t-values of canonical coefficients (ter Braak and Šmilauer 1998). Because canonical coefficients have larger variance than regression coefficients, a simple Student t-test is inappropriate. Nonetheless, canonical coefficient t-values $\geq |2.1|$ indicate the environmental variable has an effect and contributes to the fit of species and sample scores (ter Braak and Šmilauer 1998). In Tables 4.8 (fish) and 4.9 (invertebrates) we presented only those environmental variables with absolute t-values $\geq 2.1$.

**Table 4.4. Assignment of fish species for IBI species richness metric.**

| | |
|---|---|
| Non-native: | *Cyprinus carpio* |
| Darters: | *Etheostoma lepidum*<br>*Etheostoma spectabile*<br>*Percina carbonaria*<br>*Noturus nocturnus** |
| Suckers: | *Moxostoma congestum* |
| Sunfish: | *Lepomis auritus*<br>*Lepomis cyanellus*<br>*Lepomis gulosus*<br>*Lepomis macrochirus*<br>*Lepomis megalotis*<br>*Lepomis microlophus* |
| Intolerant: | *Astyanax mexicanus*<br>*Campostoma anomalum*<br>*Cyprinella lepida*<br>*Cyprinella venusta*<br>*Dionda argentosa*<br>*Dionda serena*<br>*Etheostoma lepidum*<br>*Etheostoma spectabile*<br>*Mircopterus punctulatus*<br>*Mircopterus treculi*<br>*Notropis amabalis*<br>*Notropis ludibundus*<br>*Noturus nocturnes*<br>*Percina carbonaria* |
| Tolerant: | *Ameirus natalis*<br>*Ameirus melas*<br>*Cyprinella lutrensis*<br>*Cyprinus carpio*<br>*Gambusia affinis*<br>*Lepomis cyanellus*<br>*Lepisosteus oculatus*<br>*Pimephales vigilax* |
| Not placed: | *Dorosoma cepedianum, Herichthys cyanoguttatum, Ictalurus punctatus, Lepomis hybrid, Micropterus salmoides, Notemigonus crysoleucas* |

* Madtom included with darters

**Table 4.5. Assignment of fish species for IBI trophic structure metric.**

| | |
|---|---|
| Omnivores: | *Cyprinus carpio* |
| | *Cyprinella lutrensis* |
| | *Dorosoma cepedianum* |
| | *Notemigonus crysoleucas* |
| | *Moxostoma congestum* |
| | *Pimephales vigilax* |
| Invertivores: | *Ameirus natalis* |
| | *Ameirus melas* |
| | *Astyanax mexicanus* |
| | *Campostoma anomalum* |
| | *Cyprinella lepida* |
| | *Cyprinella venusta* |
| | *Dionda argentosa* |
| | *Dionda serena* |
| | *Etheostoma lepidum* |
| | *Etheostoma spectabile* |
| | *Gambusia affinis* |
| | *Herichthys cyanoguttatum* |
| | *Ictalurus punctatus* |
| | *Lepomis auritus* |
| | *Lepomis hybrid* |
| | *Lepomis macrochirus* |
| | *Lepomis megalotis* |
| | *Lepomis microlophus* |
| | *Notropis amabalis* |
| | *Notropis ludibundus* |
| | *Noturus nocturnus* |
| | *Percina carbonaria* |
| Top carnivores: | *Lepomis cyanellus* |
| | *Lepomis gulosus* |
| | *Lepisosteus oculatus* |
| | *Mircopterus punctulatus* |
| | *Micropterus salmoides* |
| | *Mircopterus treculi* |

**Table 4.6. Interpretation of IBI Scores.**

Fish IBI Score criteria and assignment:

| IBI Score | Assessment | Color | Fish Community and Stream Attribute |
|---|---|---|---|
| 75-100 | Excellent | Blue | Comparable to the best situations with minimal human disturbance; most of the regionally expected species for habitat and stream size, including the most intolerant forms, are present with a balanced trophic structure. |
| 60-74 | Good | Green | Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species, especially top carnivores, are present with less than optimal abundances; trophic structure may show signs of imbalance. |
| 40-59 | Fair | Yellow | Signs of additional deterioration include decreased species richness, loss of intolerant forms, increased abundance of tolerant species, and / or highly skewed trophic structure (e.g., greater frequency of omnivores and lower frequency of invertebrate feeders and carnivores). |
| 25-39 | Poor | Orange | Relatively few species; dominated by omnivores, tolerant forms, and habitat generalists; few or no top carnivores. |
| 0-24 | Very Poor | Red | Very few species present, mostly exotic or tolerant forms; few large or old fish; diseased fish common. |

Invertebrate IBI Score criteria and assignment:

| IBI Score | Assessment | Color | Fish Community and Stream Attribute |
|---|---|---|---|
| 28-35 | Excellent | Blue | Comparable to the best situations with minimal human disturbance; most of the regionally expected species for habitat and stream size, including the most intolerant forms, are present with a balanced trophic structure. |
| 22-27 | Good | Green | Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species, especially top carnivores, are present with less than optimal abundances; trophic structure may show signs of imbalance. |
| 18-21 | Fair | Yellow | Signs of additional deterioration include decreased species richness, loss of intolerant forms, increased abundance of tolerant species, and / or highly skewed trophic structure (e.g., greater frequency of omnivores and lower frequency of invertebrate feeders and carnivores). |
| 14-17 | Poor | Orange | Relatively few species; dominated by omnivores, tolerant forms, and habitat generalists; few or no top carnivores. |
| 0-13 | Very Poor | Red | Very few species present, mostly exotic or tolerant forms; few large or old fish; diseased fish common. |

**Table 4.7. Individual metrics and associated scoring criteria for habitat-specific and basin specific benthic macroinvertebrate IBI calculation (modified from Kerans and Karr 1994, Lammert and Allan 1999).**

| | IBI Scoring Criteria Twin Buttes Riffle | | | IBI Scoring Criteria Twin Buttes Run/Pool | | |
|---|---|---|---|---|---|---|
| **Invertebrate IBI Metrics** | **5** | **3** | **1** | **5** | **3** | **1** |
| **Dominance** | 0-35.9 | 36-65.9 | 66+ | 0-49.9 | 50-79.9 | 80+ |
| **Percent Unionids** | 8.5+ | 0.1-8.4 | 0 | 30+ | 0.1-29.9 | 0 |
| **Percent Corbiculidae** | 0 | 0.1-1.9 | 2+ | 0 | 0.1-5.5 | 5.6+ |
| **Percent Ephemeroptera** | 45.5+ | 2.1-45.4 | 0-2 | 20+ | 0.1-19.9 | 0 |
| **Percent Chironomids** | 0 | 0.1-6.9 | 7+ | 0-20.9 | 21-79.9 | 80+ |
| **Trichopteran family richness** | 2+ | 1 | 0 | 2+ | 1 | 0 |
| **Taxa Richness** | 18+ | 11-17.9 | 0-10.9 | 16+ | 7-15.9 | 0-6.9 |

| | IBI Scoring Criteria Edwards Riffle | | | IBI Scoring Criteria Edwards Run/Pool | | |
|---|---|---|---|---|---|---|
| **Invertebrate IBI Metrics** | **5** | **3** | **1** | **5** | **3** | **1** |
| **Dominance** | 0-35.9 | 36-65.9 | 66+ | 0-49.9 | 50-79.9 | 80+ |
| **Percent Unionids** | 18.4+ | 0.1-18.3 | 0 | 10.4+ | 0.1-10.3 | 0 |
| **Percent Corbiculidae** | 0 | 0.1-2.3 | 2.4+ | 0 | 0.1-3.4 | 3.5+ |
| **Percent Ephemeroptera** | 41+ | 20-40.9 | 0-19.9 | 20+ | 0.1-19.9 | 0 |
| **Percent Chironomids** | 0 | 0.1-39.9 | 40+ | 0-20.9 | 21-79.9 | 80+ |
| **Trichopteran family richness** | 2+ | 1 | 0 | 2+ | 1 | 0 |
| **Taxa Richness** | 14+ | 5-13.9 | 0-4.9 | 14+ | 5-13.9 | 0-4.9 |

**Results and Discussion**

Field sampling produced biological and physical data from 131 sites spread across 22 regional sub-basins (Table 4.1, Figures 4.1 and 4.2). Samples collected from Hondo Creek were located slightly downstream of the southernmost sub-basin of the Edwards recharge zone(Figure 4.2), and were therefore excluded from some analyses.

During the surveys in June 2002, the Twin Buttes region was suffering the effects of prolonged drought conditions. Although some streams had significant instream flow (e.g., South Concho River, Big Rocky Creek), other streams contained mostly isolated pools with limited or no surface flow between them (Middle Concho River, Dove Creek, Spring Creek). The South Concho River and Spring Creek contained impoundments that undoubtedly influenced patterns of discharge. The South Concho River contains a series of small impoundments, and survey sites were located approximately 500 m downstream from an impoundment that may have moderated low flows under drought conditions. Survey site BC-26 was located in a broad, shallow pool formed by an impoundment, and sites BC-27 to BC-35 were located below this impoundment. Excluding Big Rocky Creek and the Middle Concho, streams had substrates dominated by gravel and cobble. Big Rocky Creek was dominated by a bedrock substrate. The Middle Concho was dominated by large, isolated pools that usually contained woody debris and floating mats of filamentous algae. The substrate was mostly gravel and cobble, sometimes overlaid with a layer of mud. Riffles connecting pools were very narrow (width as small as 1-2 m) with sand and gravel substrates. Temperature varied between 19.5˚ C in a small pool at the base of a bluff in Spring Creek (BC-30) to 31.7˚ C in a shallow isolated pool of the Middle Concho (BC-25). With few exceptions, water courses of the Twin Buttes area were bordered by woody vegetation, especially pecan, willow, mesquite and button bush. The dominant land use was cattle and sheep ranching, with low-density residential developments around survey segments of Dove Creek and the South Concho River.

Streams of the Edwards Aquifer Recharge Zone appeared to be at approximately baseflow conditions during our surveys of June-July, 2001. Virtually all streams had significant instream flow with active riffles connecting pools and runs. Stream reaches varied in size: riffle in Sabinal River at Lost Maples (channel width = 1.0 m); pool in West Frio River at Old Rock Springs Road Crossing (channel width = 40 m). The dominant substrate was gravel and bedrock, with cobbles common. Temperature varied from 23.2˚ C in a spring outflow (BC-75) to 33.2˚ C in a narrow side channel (BC-92). Riparian areas in the Edwards Recharge Zone were dominated by woody vegetation, especially bald cypress, sycamore, willow and juniper. Cattle, goat and sheep ranching were the predominant land uses around survey sites.

Although biological data was collected at 131 sites, fish data from two sites (112, 119) were not processed nor were invertebrate data from 5 sites (55, 56, 59, 64, 72) due to sample preservation problems. A total of 16,743 individual fishes representing 34 species (Table 4.8) were collected and identified. Invertebrate samples yielded 25, 322 individuals representing 51 different taxa.

Basin- and habitat-specific qualitative assessments of stream biological integrity from F-IBI scores for the 129 seine samples are given in Figure 4.3. A frequency distribution of F-IBI scores approximated a normal distribution with a low score of 0 (Spring Creek riffle downstream of a dam) and a high score of 91 (Medina River riffle). Only one other location (Middle Concho riffle) was categorized as very poor. Fourteen samples (11 percent) were categorized as poor, 56 samples (43 percent) were characterized as "fair", 48 samples (37 percent) were characterized as "good", while 9 samples (7 percent) received an "excellent" F-IBI score. Below is an examination of the relationship between F-IBI scores and sub-basin land cover characteristics.

Benthic macroinvertebrate IBI scores spanned a narrower range than F-IBI scores, and this probably was partially due to different scoring criteria for the two metrics (compare Tables 4.3 and 4.7). B-IBI scores are presented in Figure 4.4. A frequency distribution of B-IBI scores for the 126 sites also approximated a normal distribution with a low score of 13 (West Frio River run) and a high score of 33 (West Frio River run less than 200 m away from the site that scored 13).

*Comparison of F-IBI and B-IBI Scores*

To evaluate the relative merits of fish and benthic invertebrates as indicators of aquatic ecosystem health in central Texas landscapes, we compared the statistical relationship between F-IBI and B-IBI scores (Figure 4.5). Ideally, one would expect F-IBI and B-IBI scores to be significantly and positively correlated. That is, if a site was degraded then both the fish and benthic macroinvertebrates should respond negatively yielding low F-IBI and B-IBI scores, whereas both the F-IBI and B-IBI should register high scores for relatively pristine locations. Unfortunately, prior studies have failed to demonstrate high concordance between fish and benthic invertebrate IBIs. For example, a recent study conducted in Michigan (Lammert and Allan 1999) found low correlation between fish and benthic macroinvertebrate IBI scores. As in previous studies, the pattern of variation for our B-IBI scores showed little relationship to that for our F-IBI scores ($r^2 = 0.024$; $p = 0.09$ ; Figure 4.5).

There are several potential ecological and statistical explanations for the lack of correlation between our F-IBI and B-IBI scores. First, it has been argued that, because aquatic invertebrates have shorter life cycles, benthic macroinvertebrate populations integrate and reflect environmental conditions over shorter time intervals than fish populations (Karr 1991, Barbour et al. 1999). Therefore, fish and benthic macroinvertebrate assemblages may not represent synchronized responses to temporally dynamic environmental stressors, but rather each assemblage is responding in a different time-constrained manner to environmental change. Previous studies also have documented how invertebrates and fishes respond to environmental influences at different spatial scales (Lammert and Allan 1999, Fitzpatrick et al. 2001). For example, Lammert and Allan (1999) found strong positive correlations between fish IBI scores and flow stability (regional scale influence), but invertebrate IBI scores were most strongly correlated to dominant substrate size (local scale). Fitzpatrick et al. (2001) found their fish IBI was correlated with watershed land cover characteristics and stream size, whereas invertebrates were more influenced by nutrient concentrations. In general, Fitzpatrick et al. (2001) found invertebrate metrics were not as sensitive to land cover characteristics as fish metrics.

Secondly, the scale of taxonomic resolution was substantially different between fish and invertebrate analyses. All fishes were identified to species, and thus permitted explicit, well-informed decision making regarding placement of individual taxa into various groupings (e.g., tolerant or intolerant species, trophic categories). As is typically done for invertebrate samples used for environmental assessment (Plafkin et al. 1989), we identified invertebrates to family or ordinal level. These higher levels of taxonomic resolution precludes incorporating species-specific characteristics and forces broader generalizations for metric categories. Consequently, the B-IBI does not include metrics indicating “tolerant” or “intolerant” species. Therefore, we chose to assess aquatic ecosystem health and biotic response to land cover changes based entirely on F-IBI results, and we will set aside our B-IBI results from this point forward.

*Regression Analysis of F-IBI Scores and Sub-basin Land Cover Characteristics*

Biological assemblages inhabiting stream ecosystems are influenced by the condition and state of the surrounding terrestrial landscape (Cummins 1974, Vanote et al. 1980, Wallace et al. 1997, Schleiger 2000, Fitzpatrick et al. 2001). We therefore explored potential relationships between F-IBI scores and land cover characteristics of the surrounding sub-basins (figures 4.6 and 4.7) using multiple linear regression. Existing land cover characteristics of each sub-basin were provided by the TAES Blacklands research group (Scenario IV, Bednarz 2002). The average F-IBI score was computed for the sub-basins we sampled. This values (mean F-IBI score per sub-basin) served as dependent variables in our analysis.

Independent variables used in the analysis were land cover estimates for each sub-basin. Land cover data for each sub-basin and brush-cover scenario were divided into 30 classes: heavy cedar < 15 percent slope, heavy mesquite < 15 percent slope, heavy mixed < 15 percent slope, heavy oak < 15 percent slope, moderate cedar < 15 percent slope, moderate mesquite < 15 percent slope, moderate mixed < 15 percent slope, moderate oak < 15 percent slope, heavy cedar > 15 percent slope, heavy mesquite > 15 percent slope, heavy mixed > 15 percent slope, heavy oak > 15 percent slope, moderate cedar > 15 percent slope, moderate mesquite > 15 percent slope, moderate mixed > 15 percent slope, moderate oak > 15 percent slope, heavy cedar in riparian area, heavy mesquite in riparian area, heavy mixed in riparian area, heavy oak in riparian area, moderate cedar in riparian area, moderate mesquite in riparian area, moderate mixed in riparian area, moderate oak in riparian area, light brush of all species, open rangeland, pastureland, cropland, urban land.  In order to facilitate analysis, these variables were collapsed into eight distinct land cover variables: cedar, cropland, mesquite, mixed, oak, pasture, and urban. Blacklands’ classifications had cedar, mesquite, mixed, and oak represented by multiple categories, for example, six land cover categories were identified as cedar: heavy cedar < 15 percent slope,  heavy cedar > 15 percent slope, heavy cedar in riparian area, moderate cedar < 15 percent slope, moderate cedar > 15 percent slope, and moderate cedar in riparian area. In order to get a single estimate of the extent of cedar cover, each of the thirteen classifications containing cedar was multiplied by the midpoints of that cover interval code (0.05 = light, 0.20 = moderate, 0.65 = heavy) and then took the sum of these thirteen cover-adjusted values, which resulted in a single cedar cover estimate. This cedar cover estimate (in units of acres) was then divided by the total number of acres in the sub-basin, which resulted in the proportion of the basin covered by cedar. The analysis did not maintain spatial (riparian or non-riparian) or slope (> or < 15 percent) distinctions in the land cover characterizations. The same calculations were performed for mesquite, mixed, and oak classifications. Consequently, a single proportional estimate of cover was developed for each of seven land cover classes (cedar, cropland, mesquite, mixed, oak, pasture, urban) for each sub-basin.

To evaluate potential relationships between landscape-scale land-cover estimates and F-IBI values, a multiple regression of sub-basin mean F-IBI scores was performed against the proportion of each sub-basin covered by the seven land-cover categories. Multiple regression models were generated using the statistical program SAS. Using the mean F-IBI score as the dependent variable, we generated a linear model including all seven land-cover categories as predictive variables (Table 4.11). The complete model (including all seven land cover categories: cedar, mesquite, mixed, oak, pasture, urban, cropland) was a good predictor of the mean F-IBI ($r^2 = 0.62$, $p = 0.027$, see Table 4.11 for regression coefficients). As a reminder, $r^2$ equals the percentage of variation in the dependent variable accounted for by the independent predictor variables. Because the amount of cedar and mesquite land cover is of particular interest to this project, we evaluated the two factor model including only these two land cover classes (cedar, mesquite) and found them to be reasonable predictors of the mean F-IBI score ($r^2 = 0.35$, $p < 0.017$).

*Regression Analysis of F-IBI Scores and Sub-basin Modeled Discharge Characteristics*

One of the initial goals was to relate biotic indices to sub-basin discharge data to derive a predictive model useful for predicting future response to hydrologic regimes predicted by the SWAT model under alternative land-cover scenarios. We were unable to perform this analysis, because sub-basin discharge data were unavailable for the critical period associated with our field surveys (the period preceding and including June-July 2001). The team contacted staff of the USGS (Dee L. Lurry) in Fort Worth who confirmed that most of their sub-basin monitoring stations were inactive during 2001 and for several years prior. Monitoring at some of these stations has since been reestablished, however, not all sub-basins have stations.

The team then considered using SWAT model output for sub-basin discharges pertaining to the field survey period. Hydrologic data simulated from the SWAT model run through 1999 (this report). At our request, the Blacklands group considered the possibility of modeling 2001 discharges, however it was ultimately deemed inappropriate (S. T. Bednarz, personal communication).

Since hydrologic data were lacking for sub-basin conditions of both study regions immediate prior to and during the survey period, the analyses focussed on relating F-IBI scores to actual current land-cover characteristics and land covers formulated for future scenarios.

*Predictions for Alternative Land-cover Scenarios*

Using both the seven-factor (complete model) and two-factor (cedar, mesquite) regression models (Table 4.11), expected changes in mean sub-basin F-IBI scores were computed based upon five alternative land-cover scenarios (Table 4.12). Regression coefficients, $R^2$ values, and significance of the complete model and two-factor model are presented in Table 4.11. Figure 4.8 illustrates the relationship between observed and predicted mean sub-basin F-IBI scores. Although the two-factor model explained a smaller percentage of variance than the complete model, comparisons among alternative scenarios are based on the two-factor model because the two-factor model more directly relates to the management scheme of the project, i.e., it only includes cedar and mesquite as response variables.

F-IBI predictions based upon scenario-based land cover characteristics indicate the Twin Buttes watershed would experience a greater change in aquatic communities compared to the Edwards recharge zone (Table 4.12). Qualitatively, Table 4.12 clearly indicates Scenarios I, II, and III result in increased health of aquatic communities in both the Edwards and Twin Buttes watersheds. Scenario V, which represents no brush management and succession of vegetation communities through time, results in depressed aquatic community health with some sub-basins showing average F-IBI scores indicative of “Poor” conditions. Quantitative comparison between Scenario IV and Scenarios I, II, and III reveals an average improvement of F-IBI scores among Edwards sub-basins of 4-5 points. However, mean F-IBI score increased 22, 20, and 10 points for the Twin Buttes basin for Scenarios I, II, and III, respectively. Similarly, Scenario V results in a mean reduction of 2 F-IBI points for Edwards sub-basins, but Twin Buttes sub-basins decline by an average of 17 points. Thus, this analysis indicates that brush management would have potential benefits for stream ecosystem health and aquatic fauna in both regions, with greatest benefits in the Twin Buttes watershed.

*Results from multivariate analysis of assemblage patterns*

Canonical correspondence analysis indicated that water depth was an important variable influencing fish and invertebrate assemblage structure. Water depth had the highest variable loading on the dominant CCA axis (axis 1) for fish datasets from both regions (Table 4.8) and the invertebrate dataset from the Edwards recharge region (Table 4.9). Mean water velocity loaded strongly and positively on CCA axis one for Twin Buttes invertebrates, which also had a weak negative association with water depth in this region. Many stream reaches in the Twin Buttes region were reduced to series of isolated pools. Sometimes pools were connected by narrow, shallow riffles of flowing water. The second CCA axis was influenced by a different set of variables in each of the four datasets. For fishes from Twin Buttes, the second axis modeled a gradient that contrasted coarse substrates and more uniform channel width with clay-dominated substrates and more variable channel width (Table 4.8). For fishes from Edwards region, the second axis contrasted warm sites with low conductivity and fine-grained substrates with sites having the opposite set of conditions (Table 4.8). For invertebrates from Twin Buttes, the second axis contrasted sites with variable depth, high conductivity and clay/sand substrates with sites having the opposite set of conditions (Table 4.9). For invertebrates of the Edwards region, the second axis contrasted sites with high pH and substrates dominated by clay and pebbles with sites having the opposite set of conditions.

Ordination of sites on CCA axes 1 and 2 showed low correspondence with F-IBI categories for the Twin Buttes watershed (Figure 4.9), and fairly high correspondence with F-IBI categories for the Edwards recharge zone (Figure 4.10). Thus, overall, the physical environmental parameters that we measured and entered into the CCA were not good predictors of aquatic ecosystem health. This result is not surprising, since the rationale behind development of indices of biotic integrity is that faunal assemblage structure integrates disturbances to the ecosystem and provides a much better indication of overall conditions than any single environmental parameter or suite of environmental parameters. CCA ordination of aquatic invertebrates also showed relatively low correspondence with B-IBI categories (Figures 4.8 and 4.9), again with the Edwards dataset showing a stronger pattern than the Twin Buttes dataset. A factor that might explain the poor correspondence between IBI categories and environmental gradients for the Twin Buttes datasets is the fact that drought conditions were more chronic and severe in this region during our survey.

**Table 4.8. Canonical coefficients from CCA analysis of fish data.**

*Twin Buttes*

| Environmental Variable | Axis I | Axis II |
|---|---|---|
| Mean depth | **-0.2861** | -0.1525 |
| Mud | -0.0789 | **0.2507** |
| Dissolved oxygen | -0.0778 | **0.2304** |
| Cobble | -0.0286 | **0.4401** |
| Detritus | 0.0081 | **0.3258** |
| Water pH | 0.0383 | **-0.2305** |
| Clay | 0.0409 | **-0.2166** |
| Stream width coefficient of variation | 0.0793 | **-0.3114** |
| Water conductivity | 0.1053 | **-0.2881** |

*Edwards*

| Environmental Variable | Axis I | Axis II |
|---|---|---|
| Mean depth | **-0.5197** | 0.057 |
| Water temperature | **-0.3228** | **-0.3318** |
| Pebble | **-0.1849** | **0.2233** |
| Bedrock | -0.1257 | **0.2429** |
| Mud | -0.0622 | **0.1626** |
| Sand | 0.058 | **0.1803** |
| Cobble | 0.0585 | **0.166** |
| Water pH | 0.0732 | **0.2037** |
| Depth coefficient of variation | **0.1219** | **0.1256** |
| Water conductivity | **0.2745** | **0.3213** |

**Table 4.9. Canonical coefficients from CCA analysis of invertebrate data**

*Twin Buttes*

| Environmental Variable | Axis I | Axis II |
|---|---|---|
| **Mean depth** | -0.0399 | **0.354** |
| **Depth coefficient of variation** | -0.0939 | **0.8937** |
| **Mean flow velocity** | **0.9131** | 0.076 |
| **Sand** | -0.0735 | **0.2984** |
| **Clay** | -0.1335 | **0.4486** |
| **Conductivity** | 0.0267 | **0.5423** |

**Edwards**

| Environmental Variable | Axis I | Axis II |
|---|---|---|
| **Mean depth** | **-0.3569** | 0.1423 |
| **Clay** | -0.3306 | **0.8343** |
| **pH of water** | -0.2993 | **0.7164** |
| **Pebble** | 0.0674 | **0.6709** |
| **Depth coefficient of variation** | **0.392** | -0.0442 |
| **Mean flow velocity** | **0.4649** | 0.1556 |

**Table 4.10. Fishes collected by drainage.**

| Fish Species | | Drainage | |
|---|---|---|---|
| **Scientific name** | **Common name** | **Edwards** | **Twin Buttes** |
| *Ameirus natalis* | Yellow bullhead | X | |
| *Ameirus melas* | Black bullhead | | X |
| *Astyanax mexicanus* | Mexican tetra | X | |
| *Campostoma anomalum* | Central stoneroller | X | X |
| *Cyprinella lutrensis* | Red shiner | X | X |
| *Cyprinella lepida* | Edwards Plateau shiner | X | |
| *Cyprinella venusta* | Blacktail shiner | X | X |
| *Cyprinus carpio* | Common carp | | X |
| *Dionda argentosa* | Manantial roundnose minnow | X | X |
| *Dionda serena* | Nueces roundnose minnow | X | |
| *Dorosoma cepedianum* | Gizzard shad | | X |
| *Etheostoma lepidum* | Greenthroat darter | X | X |
| *Etheostoma spectabile* | Orangethroat darter | X | X |
| *Gambusia affinis* | Mosquitofish | X | X |
| *Herichthys cyanoguttatum* | Rio Grande cichlid | X | |
| *Ictalurus punctatus* | Channel catfish | X | X |
| *Lepisosteus oculatus* | Spotted gar | | X |
| *Lepomis auritus* | Redbreast sunfish | X | X |
| *Lepomis cyanellus* | Green sunfish | X | X |
| *Lepomis gulosus* | Warmouth | X | X |
| *Lepomis hybrid* | Sunfish hybrid | X | X |
| *Lepomis macrochirus* | Bluegill | X | X |
| *Lepomis megalotis* | Longear sunfish | X | X |
| *Lepomis microlophus* | Redear sunfish | X | X |
| *Micropterus salmoides* | Largemouth bass | X | X |
| *Mircopterus punctulatus* | Spotted bass | X | X |
| *Mircopterus treculi* | Guadalupe bass | X | X |
| *Moxostoma congestum* | Gray redhorse | X | |
| *Notemigonus crysoleucas* | Golden shiner | | X |
| *Notropis amabalis* | Texas shiner | X | X |
| *Notropis ludibundus* | Sand shiner | X | X |
| *Noturus nocturnus* | Freckled madtom | | X |
| *Percina carbonaria* | Texas logperch | X | |
| *Pimephales vigilax* | Bullhead minnow | X | X |

**Table 4.11. Regression model coefficients and significance**

| | Intercept | Cedar | Mesquite | Mixed | Oak | Pasture | Urban | Cropland | $r^2$ (Adjusted $r^2$) | P |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Mean Fish IBI Score* | | | | | |
| Complete Model | 58.3 | -193.4 | 79.4 | 31.9 | 214.1 | 235.0 | 1534.6 | -238.8 | 0.6228 (0.4342) | 0.0272 |
| Two Factor Model | 77.3 | -94.1 | -75.3 | | | | | | 0.3509 (0.2825) | 0.0165 |

*$r^2$ equals the percent of variation in the dependent variable accounted for by the independent predictor variables.*

**Recommendations for future studies**

Future studies seeking to evaluate the status of stream systems in the Twin Buttes and Edwards watersheds should focus their limited resources on fish samples. Analysis of fish samples had greater predictive power than costly and time-consuming analysis of benthic invertebrate samples. Time spent sorting and identifying benthic macroinvertebrates would be better spent collecting additional fish samples from more sites during more periods.

More robust IBIs and regression models could be achieved by increasing the number of samples and spatial coverage on landscapes. Our project was preliminary and short duration. Our field surveys were conducted during conditions of prolonged drought (especially in the Twin Buttes region) and access to private lands was restricted. Consequently, the team was constrained to sampling a subset of the sub-basins in each region. Future studies should be afforded more time for survey planning that could encompass more sites within and among sub-basins. In addition, the influence of spatial scale of resolution on model predictions (Roth et al. 1996) should be investigated.

Temporal variation in environmental conditions needs to be incorporated into future studies. We believe sampling during summer base flow is the most suitable time for sampling stream fauna; however, data need to be collected from multiple years to ensure robust predictive models. Because we sampled during a drought year, our model may not predict well for non-drought years. Sampling over multiple years would increase confidence in predictive models developed from field-based samples. Empirically-based models can be influenced by changing environmental conditions such as those associated with drought or altered land cover or land use (Harding et al. 1998).

Now that our IBI and predictive models have been constructed, they need to be validated (tested with independent data). Ideally, one could identify additional sample sites and estimate the health of these new sites using another set of criteria. Our IBI assessment then could be compared with the alternative set of criteria and modified if necessary.

Lotic ecosystems are influenced directly by discharge characteristics. In future studies, discharge and instream flow characteristics should be modeled at the sub-basin scale. This would permit formal linkage between IBI scores and model discharge outputs

**Table 4.12. Mean observed F-IBI score by sub-basin, and F-IBI scores by scenario by sub-basin as predicted by the two factor (cedar and mewquite) model.**

| Watershed | Sub-basin Number | Observed | Scenario I | Scenario II | Scenario III | Scenario IV | Scenario V |
|---|---|---|---|---|---|---|---|
| Edwards | 2010301 | 76 | 68 | 67 | 67 | 63 | 62 |
| Edwards | 2010401 | 60 | 65 | 64 | 64 | 60 | 59 |
| Edwards | 2010501 | 68 | 71 | 71 | 71 | 68 | 66 |
| Edwards | 2010601 | 64 | 68 | 67 | 67 | 64 | 63 |
| Edwards | 2020201 | 66 | 70 | 73 | 73 | 68 | 65 |
| Edwards | 2020303 | 79 | 75 | 74 | 73 | 68 | 65 |
| Edwards | 6010101 | 77 | 75 | 75 | 74 | 71 | 68 |
| Edwards | 6010301 | 63 | 69 | 68 | 68 | 65 | 64 |
| Edwards | 6010501 | 61 | 67 | 66 | 66 | 63 | 62 |
| Edwards | 6010503 | 61 | 68 | 68 | 68 | 65 | 64 |
| Edwards | 6010801 | 75 | 73 | 73 | 73 | 69 | 67 |
| Edwards | 6060101 | 65 | 65 | 64 | 64 | 60 | 59 |
| Edwards | 6060201 | 62 | 64 | 63 | 63 | 59 | 59 |
| Edwards | 6060301 | 61 | 72 | 72 | 72 | 69 | 66 |
| Edwards | 6060501 | 59 | 77 | 76 | 74 | 72 | 68 |
| Edwards | 7060105 | 59 | 69 | 68 | 68 | 60 | 59 |
| Twin Buttes | MC 25 | 40 | 76 | 74 | 64 | 54 | 36 |
| Twin Buttes | MC 27 | 60 | 76 | 75 | 64 | 53 | 36 |
| Twin Buttes | SC 16 | 71 | 77 | 75 | 66 | 55 | 39 |
| Twin Buttes | SD 13 | 43 | 76 | 74 | 65 | 51 | 36 |
| Twin Buttes | SD 15 | 44 | 76 | 76 | 66 | 57 | 39 |
| Twin Buttes | SD 21 | 66 | 77 | 76 | 66 | 58 | 41 |

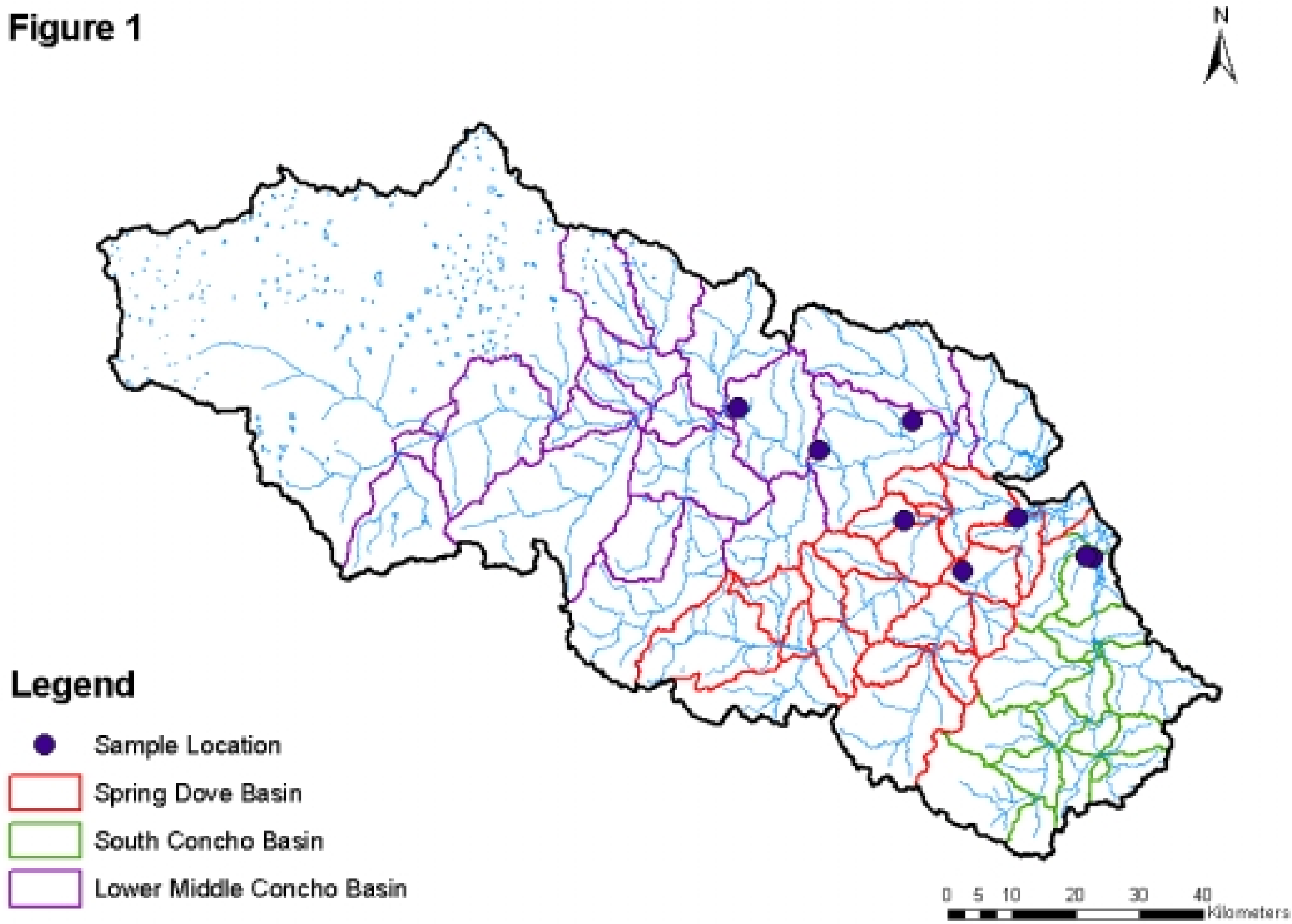


**Figure 4.1.** **Twin Buttes watershed with basin and sub-basin boundaries and aquatic biological survey locations illustrated. Sample locations are represented by filled circles. Typically, multiple samples were collected at each location.**

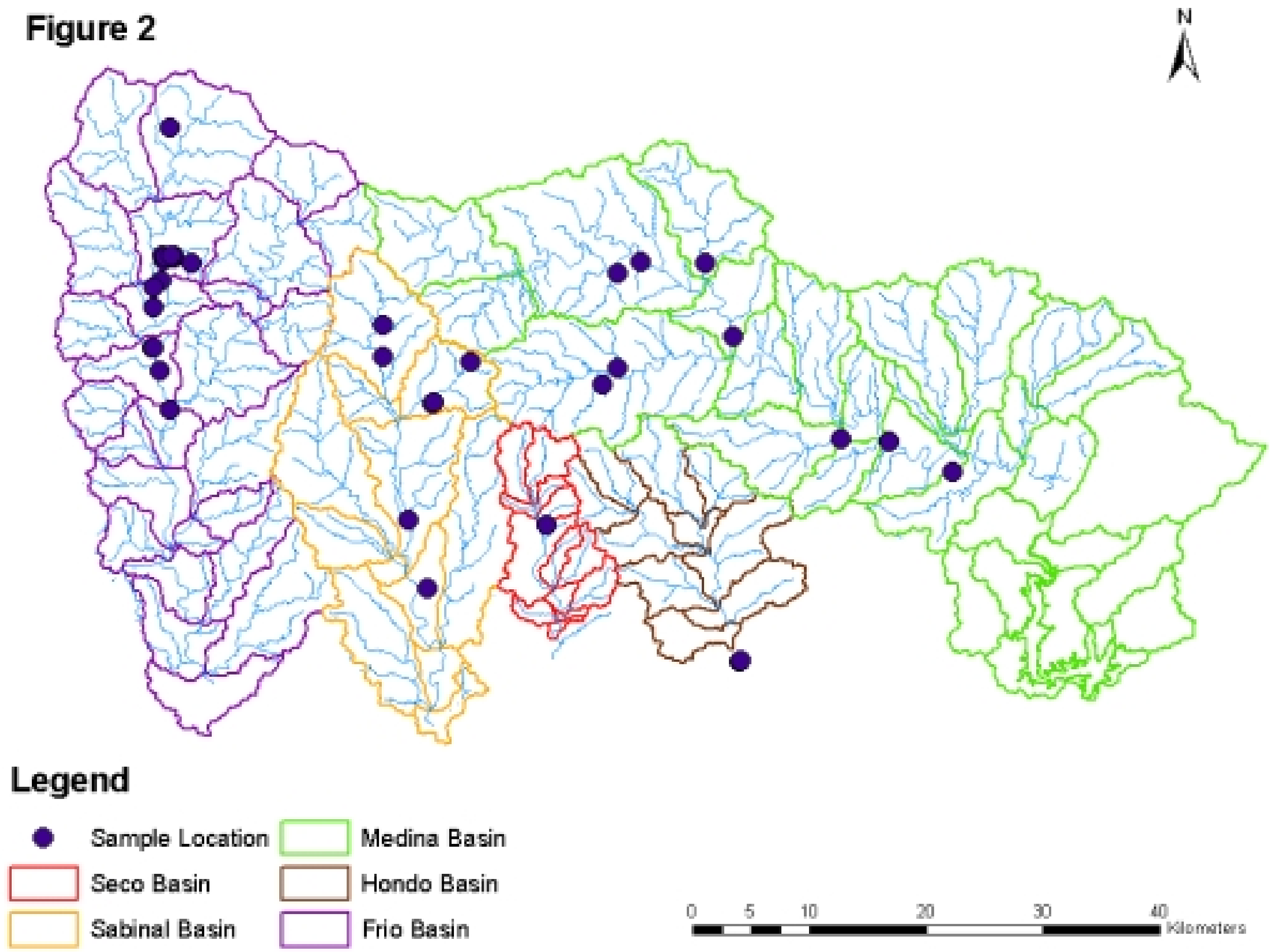


**Figure 4.2** **Edwards watershed with basin and sub-basin boundaries and aquatic biological survey locations illustrated. Sample locations are represented by filled circles. Typically, multiple samples were collected at each location.**

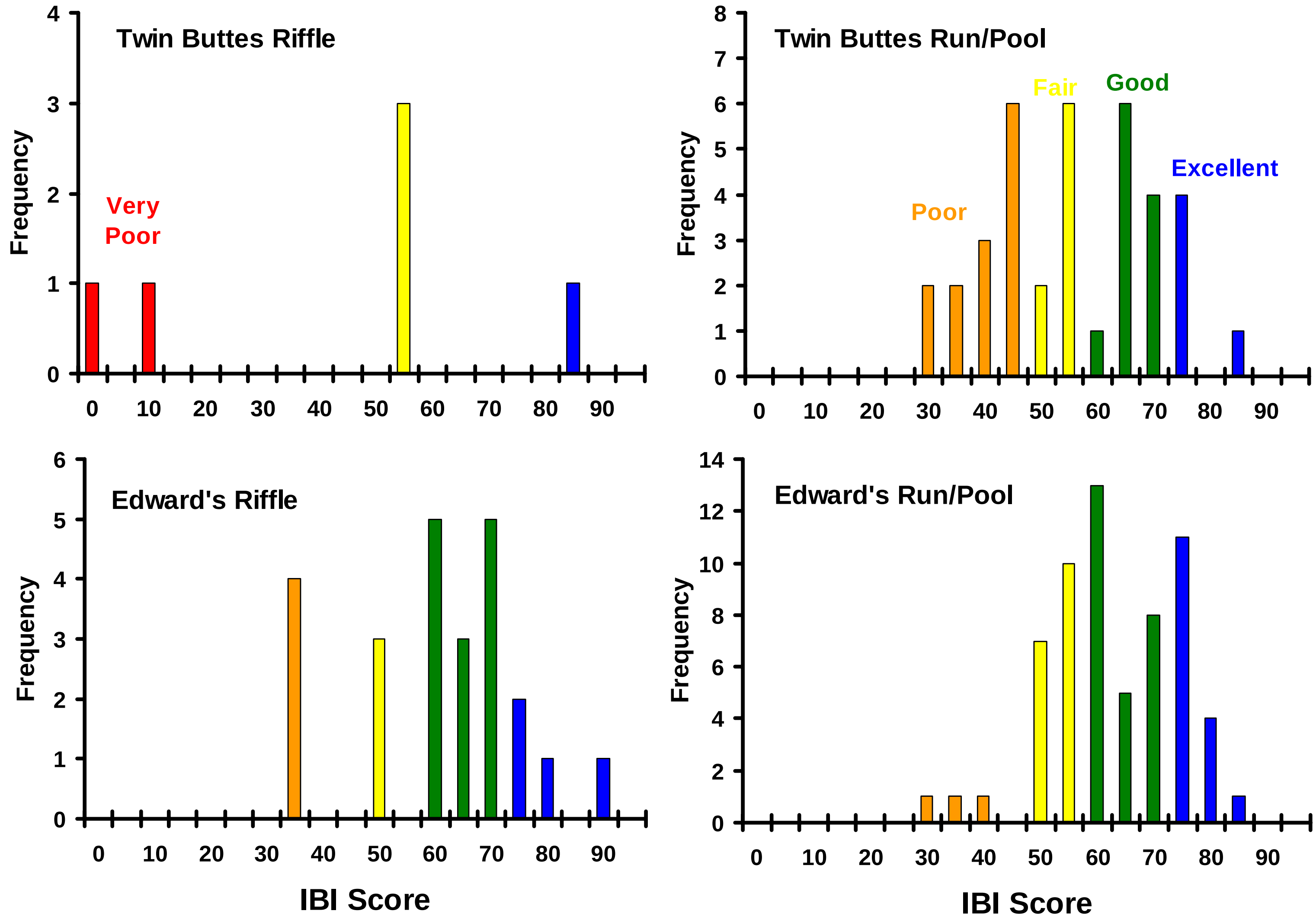


**Figure 4.3.** **Frequency histograms of F-IBI scores by drainage by habitat.**

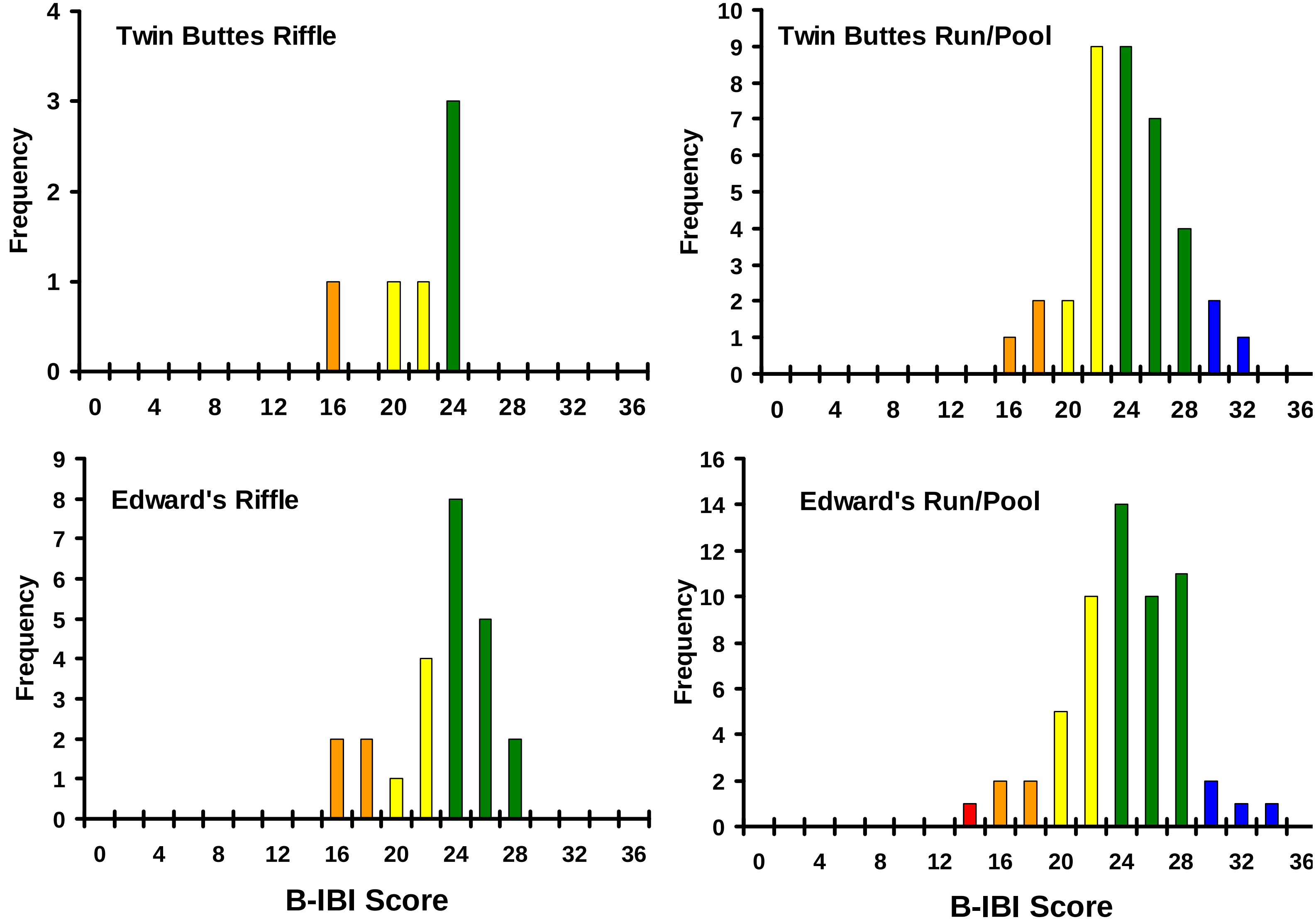


**Figure 4.4. Frequency histograms of B-IBI scores by drainage by habitat.**

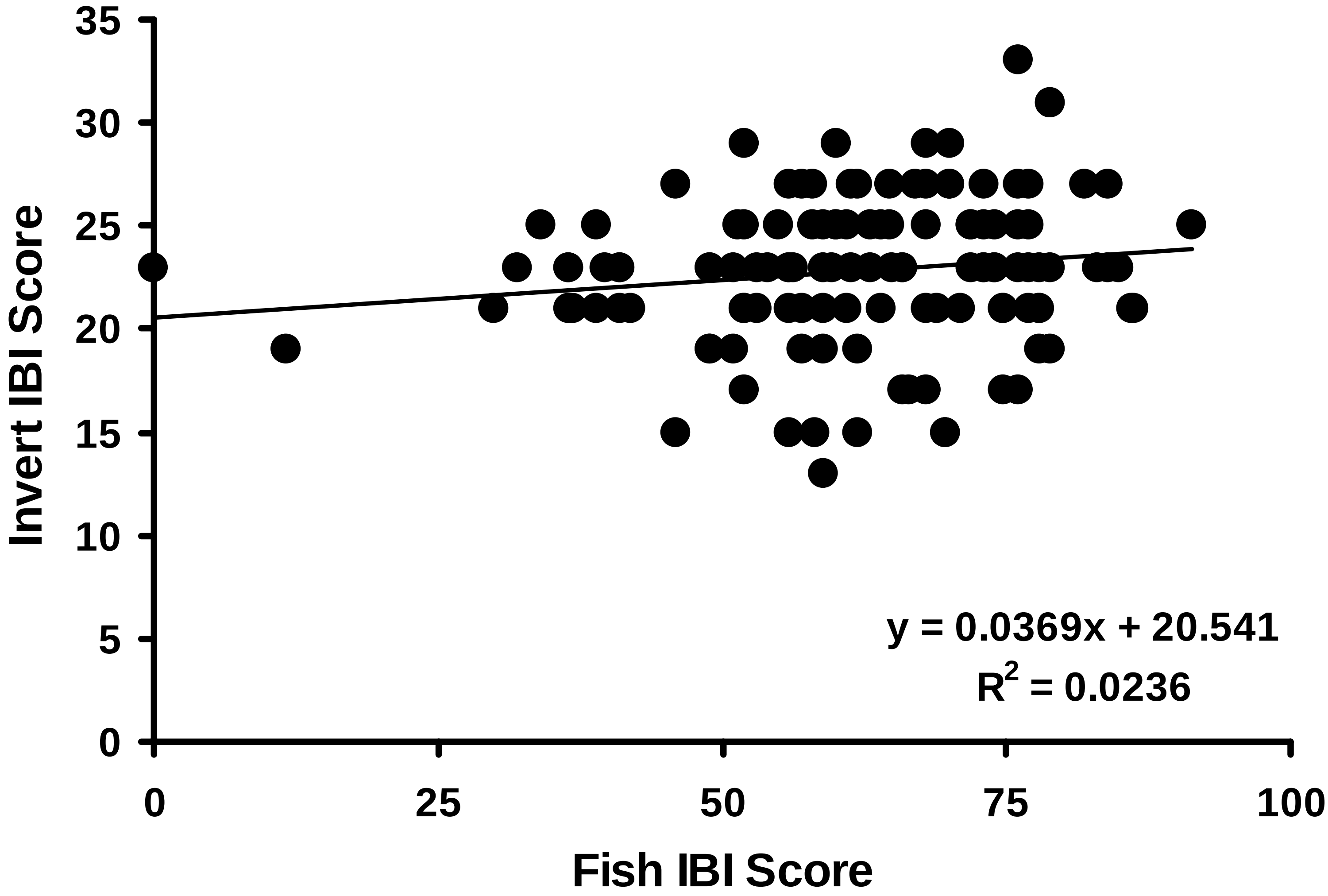


**Figure 4.5.** **Relationship between calculated fish (F-IBI) and benthic macroinvertebrate (B-IBI) IBI scores. There was little concordance between fish and invertebrate IBI scores ($R^2$ = 0.024; P = 0.09).**

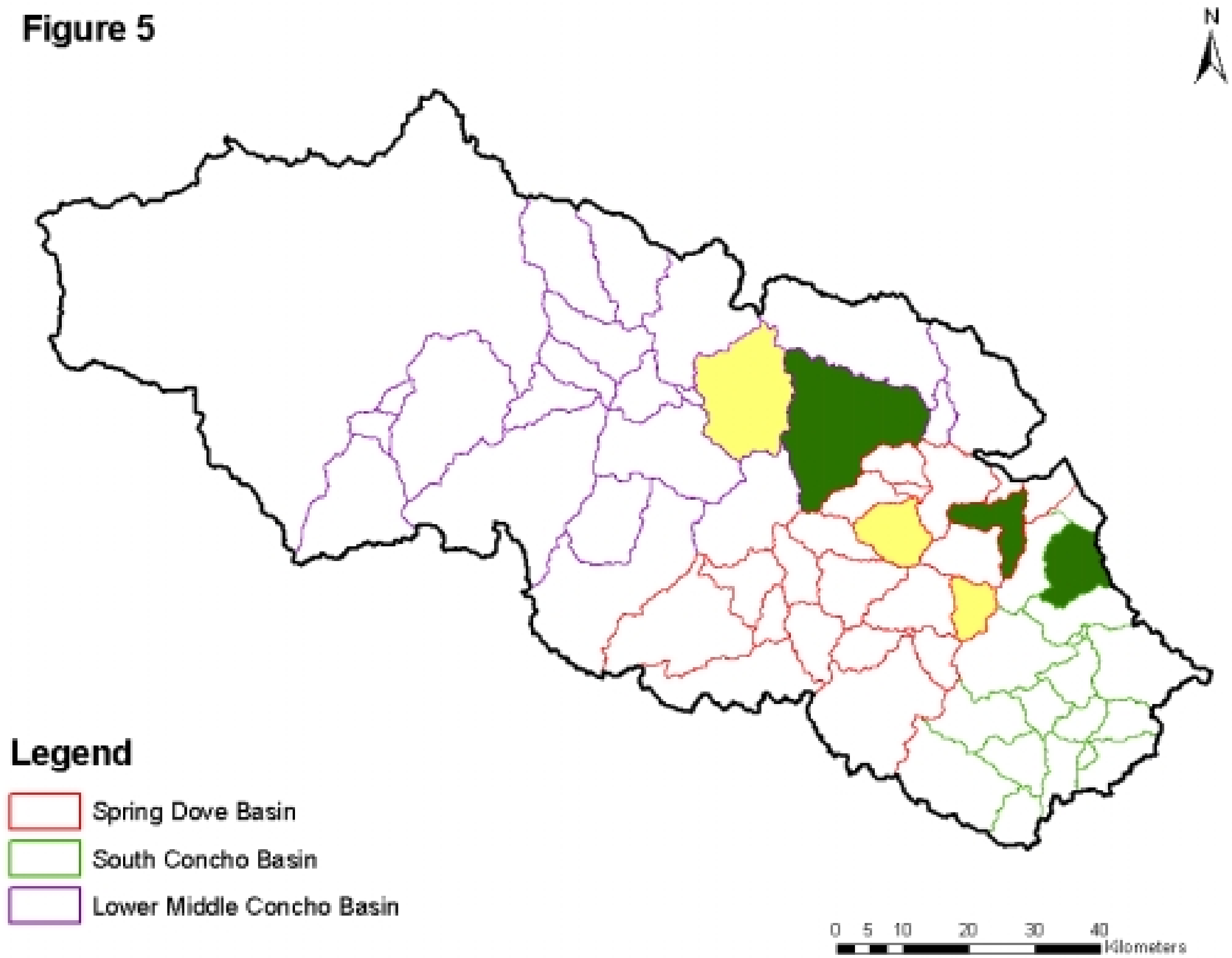


**Figure 4.6.** **Twin Buttes sub-basins colored by the minimum F-IBI score.**

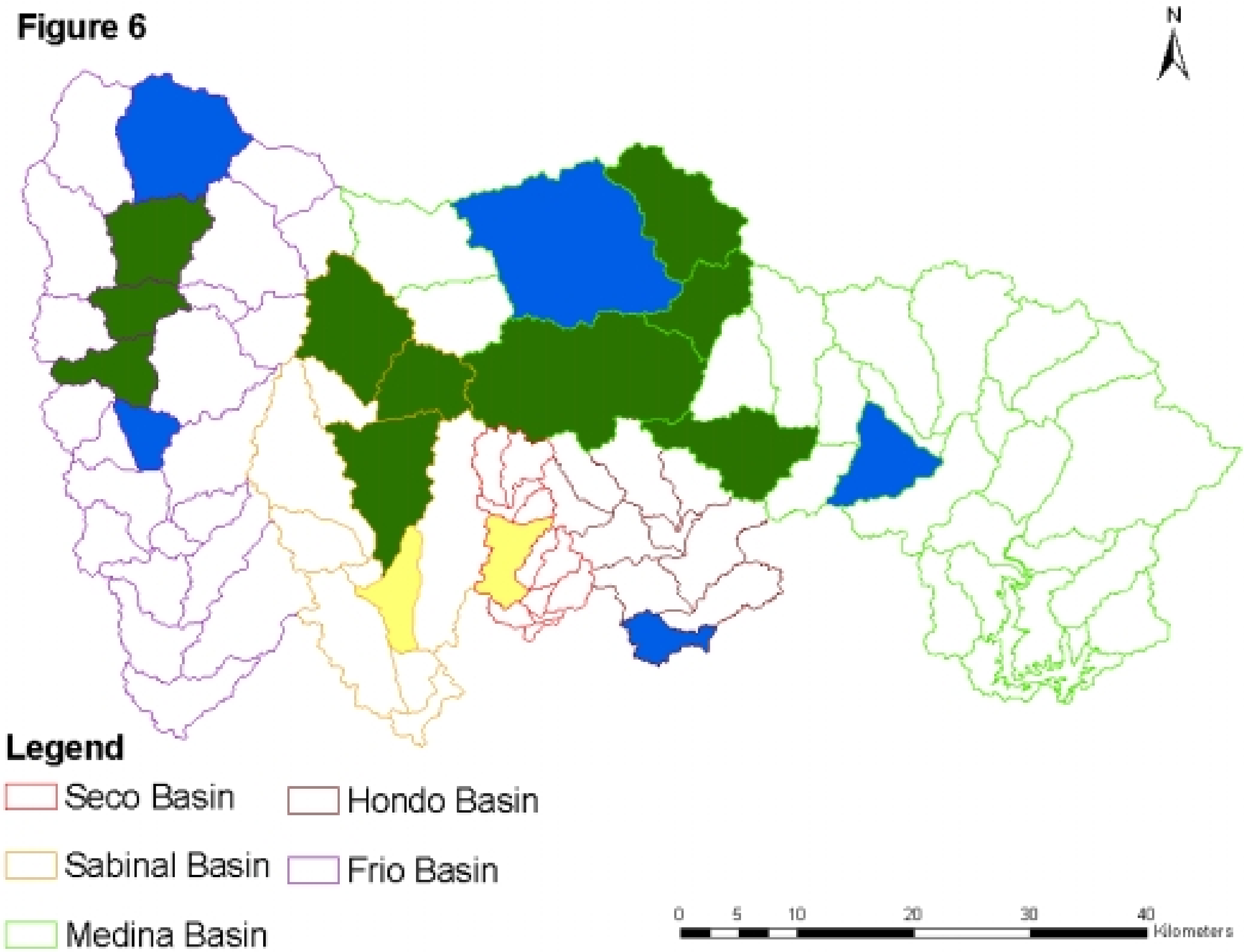


**Figure 4.7.** **Edwards sub-basins colored by the minimum F-IBI score.**

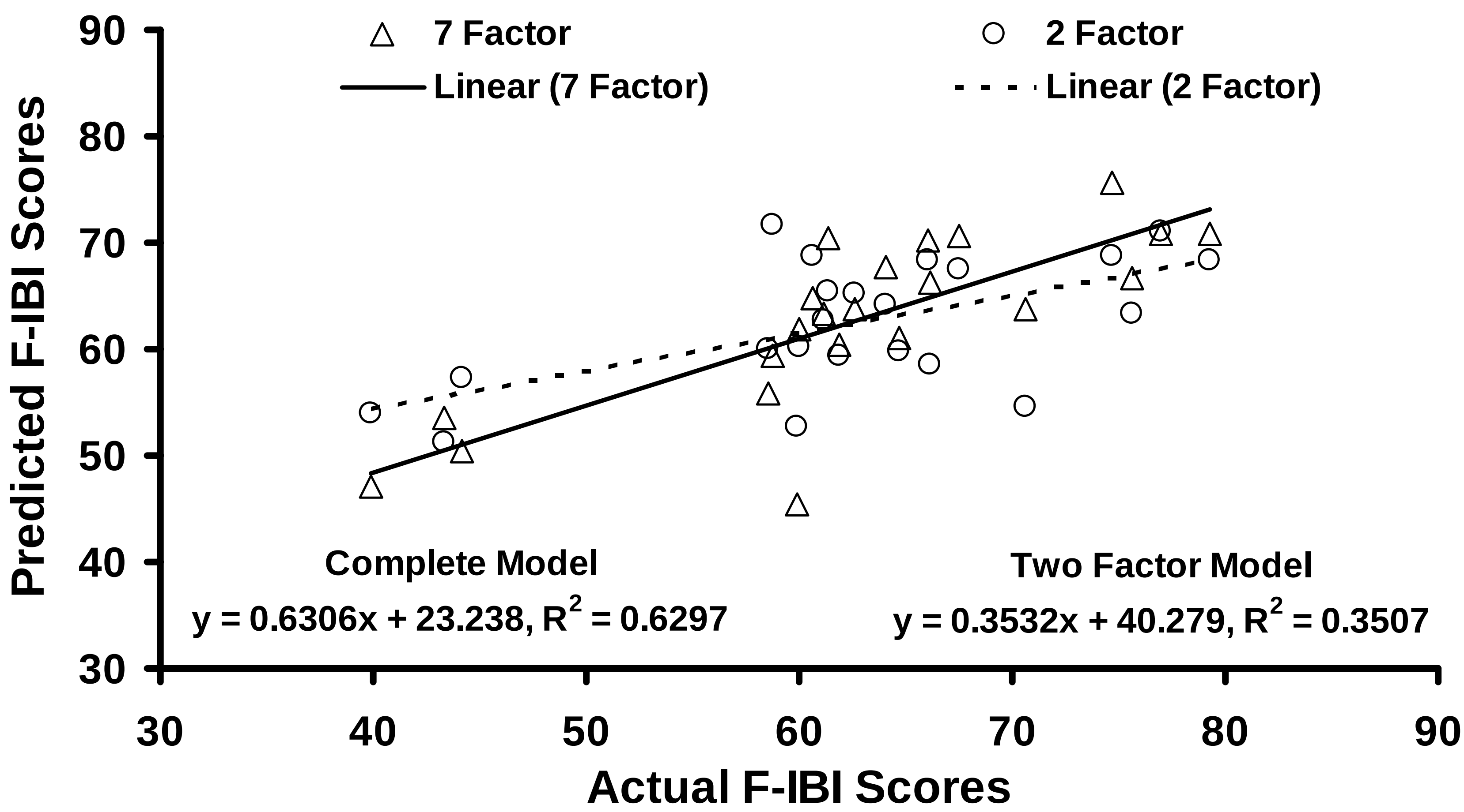


**Figure 4.8.** **Relationship between observed and predicted F-IBI scores by sub-basin for both the complete seven factor model and the selected two factor (cedar and mesquite) model.**

Twin Buttes Fish CCA

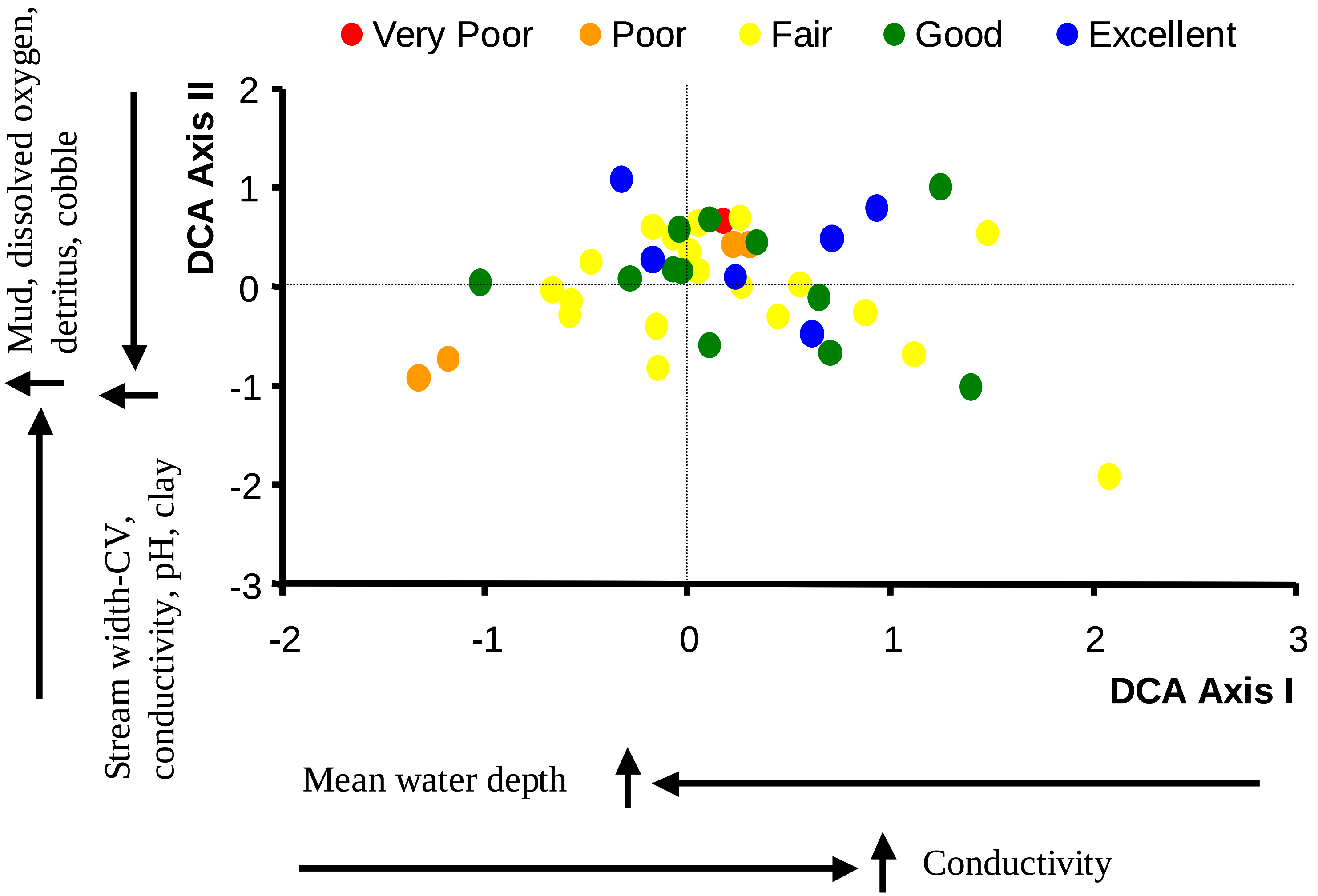


**Figure 4.9. Twin Buttes CCA analysis results indicating the influence of physical habitat parameters on fish assemblages and the observed relationship between these parameters on observed F-IBI scores.**

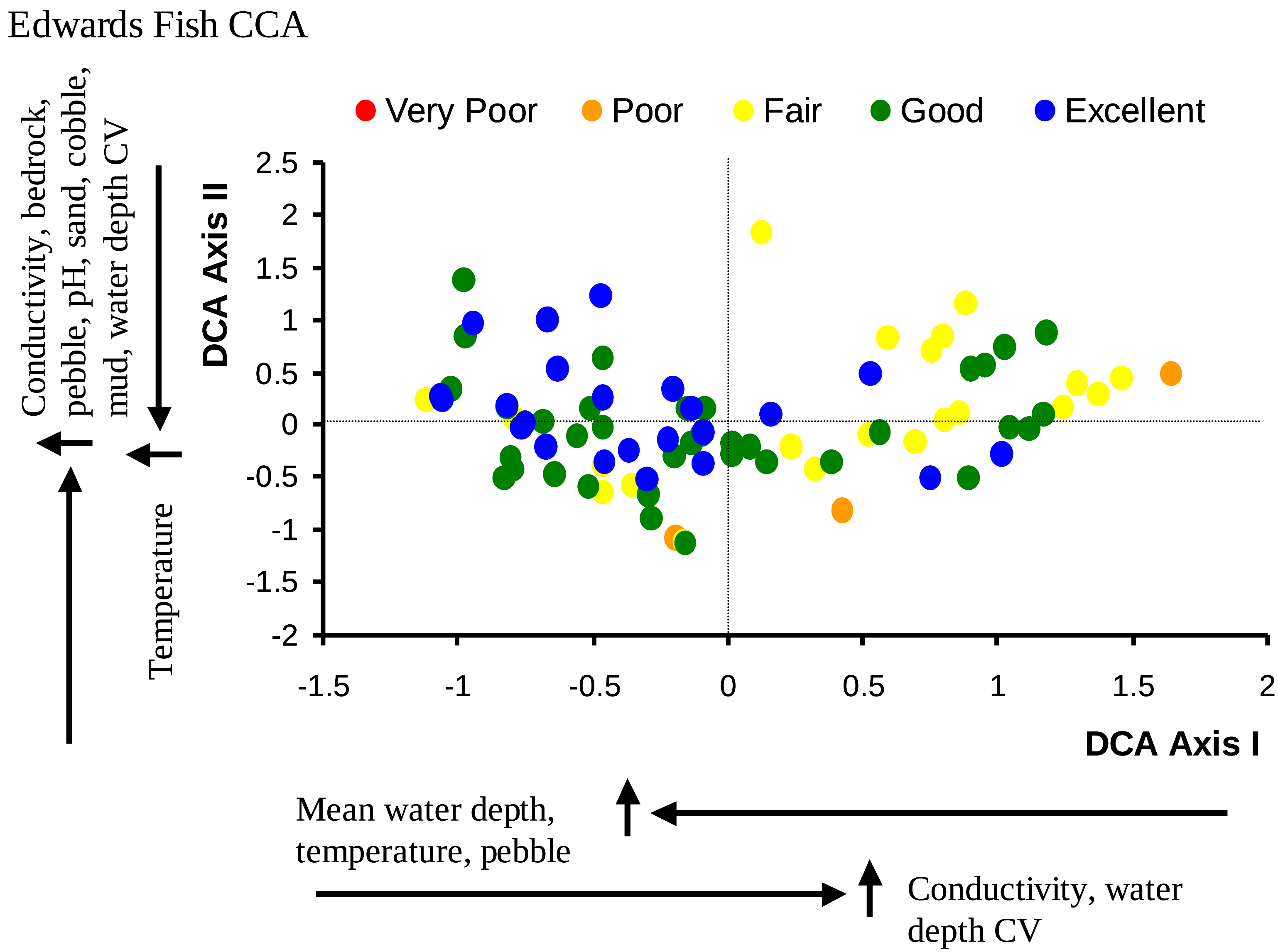


**Figure 4.10.** **Edwards CCA analysis results indicating the influence of physical habitat parameters on fish assemblages and the observed relationship between these parameters on observed F-IBI scores.**

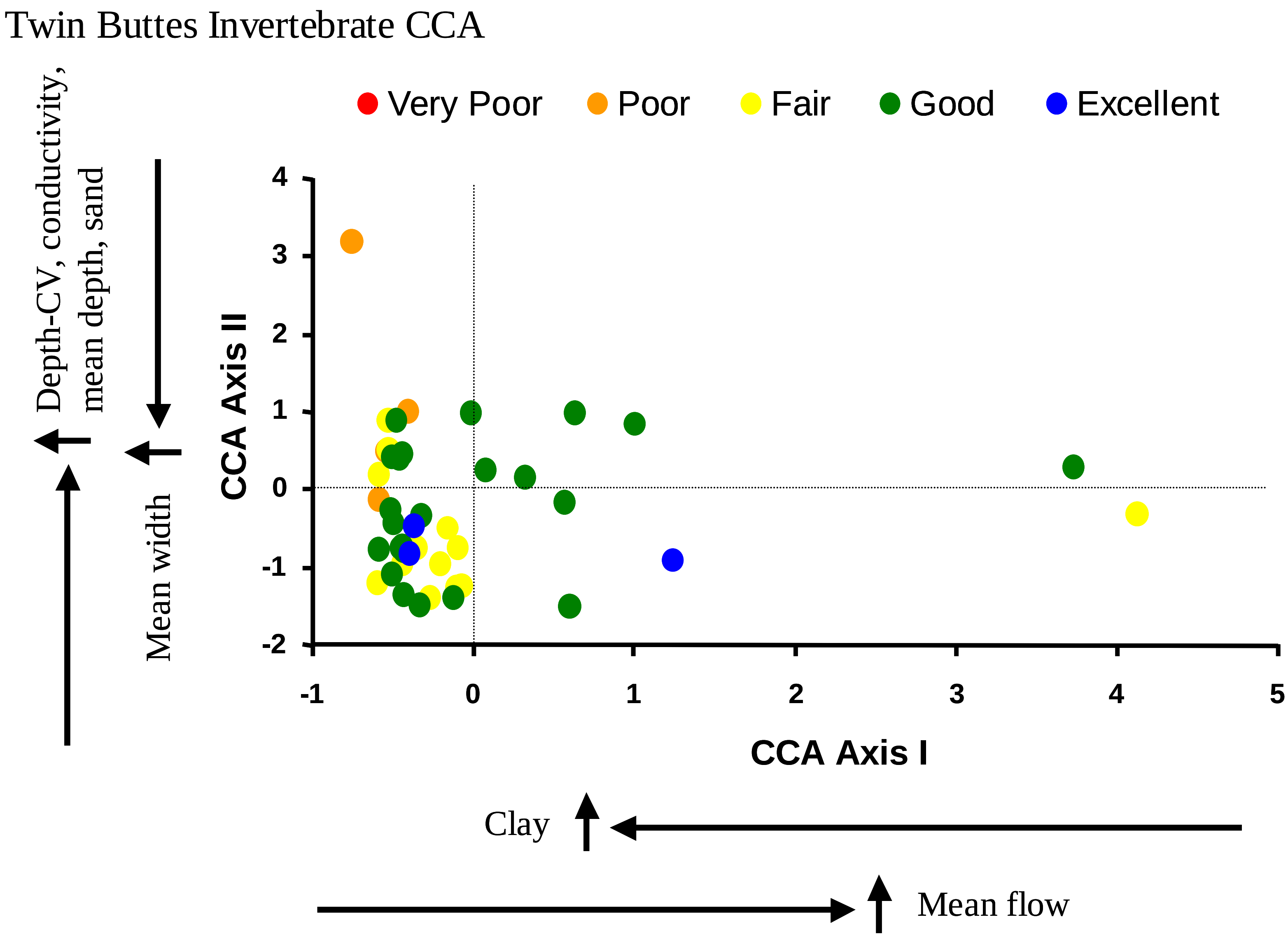


**Figure 4.11. Twin Buttes CCA analysis results indicating the influence of physical habitat parameters on invertebrate assemblages and the observed relationship between these parameters on observed B-IBI scores.**

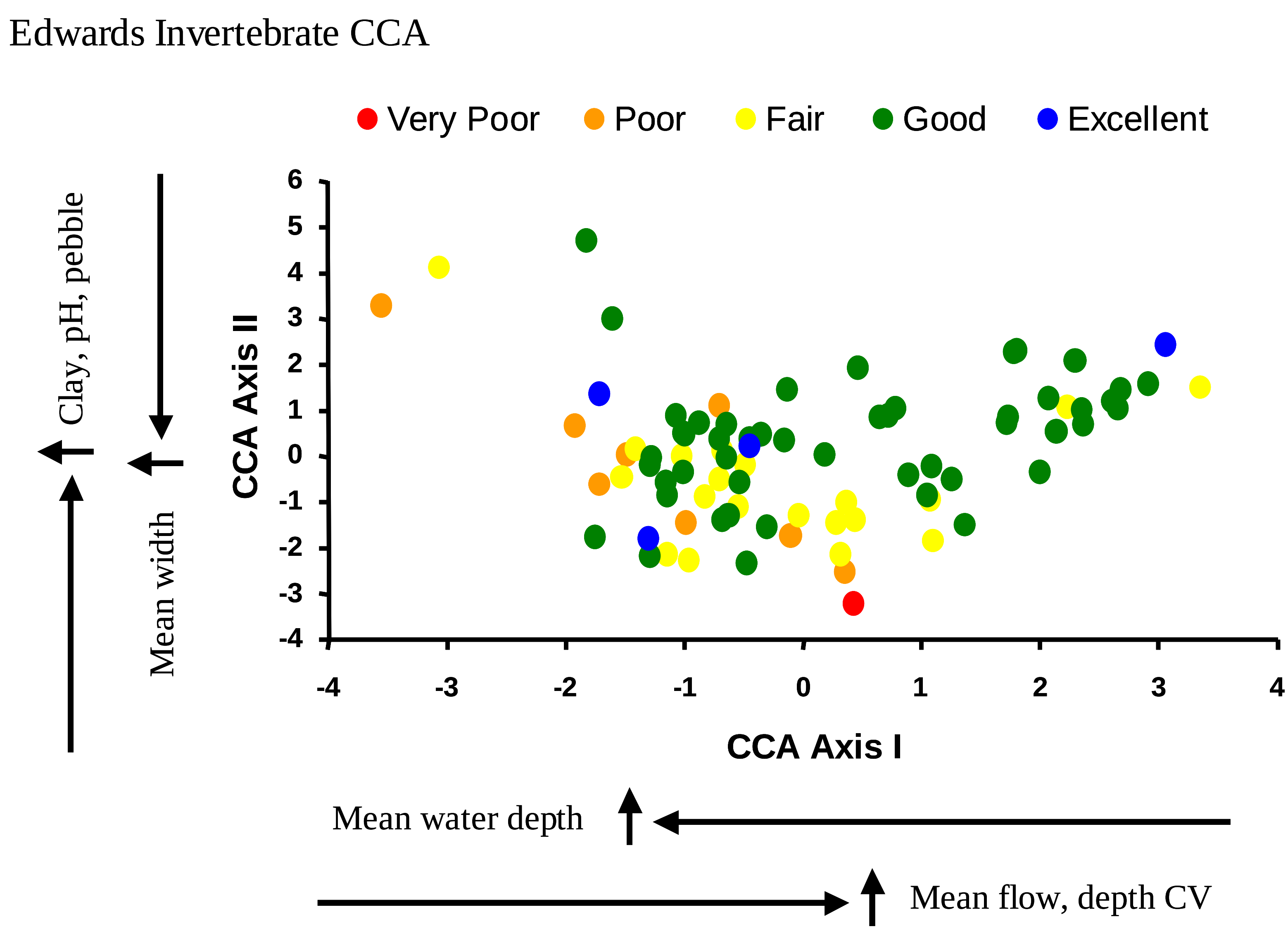


**Figure 4.12. Edwards CCA analysis results indicating the influence of physical habitat parameters on invertebrate assemblages and the observed relationship between these parameters on observed B-IBI scores.**

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# APPENDIX A. Refinement of Riparian Areas

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**Introduction**

This appendix is to supplement the range/economics chapter of the report. In this section, various riparian-specific restoration treatments are incorporated to existing brush management/restoration practices for Scenarios II and III for all watersheds within both study areas.

Specifically, the objectives of this supplement effort are to identify the different broad riparian types in both watersheds with respect to soils, water flows, landform type, vegetation, and management emphasis. Appropriate treatments and associated costs for all riparian types are then summarized. Finally, total society cost of each scenario and society cost for added acre-feet of water for all watersheds within both study areas assuming the identified riparian restoration treatments are conducted are estimated and compared across treatments and with Scenarios II and III in Chapter II.

**Methods**

Methodology used in Chapter II to calculate total society cost and cost of additional water closely mirrors that which is used in this appendix. The key difference in this section is the treatment of light, moderate, and heavy brush occurring within the 150m riparian buffer. For Scenarios II and III in Chapter II, all brush occurring in the buffer was not treated and no other treatments were performed. Here, total acres of light, moderate, and heavy brush occurring in the riparian buffer zone on slopes less than 15% were summed to form an estimated total treatable riparian acres figure for Scenarios II and III (in this section of the report, these scenarios will be referred to as Scenario II Rip and Scenario III Rip). This figure was then multiplied by a study area-specific estimated percentage of each riparian type to arrive at total acres of each riparian condition. Treatment costs for each riparian condition were calculated by multiplying the amount of each riparian type occurring in each sub-basin by the treatment cost for that riparian type. Next, riparian restoration treatment costs were added to estimated society costs for the non-riparian areas to arrive at a total society cost of additional water. Like Chapter II, the total society cost of additional water was divided by the additional acre feet yielded from Scenario II and III to estimate the society cost per additional acre-foot of water.

For non-riparian buffer zone areas, assumptions for changes in livestock carrying capacity, brush management/restoration techniques and costs, livestock/wildlife enterprises, and discount rate are identical to those used in Chapter II. Like Chapter II, this analysis also assumes restoration treatments such as reseeding, grazing deferments, and implementation of improved grazing management systems were used for non-riparian areas.

Recommended riparian restoration treatments and associated costs were identified by range scientists. Because existing riparian types differ between the Edwards and the Twin Buttes, different assumptions are used for each (Tables A1 and A2). Cross fencing and additional water source costs are identical to those used in Chapter II. Cost of buffer fencing was determined by taking the stream length distance of one acre in the riparian zone assumed to be 150m wide. Next, this distance was multiplied by the cost of fencing ($1.25) and then by the number of sides of the corridor (2). Ten year grazing deferment costs were calculated by taking the inverse of the grazing capacity of the riparian type to compute the number of animal units that one acre of that riparian type would support. Next, a yearly lease value of $100 was multiplied by the number of animal units that could be supported by the acre. This product was then discounted for each of the ten years in the investment analysis using the 6% discount rate assumed in Chapter II. Costs associated with treating riparian acres were assumed to be entirely society costs. Where grazing deferments exists, an explicit assumption is that the society will pay the cost of deferments directly to landowners.

The Blackland Research Center provided the data used to determine the amount of brush located in the buffer zone. Acres of brush to be treated with riparian treatments was calculated by first taking the total amount of light, moderate, and heavy brush located in the riparian area. Next, this sum was multiplied by the percentage of all brush in a particular sub-basin occurring on slopes less than 15% to arrive at an estimated amount of treatable acres of riparian brush. Similar to Chapter II, all treatments are only conducted on sub-basins that receive an average yearly rainfall of 18 inches or more.

Assumptions for water yield used for Scenarios II Rip and III Rip are identical to those assumed for Scenario II and III in Chapter II. Because the relatively small amounts restoration treatments performed in the eight watersheds will not dramatically alter vegetation over Scenarios II and III, we feel this is a safe assumption.

**Results and Discussion**

*Riparian Types*

**Twin Buttes**

The Twin Buttes was divided into three broad riparian conditions. Riparian Type I is described as a shallow draw. Angelo Silty Clay Loam [AnB] is usually associated with a Type I riparian area. It is a first order stream zone whose flow is ephemeral, usually flowing for short periods following major rainfalls. Its landform is a shallow draw with parabolic valley floor having 3-5% channel gradient (max ~8%). It has very few channel cuts and is straight with few meanders. Land classified as Type I generally does not contain "riparian" woody plants, but are often dominated at their upper ends by mesquite and redberry juniper. Dominant grasses include sideoats grama, Texas wintergrass and Wrights threawn. The management emphasis includes mechanical control of juniper and mesquite regrowth adjacent to channel as well as prescribed fire or individual plant treatments.

Riparian Type II, dry creeks and draws, are generally 2$^{nd}$ order streams with Rio Concho and Angelo soils [RV, RO][AnA, AnB]. It has intermittent surface flow with a moderately confined channel. The stream channel is identifiable and has some meandering. Stream gradient is 1-3% (max~5%). Woody shrubs include lotebush, juniper, mesquite, Texas persimmon, and dominant grasses include buffalograss and vinemesquite. The management emphasis for Type II riparian areas in the Twin Buttes include the thinning of juniper and mesquite, buffer fencing where possible, grazing deferment, and prescribed fire or individual plant treatments.

Riparian Type III are areas having perennial streams that are primarily 3rd order, though some are of higher order. Soils are almost exclusively Rio Concho [RV, RO]. The perennial stream flow may pool at infrequent intervals. The associated landform of Type III is a relatively broad flood plain with unconfined channels and a 1-3% channel gradient. Woody indicators include hackberry, walnut, oak, and pecan, which increases in abundance down stream. In addition, large juniper and mesquite can be found as well as littleleaf sumac. Herbs include vinemesquite, buffalograss, sideoats grama, cane bluestem, and Texas wintergrass. The management emphasis includes selective removal of juniper and buffer fencing, though excluded areas may be flash-grazed at multi-year intervals. Individual plant treatments are the recommended follow-up treatment.

**Edwards**

Four broad riparian classifications exist in the Edwards. Type I is characterized by largely unmapped headwaters that are primarily 1st order streams. Various upland soils including Tarrant-Rock and Bracket [TSX, BKX] are associated with this riparian type. Water flow is ephemeral, generally flowing for short periods following major rainfall events. The landform is V-shaped with small valleys, steep sided slopes, and highly confined channels. There are no woody plant indicators for Type I, though this riparian classification is often dominated at the upper end by large juniper. The management emphasis calls for mechanical control of juniper adjacent to the channel and follow-up treatments of prescribed fire or individual plant treatments.

Type II riparian areas contain small streams of 2nd order. Dominant soils are Brackett [BRX, BKX] at the upper end, Krum-Denton [KRX] in the middle ranges, and Frio [FR] at the lower ends. Flow is intermittent. Landforms are highly variable, but include a moderately confined channel with parabola shaped valleys that may be incised if overgrazed. Channel gradient is 3-7% (Max~10%). Woody plant indicators include elm and black walnut. Understory vegetation of Type II areas in good condition are tall grasses (switchgrass, eastern gama). Management emphasis should be the establishment of tallgrass on upper reaches of stream segments, buffer fencing, and prescribed fire or individual plant treatments as follow-up treatments.

Riparian classification III areas are 3rd order perennial streams. Soils are almost exclusively Frio [FR]. Relatively broad flood plains, unconfined channels, and a 1-5% channel gradient (max~7%) characterize the landform. Woody indicators include elm, walnut, pecan, and bald cypress, though bald cypress is more commonly found at the down stream end of this riparian type. Buffer fencing is recommended with flash-grazing for 3 to 4 days out of the year. Selective removal juniper should be followed in later years by individual plant treatments. Tallgrass species should be reestablished.

Type IV riparian areas contain large rivers characterized by Frio [FR] and Orif-Karnes [OKX] soils. Water flow is perennial. Broad alluvial plains with substantial channel disturbance zones are the dominant landforms. Examples include the Medina and Frio rivers. Woody indicators include willow and sycamore in disturbance zone with adjacent cypress and pecan on terraces. Management should emphasize the protection of woody riparian vegetation. Buffer fencing is recommended.

*Ecological Restoration*

In addition to brush control, reseeding, and improved grazing management systems, this appendix incorporates additional riparian restoration practices including the establishment of buffer fencing and flash-grazing or total absence of grazing restrictions.

Brush control treatments chosen for all riparian types is selective. Tree shearing and excavation, also known as grubbing, of cedar and mesquite will lower the abundance of these species, thus making room for other riparian woody plants. Redberry juniper, the dominant juniper species found in the Twin Buttes, will need to be stump-sprayed with herbicide if tree shearing is chosen. Seeded grasses for both areas will include native tallgrass species such as switchgrass, Indiangrass, littlebluestem, and Eastern gama. The establishment of these grasses on upper reaches of streams will produce a ready seed source for downstream areas.

The construction of a buffer fence around certain riparian types will enable the riparian unit to be treated as a separate unit for management purposes. Where flash-grazing is recommended, livestock will be only be allowed to graze for several days each year. This restriction should facilitate the success of seeded tallgrasses and help currently existing grasses recover. In addition, highly palatable woody species will be able to recover with substantially lower grazing pressure.

**Twin Buttes**

The amounts of light, moderate, and heavy brush occurring in the riparian buffer zone on slopes less than 15% to be treated under Scenarios II Rip and III Rip in this analysis are 39,087, 11,727, and 18,712 acres for the Middle Concho, South Concho, and Sprind/Dove Creeks, respectively (Table A3). For the entire Twin Buttes study area, the amount of restored riparian acres is 69,529 acres.

**Edwards**

Riparian treatments total 12,177, 2,901, 21,752, 6,292 and 1,241 for the Frio, Hondo, Medina, Sabinal, and Seco watersheds, respectively (Table A3). Total riparian land treated was 44,363 acres for the entire Edwards.

**Total Society Cost and Society Cost of Added Water**

*Twin Buttes*

**Middle Concho**. For Scenarios II Rip and III Rip, total society costs are $53M and $25.8M, respectively (Tables A4a and A4b). The incremental society cost of riparian treatments, which was equal to total society cost of Scenario II Rip minus the total society cost of Scenario II (or Scenario III Rip minus Scenario III) is $9.7M. Costs per additional acre-foot of water associated with Scenario II Rip and Scenario III Rip were $194 and $218, respectively.

**South Concho**. Total society costs for Scenario II Rip and Scenario III Rip were $17.6M and $9.1M, respectively (Tables 5a and 5b). Incremental society cost of riparian treatments for the South Concho was $3.2M. Costs per additional acre-foot of water were $77 for Scenario II Rip and $97 for Scenario III Rip.

**Spring/Dove Creeks.** Total society costs for implementing brush management/restoration Scenarios II Rip and III Rip were $28.6M and $14.9M respectively (Tables 4a and 4b). The society cost of the riparian restoration treatments was $5.1M. Estimates for cost per additional acre-foot of water for the two scenarios were $101 and $125, respectively.

Large differences between Scenarios II Rip and III-Rip are similar to the trend existing between Scenarios II and III presented in Chapter 2 (Figure A1). Compared with Scenario II, total society costs for Scenario II Rip were between 22% (Spring/Dove Creeks) and 23% (Middle Concho and South Concho) more expensive. For Scenario III Rip, percentage increases in total society costs over Scenario III ranged from 53% (Spring/Dove Creeks) to 61% (Middle Concho). The range of percentage costs increases for cost of added acre-feet of water for Scenarios II Rip and III Rip over Scenarios II and III, respectively, are identical to those for the total society Costs (Figure A3). The South Concho watershed yielded the lowest cost of additional acre-feet of water for both Scenarios II Rip and III Rip.

*Edwards*

**Frio.** For Scenarios II Rip and III Rip, total society costs were $13.8M and $13.2M, respectively (Table A5a and A5b). Society costs of treating riparian areas was $3.8M. Costs per additional acre-foot of water for the two scenarios were $70 and $69, respectively.
**Hondo.** Total society costs were $4.3M for Scenario II Rip and $4.2M for Scenario III Rip (Tables 6a and 6b). Riparian restoration treatments cost was $0.9M. Cost per additional acre-foot of water for Scenarios II Rip and III Rip were $41 and $42, respectively.
**Medina.** For Scenarios II Rip and III Rip, total society costs were $29.8M and $28.9M, respectively (Tables 7a and 7b). Riparian treatments cost $6.7M. Cost per additional acre-foot of water are estimated for Scenario II Rip at $46 and Scenario III Rip costs at $47.
**Sabinal.** Total society costs were $8.0M and $7.7M for Scenarios II Rip and III Rip, respectively (Tables 8a and 8b). Costs of riparian treatments were $2.0M. An estimated $60 was the cost per additional acre-foot of water for both Scenarios.
**Seco.** For Scenarios II Rip and III Rip, total society costs were $1.7M and $1.7M, respectively (Tables 9a and 9b). Riparian treatments for both scenarios were $0.3M. Cost per additional acre-foot of water was $56 for both Scenarios.
Total society costs for Scenarios II Rip and III Rip are very similar for all watersheds within the Edwards (Figure A1). Compared with Scenario II, Scenario II Rip is between 24% (Seco) and 38% (Frio) more expensive. For Scenario III Rip, percentage increases over Scenario III ranged from 24% (Seco) to 40% (Frio). Like the Twin Buttes, the range of percentage costs increases for cost of added acre-feet of water for Scenarios II Rip and III Rip over Scenarios II and III, respectively, are identical to those for the total society Costs (Figure A3). From a water production viewpoint, the Hondo and Medina watersheds were more efficient at yielding additional water.

**Comparison Across Watersheds**

As might be expected, the amount of restored riparian areas were higher for the combined Twin Buttes' watersheds than for the entire Edwards. The percentage increase of riparian acres treated is 57% more for the combined three watersheds of the Twin Buttes than the five Edwards' watersheds.
When comparing the different watersheds of the Twin Buttes and Edwards, the most expensive watershed to implement Scenario II Rip is the Middle Concho while the Medina is the most costly for Scenario III Rip (Figure A1). When comparing total society costs for the entire Edwards and the entire Twin Buttes, Scenario II Rip for the Twin Buttes cost 72% more than Scenario II Rip for the Edwards (Figures A3 and A4). In contrast, Scenario III Rip for the entire

Edwards study area is 12% more costly than Scenario III Rip for the combined Twin Buttes' watersheds.

Society cost of additional acre-feet of water for each of the Edwards' watershed was cheaper than for any of the Twin Buttes watersheds (Figure A2). When combining watersheds into their respective study area, society cost of additional acre-feet of water for Scenario II Rip in the Twin Buttes was 143% more expensive than Scenario II Rip in the Edwards. The percentage difference for Scenario III Rip was an even greater 189%.

**Conclusion**

While the methodology used in this section to determine cost implications for two brush management/restoration scenarios was very similar to that used in Chapter II, the restoration treatments assumed are much different. In the model presented in this appendix, restoration treatments were conducted in the riparian buffer zone in addition to other brush management and restoration practices performed in Chapter II.

By incorporating the riparian type-specific restoration recommendations, treated riparian areas will be restored closer to a historical climax vegetative community. The total amount of treated riparian areas is larger for the Twin Buttes than the Edwards.

Total society cost and cost for additional water added were very similar for Scenarios II Rip and III Rip in the Edwards' watersheds. Significant differences existed between Scenarios II Rip and III Rip in the Twin Buttes' watersheds due to the large difference in upland brush treated. When comparing entire study areas, total society costs for Scenario II Rip were much higher for the Twin Buttes while the Edwards was slightly higher for Scenario III Rip. Similar to the results reached in Chapter II, the cost of added water was much cheaper for Scenarios II Rip and III Rip in the Edwards.

**Additional Considerations**

The estimated proportions of each riparian condition type are most useful on a watershed and study area spatial scale. Because of variations of amounts and types of streams in individual sub-basins, useful comparisons between total society costs and society costs of additional water added on a sub-basin scale are subject to error.

**Table A1. Cost of Water Yield Brush Control Programs by Riparian Condition - Twin Buttes.**

| | | | |
|---|---|---|---|
| % of Type I Riparian Area | 65% | % of Type III Riparian Area | 10% |
| % of Type II Riparian Area | 25% | | |

**Riparian Condition I - Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Shearing | 125.00 | 125.00 |
| 0 | Reseeding | 20.00 | 20.00 |
| 0 | Cross Fencing | 3.88 | 3.88 |
| 0 | Additional Water Source | 2.66 | 2.66 |
| 0 | Deferment (30 acres per AUY) | 3.33 | 3.33 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 189.16 |

[1] Tree shearing with stump spray and later burn, or excavation and later burn.

**Riparian Condition II - Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Shearing | 125.00 | 125.00 |
| 0 | Reseeding | 20.00 | 20.00 |
| 0 | Buffer fencing | 221.29 | 221.29 |
| 0 | Additional Water Source | 2.66 | 2.66 |
| 0-10 | Deferment (25 acres per AUY) | 4.00 | 31.21 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 434.45 |

[1] Tree shearing with stump spray and later burn, or excavation and later burn.

**Riparian Condition III - Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Shearing | 125.00 | 125.00 |
| 0 | Reseeding | 20.00 | 20.00 |
| 0 | Buffer fencing | 221.29 | 221.29 |
| 0 | Additional Water Source | 2.66 | 2.66 |
| 0-10 | Deferment (20 ac per AUY) | 5.00 | 39.01 |
| 3 | IPT | 25.00 | 20.99 |
| 7 | IPT | 20.00 | 13.30 |
| | | Total | 442.25 |

[1] Tree shearing with stump spray and later burn, or excavation and later burn.

**Table A2. Cost of Water Yield Brush Control Programs by Riparian Condition - Twin Buttes.**

| | | | |
|---|---|---|---|
| % of Type I Riparian Area | 65% | % of Type III Riparian Area | 10% |
| % of Type II Riparian Area | 25% | | |

**Riparian Condition I - Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Shearing | 125.00 | 125.00 |
| 0 | Reseeding | 20.00 | 20.00 |
| 0 | Cross Fencing | 3.88 | 3.88 |
| 0 | Additional Water Source | 2.66 | 2.66 |
| 0 | Deferment (30 acres per AUY) | 3.33 | 3.33 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 189.16 |

[1] Tree shearing with stump spray and later burn, or excavation and later burn.

**Riparian Condition II - Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Shearing | 125.00 | 125.00 |
| 0 | Reseeding | 20.00 | 20.00 |
| 0 | Buffer fencing | 221.29 | 221.29 |
| 0 | Additional Water Source | 2.66 | 2.66 |
| 0-10 | Deferment (25 acres per AUY) | 4.00 | 31.21 |
| 3 | IPT or Burn | 25.00 | 20.99 |
| 7 | IPT or Burn | 20.00 | 13.30 |
| | | Total | 434.45 |

[1] Tree shearing with stump spray and later burn, or excavation and later burn.

**Riparian Condition III - Mechanical[1]**

| Year | Treatment | Treatment Cost($) / Acre | Present Value($) / Acre |
|---|---|---|---|
| 0 | Tree Shearing | 125.00 | 125.00 |
| 0 | Reseeding | 20.00 | 20.00 |
| 0 | Buffer fencing | 221.29 | 221.29 |
| 0 | Additional Water Source | 2.66 | 2.66 |
| 0-10 | Deferment (20 ac per AUY) | 5.00 | 39.01 |
| 3 | IPT | 25.00 | 20.99 |
| 7 | IPT | 20.00 | 13.30 |
| | | Total | 442.25 |

[1] Tree shearing with stump spray and later burn, or excavation and later burn.

**Table A3. Treated Riparian Acres for Scenarios II-Rip and III-Rip.**

| | ED-FRIO | ED-HONDO | ED-MEDINA | ED-SABINAL | ED-SECO | MIDDLE CONCHO | SOUTH CONCHO | SPRIND / DOVE CREEKS |
|---|---|---|---|---|---|---|---|---|
| Acres of treated riparian brush in scenarios II rip and III rip | 12,177 | 2,901 | 21,752 | 6,292 | 1,241 | 39,087 | 11,727 | 18,712 |

**Table A4a. Cost of Added Water From Brush Control By Subbasin (Acre-Foot).**

| Middle Concho - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 0 | 0 | 0 | 0 | - |
| 2 | 427,116 | 88,557,647 | 272 | 2,120 | 201 |
| 3 | 0 | 0 | 0 | 0 | - |
| 4 | 0 | 0 | 0 | 0 | - |
| 5 | 451,012 | 75,140,439 | 231 | 1,799 | 251 |
| 6 | 0 | 0 | 0 | 0 | - |
| 7 | 1,800,533 | 209,399,223 | 643 | 5,013 | 359 |
| 8 | 191,823 | 29,308,982 | 90 | 702 | 273 |
| 9 | 1,912,289 | 279,524,263 | 858 | 6,692 | 286 |
| 10 | 85,924 | 11,999,008 | 37 | 287 | 299 |
| 11 | 0 | 0 | 0 | 0 | - |
| 12 | 1,913,561 | 282,373,163 | 866 | 6,760 | 283 |
| 13 | 1,836,307 | 339,474,264 | 1,042 | 8,127 | 226 |
| 14 | 959,436 | 180,372,534 | 553 | 4,318 | 222 |
| 15 | 651,577 | 117,245,591 | 360 | 2,807 | 232 |
| 16 | 4,479,460 | 805,759,130 | 2,472 | 19,289 | 232 |
| 17 | 2,302,156 | 547,573,838 | 1,680 | 13,108 | 176 |
| 18 | 3,409,287 | 683,536,070 | 2,097 | 16,363 | 208 |
| 19 | 905,588 | 180,676,019 | 554 | 4,325 | 209 |
| 20 | 101,357 | 22,984,786 | 71 | 550 | 184 |
| 21 | 2,952,863 | 570,809,580 | 1,751 | 13,665 | 216 |
| 22 | 1,815,599 | 461,625,349 | 1,416 | 11,051 | 164 |
| 23 | 5,752,176 | 1,665,624,936 | 5,111 | 39,873 | 144 |
| 24 | 3,394,902 | 892,989,955 | 2,740 | 21,377 | 159 |
| 25 | 3,915,082 | 988,256,018 | 3,032 | 23,658 | 165 |
| 26 | 4,762,132 | 1,103,388,621 | 3,386 | 26,414 | 180 |
| 27 | 5,798,890 | 1,266,327,999 | 3,886 | 30,315 | 191 |
| 28 | 2,813,816 | 501,190,114 | 1,538 | 11,998 | 235 |
| **Total** | **52,632,885** | | | **270,609** | **194** |

**Table A4b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Middle Concho - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 0 | 0 | 0 | 0 | - |
| 2 | 193,682 | 35,112,688 | 108 | 841 | 230 |
| 3 | 0 | 0 | 0 | 0 | - |
| 4 | 0 | 0 | 0 | 0 | - |
| 5 | 110,321 | 0 | 0 | 0 | - |
| 6 | 0 | 0 | 0 | 0 | - |
| 7 | 427,988 | 0 | 0 | 0 | - |
| 8 | 77,187 | 0 | 0 | 0 | - |
| 9 | 510,759 | 0 | 0 | 0 | - |
| 10 | 33,264 | 0 | 0 | 0 | - |
| 11 | 0 | 0 | 0 | 0 | - |
| 12 | 721,124 | 87,000,778 | 267 | 2,083 | 346 |
| 13 | 1,211,920 | 212,954,335 | 653 | 5,098 | 238 |
| 14 | 602,986 | 97,457,549 | 299 | 2,333 | 258 |
| 15 | 194,388 | 5,159,438 | 16 | 124 | 1,574 |
| 16 | 1,006,483 | 0 | 0 | 0 | - |
| 17 | 1,218,922 | 264,918,935 | 813 | 6,342 | 192 |
| 18 | 1,786,119 | 317,758,785 | 975 | 7,607 | 235 |
| 19 | 496,005 | 80,669,006 | 248 | 1,931 | 257 |
| 20 | 53,975 | 10,887,432 | 33 | 261 | 207 |
| 21 | 1,182,536 | 166,083,987 | 510 | 3,976 | 297 |
| 22 | 850,505 | 190,582,942 | 585 | 4,562 | 186 |
| 23 | 3,216,043 | 881,715,726 | 2,705 | 21,107 | 152 |
| 24 | 2,154,250 | 559,393,687 | 1,716 | 13,391 | 161 |
| 25 | 2,342,141 | 542,779,712 | 1,665 | 12,994 | 180 |
| 26 | 2,676,630 | 616,657,109 | 1,892 | 14,762 | 181 |
| 27 | 3,445,555 | 709,979,540 | 2,179 | 16,996 | 203 |
| 28 | 1,257,885 | 168,760,988 | 518 | 4,040 | 311 |
| **Total** | **25,770,667** | | | **118,447** | **218** |

**Table A5a. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| South Concho - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,019,283 | 598,961,040 | 1,838 | 14,338 | 71 |
| 2 | 381,582 | 254,471,687 | 781 | 6,092 | 63 |
| 3 | 1,129,122 | 763,866,554 | 2,344 | 18,286 | 62 |
| 4 | 863,495 | 486,914,198 | 1,494 | 11,656 | 74 |
| 5 | 850,286 | 441,565,269 | 1,355 | 10,571 | 80 |
| 6 | 126,303 | 62,703,385 | 192 | 1,501 | 84 |
| 7 | 695,251 | 372,899,956 | 1,144 | 8,927 | 78 |
| 8 | 564,146 | 336,871,727 | 1,034 | 8,064 | 70 |
| 9 | 628,070 | 310,829,681 | 954 | 7,441 | 84 |
| 10 | 828,453 | 365,822,898 | 1,123 | 8,757 | 95 |
| 11 | 2,369,405 | 1,574,829,042 | 4,832 | 37,700 | 63 |
| 12 | 836,080 | 477,061,384 | 1,464 | 11,420 | 73 |
| 13 | 2,648,933 | 1,184,195,959 | 3,634 | 28,348 | 93 |
| 14 | 82,068 | 35,550,868 | 109 | 851 | 96 |
| 15 | 1,379,267 | 775,219,423 | 2,379 | 18,558 | 74 |
| 16 | 1,551,566 | 813,793,215 | 2,497 | 19,481 | 80 |
| 17 | 1,275,170 | 635,716,079 | 1,951 | 15,218 | 84 |
| 18 | 336,471 | 68,625,815 | 211 | 1,643 | 205 |
| **Total** | **17,564,953** | | | **228,854** | **77** |

Table A5b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).

| South Concho - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 294,566 | 0 | 0 | 0 | - |
| 2 | 62,658 | 0 | 0 | 0 | - |
| 3 | 416,532 | 197,292,290 | 605 | 4,723 | 88 |
| 4 | 408,472 | 177,572,447 | 545 | 4,251 | 96 |
| 5 | 452,990 | 169,202,732 | 519 | 4,051 | 112 |
| 6 | 64,284 | 31,234,879 | 96 | 748 | 86 |
| 7 | 222,791 | 22,714,382 | 70 | 544 | 410 |
| 8 | 208,088 | 78,350,790 | 240 | 1,876 | 111 |
| 9 | 359,864 | 154,412,946 | 474 | 3,696 | 97 |
| 10 | 533,646 | 201,054,441 | 617 | 4,813 | 111 |
| 11 | 1,300,312 | 764,926,085 | 2,347 | 18,312 | 71 |
| 12 | 466,467 | 239,242,397 | 734 | 5,727 | 81 |
| 13 | 1,566,714 | 617,334,557 | 1,894 | 14,778 | 106 |
| 14 | 66,719 | 24,651,101 | 76 | 590 | 113 |
| 15 | 846,118 | 435,341,897 | 1,336 | 10,422 | 81 |
| 16 | 965,445 | 451,228,529 | 1,385 | 10,802 | 89 |
| 17 | 754,734 | 333,778,659 | 1,024 | 7,990 | 94 |
| 18 | 157,671 | 26,101,404 | 80 | 625 | 252 |
| **Total** | **9,148,070** | | | **93,947** | **97** |

**Table A6a. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| South Concho - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,019,283 | 598,961,040 | 1,838 | 14,338 | 71 |
| 2 | 381,582 | 254,471,687 | 781 | 6,092 | 63 |
| 3 | 1,129,122 | 763,866,554 | 2,344 | 18,286 | 62 |
| 4 | 863,495 | 486,914,198 | 1,494 | 11,656 | 74 |
| 5 | 850,286 | 441,565,269 | 1,355 | 10,571 | 80 |
| 6 | 126,303 | 62,703,385 | 192 | 1,501 | 84 |
| 7 | 695,251 | 372,899,956 | 1,144 | 8,927 | 78 |
| 8 | 564,146 | 336,871,727 | 1,034 | 8,064 | 70 |
| 9 | 628,070 | 310,829,681 | 954 | 7,441 | 84 |
| 10 | 828,453 | 365,822,898 | 1,123 | 8,757 | 95 |
| 11 | 2,369,405 | 1,574,829,042 | 4,832 | 37,700 | 63 |
| 12 | 836,080 | 477,061,384 | 1,464 | 11,420 | 73 |
| 13 | 2,648,933 | 1,184,195,959 | 3,634 | 28,348 | 93 |
| 14 | 82,068 | 35,550,868 | 109 | 851 | 96 |
| 15 | 1,379,267 | 775,219,423 | 2,379 | 18,558 | 74 |
| 16 | 1,551,566 | 813,793,215 | 2,497 | 19,481 | 80 |
| 17 | 1,275,170 | 635,716,079 | 1,951 | 15,218 | 84 |
| 18 | 336,471 | 68,625,815 | 211 | 1,643 | 205 |
| **Total** | **17,564,953** | | | **228,854** | **77** |

Table A6b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).

| South Concho - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 294,566 | 0 | 0 | 0 | - |
| 2 | 62,658 | 0 | 0 | 0 | - |
| 3 | 416,532 | 197,292,290 | 605 | 4,723 | 88 |
| 4 | 408,472 | 177,572,447 | 545 | 4,251 | 96 |
| 5 | 452,990 | 169,202,732 | 519 | 4,051 | 112 |
| 6 | 64,284 | 31,234,879 | 96 | 748 | 86 |
| 7 | 222,791 | 22,714,382 | 70 | 544 | 410 |
| 8 | 208,088 | 78,350,790 | 240 | 1,876 | 111 |
| 9 | 359,864 | 154,412,946 | 474 | 3,696 | 97 |
| 10 | 533,646 | 201,054,441 | 617 | 4,813 | 111 |
| 11 | 1,300,312 | 764,926,085 | 2,347 | 18,312 | 71 |
| 12 | 466,467 | 239,242,397 | 734 | 5,727 | 81 |
| 13 | 1,566,714 | 617,334,557 | 1,894 | 14,778 | 106 |
| 14 | 66,719 | 24,651,101 | 76 | 590 | 113 |
| 15 | 846,118 | 435,341,897 | 1,336 | 10,422 | 81 |
| 16 | 965,445 | 451,228,529 | 1,385 | 10,802 | 89 |
| 17 | 754,734 | 333,778,659 | 1,024 | 7,990 | 94 |
| 18 | 157,671 | 26,101,404 | 80 | 625 | 252 |
| **Total** | **9,148,070** | | | **93,947** | **97** |

**Table A7a. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Frio - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,697,166 | 993,747,761 | 3,049 | 23,789 | 71 |
| 2 | 1,111,287 | 642,336,279 | 1,971 | 15,377 | 72 |
| 3 | 581,339 | 295,626,757 | 907 | 7,077 | 82 |
| 4 | 664,999 | 372,311,349 | 1,142 | 8,913 | 75 |
| 5 | 304,216 | 198,671,857 | 610 | 4,756 | 64 |
| 6 | 237,400 | 137,175,094 | 421 | 3,284 | 72 |
| 7 | 327,118 | 225,041,564 | 691 | 5,387 | 61 |
| 8 | 704,056 | 475,642,141 | 1,459 | 11,386 | 62 |
| 9 | 676,656 | 374,891,345 | 1,150 | 8,974 | 75 |
| 10 | 860,529 | 478,079,745 | 1,467 | 11,445 | 75 |
| 11 | 94,956 | 53,132,441 | 163 | 1,272 | 75 |
| 12 | 301,536 | 155,872,124 | 478 | 3,731 | 81 |
| 13 | 625,629 | 371,757,207 | 1,141 | 8,899 | 70 |
| 14 | 408,164 | 333,347,074 | 1,023 | 7,980 | 51 |
| 15 | 186,459 | 104,789,824 | 322 | 2,509 | 74 |
| 16 | 222,447 | 144,550,541 | 444 | 3,460 | 64 |
| 17 | 654,099 | 593,470,085 | 1,821 | 14,207 | 46 |
| 18 | 608,300 | 383,484,533 | 1,177 | 9,180 | 66 |
| 19 | 198,471 | 145,121,723 | 445 | 3,474 | 57 |
| 20 | 152,648 | 113,910,096 | 350 | 2,727 | 56 |
| 21 | 285,823 | 182,696,422 | 561 | 4,374 | 65 |
| 22 | 536,458 | 248,227,007 | 762 | 5,942 | 90 |
| 23 | 397,977 | 189,677,616 | 582 | 4,541 | 88 |
| 24 | 497,589 | 237,166,355 | 728 | 5,678 | 88 |
| 25 | 842,397 | 439,292,694 | 1,348 | 10,516 | 80 |
| 26 | 640,800 | 312,342,334 | 958 | 7,477 | 86 |
| **Total** | **13,818,520** | | | **196,356** | **70** |

**Table A7b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Frio - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,451,217 | 835,249,117 | 2,563 | 19,995 | 73 |
| 2 | 1,015,597 | 583,116,558 | 1,789 | 13,959 | 73 |
| 3 | 581,339 | 305,134,261 | 936 | 7,305 | 80 |
| 4 | 664,999 | 383,437,149 | 1,177 | 9,179 | 72 |
| 5 | 304,216 | 205,453,452 | 630 | 4,918 | 62 |
| 6 | 237,400 | 141,324,820 | 434 | 3,383 | 70 |
| 7 | 327,118 | 232,775,761 | 714 | 5,572 | 59 |
| 8 | 560,559 | 363,206,296 | 1,114 | 8,695 | 64 |
| 9 | 541,973 | 283,507,274 | 870 | 6,787 | 80 |
| 10 | 860,529 | 491,409,053 | 1,508 | 11,764 | 73 |
| 11 | 94,956 | 54,917,624 | 169 | 1,315 | 72 |
| 12 | 301,536 | 160,042,828 | 491 | 3,831 | 79 |
| 13 | 625,629 | 384,256,591 | 1,179 | 9,199 | 68 |
| 14 | 408,164 | 344,788,729 | 1,058 | 8,254 | 49 |
| 15 | 186,459 | 108,151,588 | 332 | 2,589 | 72 |
| 16 | 222,447 | 149,408,964 | 458 | 3,577 | 62 |
| 17 | 654,099 | 611,904,665 | 1,878 | 14,648 | 45 |
| 18 | 608,300 | 395,765,572 | 1,214 | 9,474 | 64 |
| 19 | 198,471 | 149,751,843 | 460 | 3,585 | 55 |
| 20 | 152,648 | 117,495,332 | 361 | 2,813 | 54 |
| 21 | 285,823 | 188,982,573 | 580 | 4,524 | 63 |
| 22 | 536,458 | 259,157,763 | 795 | 6,204 | 86 |
| 23 | 397,977 | 196,276,006 | 602 | 4,699 | 85 |
| 24 | 497,589 | 246,448,445 | 756 | 5,900 | 84 |
| 25 | 842,397 | 454,822,313 | 1,396 | 10,888 | 77 |
| 26 | 640,800 | 324,890,070 | 997 | 7,778 | 82 |
| **Total** | **13,198,700** | | | **190,833** | **69** |

**Table A8a. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Hondo - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 310,766 | 299,697,220 | 920 | 7,174 | 43 |
| 2 | 164,166 | 129,337,919 | 397 | 3,096 | 53 |
| 3 | 373,561 | 415,609,256 | 1,275 | 9,949 | 38 |
| 4 | 415,859 | 428,786,401 | 1,316 | 10,265 | 41 |
| 5 | 327,951 | 257,661,586 | 791 | 6,168 | 53 |
| 6 | 160,325 | 233,445,728 | 716 | 5,588 | 29 |
| 7 | 855,715 | 970,987,965 | 2,979 | 23,244 | 37 |
| 8 | 476,558 | 440,726,057 | 1,352 | 10,551 | 45 |
| 9 | 676,832 | 738,988,447 | 2,268 | 17,691 | 38 |
| 10 | 506,186 | 427,637,116 | 1,312 | 10,237 | 49 |
| Total | 4,267,920 | | | 103,964 | 41 |

**Table A8b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| **Hondo - Scenario 3 With Riparian Restoration Treatments** | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 310,766 | 299,697,220 | 920 | 7,174 | 43 |
| 2 | 164,166 | 129,337,919 | 397 | 3,096 | 53 |
| 3 | 373,561 | 415,609,256 | 1,275 | 9,949 | 38 |
| 4 | 415,859 | 428,786,401 | 1,316 | 10,265 | 41 |
| 5 | 327,951 | 257,661,586 | 791 | 6,168 | 53 |
| 6 | 93,797 | 111,947,278 | 344 | 2,680 | 35 |
| 7 | 855,715 | 970,987,965 | 2,979 | 23,244 | 37 |
| 8 | 476,558 | 440,726,057 | 1,352 | 10,551 | 45 |
| 9 | 676,832 | 738,988,447 | 2,268 | 17,691 | 38 |
| 10 | 506,186 | 427,637,116 | 1,312 | 10,237 | 49 |
| **Total** | **4,201,392** | | | **101,055** | **42** |

**Table A9a. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Medina - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,701,891 | 1,049,035,495 | 3,219 | 25,113 | 68 |
| 2 | 1,134,017 | 688,762,673 | 2,113 | 16,488 | 69 |
| 3 | 1,829,509 | 1,126,386,688 | 3,456 | 26,964 | 68 |
| 4 | 791,369 | 500,282,238 | 1,535 | 11,976 | 66 |
| 5 | 570,542 | 621,706,130 | 1,908 | 14,883 | 38 |
| 6 | 1,839,687 | 1,396,666,006 | 4,286 | 33,435 | 55 |
| 7 | 883,163 | 801,913,165 | 2,461 | 19,197 | 46 |
| 8 | 1,167,633 | 1,071,079,174 | 3,287 | 25,640 | 46 |
| 9 | 915,379 | 890,682,429 | 2,733 | 21,322 | 43 |
| 10 | 696,568 | 634,258,100 | 1,946 | 15,183 | 46 |
| 11 | 578,705 | 636,863,550 | 1,954 | 15,246 | 38 |
| 12 | 933,919 | 871,043,791 | 2,673 | 20,852 | 45 |
| 13 | 1,522,814 | 1,412,119,188 | 4,333 | 33,805 | 45 |
| 14 | 1,347,784 | 1,437,272,258 | 4,410 | 34,407 | 39 |
| 15 | 335,742 | 305,916,628 | 939 | 7,323 | 46 |
| 16 | 1,207,965 | 1,193,573,568 | 3,662 | 28,573 | 42 |
| 17 | 785,120 | 755,469,025 | 2,318 | 18,085 | 43 |
| 18 | 754,466 | 673,780,472 | 2,067 | 16,130 | 47 |
| 19 | 477,020 | 453,574,395 | 1,392 | 10,858 | 44 |
| 20 | 3,184,491 | 3,373,054,349 | 10,350 | 80,747 | 39 |
| 21 | 1,180,980 | 1,126,649,341 | 3,457 | 26,971 | 44 |
| 22 | 838,392 | 885,596,177 | 2,717 | 21,200 | 40 |
| 23 | 645,193 | 518,803,539 | 1,592 | 12,420 | 52 |
| 24 | 545,186 | 523,857,310 | 1,607 | 12,541 | 43 |
| 25 | 812,699 | 749,127,626 | 2,299 | 17,933 | 45 |
| 26 | 613,452 | 510,632,109 | 1,567 | 12,224 | 50 |
| 27 | 745,617 | 885,421,339 | 2,717 | 21,196 | 35 |
| 28 | 953,003 | 924,076,908 | 2,835 | 22,121 | 43 |
| 29 | 468,673 | 339,976,967 | 1,043 | 8,139 | 58 |
| 30 | 82,851 | 93,135,712 | 286 | 2,230 | 37 |
| 31 | 127,612 | 110,880,472 | 340 | 2,654 | 48 |
| 32 | 200,004 | 443,382,713 | 1,360 | 10,614 | 19 |
| **Total** | **29,871,445** | | | **646,470** | **46** |

Table A9b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).

| Medina - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons / Acre / Year | Added Acre / Feet / Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 1,701,891 | 1,049,035,495 | 3,219 | 25,113 | 68 |
| 2 | 1,134,017 | 688,762,673 | 2,113 | 16,488 | 69 |
| 3 | 1,829,509 | 1,126,386,688 | 3,456 | 26,964 | 68 |
| 4 | 791,369 | 500,282,238 | 1,535 | 11,976 | 66 |
| 5 | 570,542 | 621,706,130 | 1,908 | 14,883 | 38 |
| 6 | 1,839,687 | 1,396,666,006 | 4,286 | 33,435 | 55 |
| 7 | 883,163 | 801,913,165 | 2,461 | 19,197 | 46 |
| 8 | 1,167,633 | 1,071,079,174 | 3,287 | 25,640 | 46 |
| 9 | 915,379 | 890,682,429 | 2,733 | 21,322 | 43 |
| 10 | 588,121 | 493,463,124 | 1,514 | 11,813 | 50 |
| 11 | 578,705 | 636,863,550 | 1,954 | 15,246 | 38 |
| 12 | 853,408 | 788,683,337 | 2,420 | 18,880 | 45 |
| 13 | 1,522,814 | 1,412,119,188 | 4,333 | 33,805 | 45 |
| 14 | 1,266,351 | 1,346,453,230 | 4,131 | 32,233 | 39 |
| 15 | 240,618 | 163,375,677 | 501 | 3,911 | 62 |
| 16 | 1,133,801 | 1,117,309,667 | 3,428 | 26,747 | 42 |
| 17 | 785,120 | 755,469,025 | 2,318 | 18,085 | 43 |
| 18 | 754,466 | 673,780,472 | 2,067 | 16,130 | 47 |
| 19 | 443,244 | 422,511,727 | 1,296 | 10,114 | 44 |
| 20 | 3,184,491 | 3,373,054,349 | 10,350 | 80,747 | 39 |
| 21 | 1,021,228 | 960,957,978 | 2,949 | 23,004 | 44 |
| 22 | 741,724 | 778,411,742 | 2,388 | 18,634 | 40 |
| 23 | 621,825 | 506,332,189 | 1,554 | 12,121 | 51 |
| 24 | 545,186 | 523,857,310 | 1,607 | 12,541 | 43 |
| 25 | 812,699 | 749,127,626 | 2,299 | 17,933 | 45 |
| 26 | 613,452 | 510,632,109 | 1,567 | 12,224 | 50 |
| 27 | 645,178 | 767,301,360 | 2,354 | 18,368 | 35 |
| 28 | 829,468 | 815,437,619 | 2,502 | 19,521 | 42 |
| 29 | 468,673 | 339,976,967 | 1,043 | 8,139 | 58 |
| 30 | 82,851 | 93,135,712 | 286 | 2,230 | 37 |
| 31 | 127,612 | 110,880,472 | 340 | 2,654 | 48 |
| 32 | 200,004 | 443,382,713 | 1,360 | 10,614 | 19 |
| **Total** | **28,894,227** | | | **620,713** | **47** |

Table A10a. Cost of Added Water From Brush Control By Subbasin (Acre-Foot).

| Sabinal - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 749,269 | 446,689,576 | 1,371 | 10,693 | 70 |
| 2 | 189,423 | 105,290,583 | 323 | 2,521 | 75 |
| 3 | 370,718 | 241,107,277 | 740 | 5,772 | 64 |
| 4 | 1,241,001 | 987,179,110 | 3,029 | 23,632 | 53 |
| 5 | 976,479 | 760,240,821 | 2,333 | 18,199 | 54 |
| 6 | 374,843 | 356,720,371 | 1,095 | 8,539 | 44 |
| 7 | 129,607 | 74,440,755 | 228 | 1,782 | 73 |
| 8 | 585,037 | 573,271,967 | 1,759 | 13,724 | 43 |
| 9 | 1,649,113 | 1,017,060,451 | 3,121 | 24,347 | 68 |
| 10 | 384,635 | 304,732,214 | 935 | 7,295 | 53 |
| 11 | 1,019,605 | 514,125,566 | 1,578 | 12,308 | 83 |
| 12 | 293,314 | 127,126,119 | 390 | 3,043 | 96 |
| **Total** | **7,963,046** | | | **131,855** | **60** |

Table A10b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).

| Sabinal - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 749,269 | 458,463,614 | 1,407 | 10,975 | 68 |
| 2 | 189,423 | 107,450,484 | 330 | 2,572 | 74 |
| 3 | 370,718 | 248,062,817 | 761 | 5,938 | 62 |
| 4 | 1,241,001 | 1,004,584,207 | 3,082 | 24,049 | 52 |
| 5 | 976,479 | 775,416,609 | 2,379 | 18,563 | 53 |
| 6 | 374,843 | 364,338,044 | 1,118 | 8,722 | 43 |
| 7 | 108,806 | 62,341,557 | 191 | 1,492 | 73 |
| 8 | 372,051 | 331,900,708 | 1,018 | 7,945 | 47 |
| 9 | 1,649,113 | 1,036,435,284 | 3,180 | 24,811 | 66 |
| 10 | 337,293 | 266,298,000 | 817 | 6,375 | 53 |
| 11 | 1,019,605 | 528,818,380 | 1,623 | 12,659 | 81 |
| 12 | 293,314 | 130,962,007 | 402 | 3,135 | 94 |
| **Total** | **7,681,918** | | | **127,237** | **60** |

**Table A11a. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Seco - Scenario 2 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 156,967 | 114,843,246 | 352 | 2,749 | 57 |
| 2 | 161,990 | 128,118,572 | 393 | 3,067 | 53 |
| 3 | 128,025 | 75,848,332 | 233 | 1,816 | 71 |
| 4 | 79,490 | 53,339,468 | 164 | 1,277 | 62 |
| 5 | 504,381 | 391,662,334 | 1,202 | 9,376 | 54 |
| 6 | 125,246 | 72,408,344 | 222 | 1,733 | 72 |
| 7 | 136,638 | 89,656,937 | 275 | 2,146 | 64 |
| 8 | 99,363 | 90,464,468 | 278 | 2,166 | 46 |
| 9 | 140,958 | 95,427,779 | 293 | 2,284 | 62 |
| 10 | 48,268 | 37,690,257 | 116 | 902 | 53 |
| 11 | 110,319 | 57,414,774 | 176 | 1,374 | 80 |
| 12 | 58,681 | 43,647,482 | 134 | 1,045 | 56 |
| **Total** | **1,750,326** | | | **29,936** | **58** |

**Table A11b. Cost of Added Water From Brush Control By Sub-Basin (Acre-Foot).**

| Seco - Scenario 3 With Riparian Restoration Treatments | | | | | |
|---|---|---|---|---|---|
| Subbasin No. | Total Society Cost (Dollars) | Added Gallons/Acre/Year | Added Acre/Feet/Year | 10 year Added Water (Acre-Feet) | Society Cost for Added Water (Dollars Per Acre Foot) |
| 1 | 156,923 | 114,843,246 | 352 | 2,749 | 57 |
| 2 | 161,990 | 128,118,572 | 393 | 3,067 | 53 |
| 3 | 128,025 | 75,848,332 | 233 | 1,816 | 71 |
| 4 | 79,490 | 53,339,468 | 164 | 1,277 | 62 |
| 5 | 504,381 | 391,662,334 | 1,202 | 9,376 | 54 |
| 6 | 125,246 | 72,408,344 | 222 | 1,733 | 72 |
| 7 | 136,638 | 89,656,937 | 275 | 2,146 | 64 |
| 8 | 99,363 | 90,464,468 | 278 | 2,166 | 46 |
| 9 | 140,958 | 95,427,779 | 293 | 2,284 | 62 |
| 10 | 48,268 | 37,690,257 | 116 | 902 | 53 |
| 11 | 110,319 | 57,414,774 | 176 | 1,374 | 80 |
| 12 | 58,681 | 43,647,482 | 134 | 1,045 | 56 |
| **Total** | **1,750,282** | | | **29,936** | **58** |

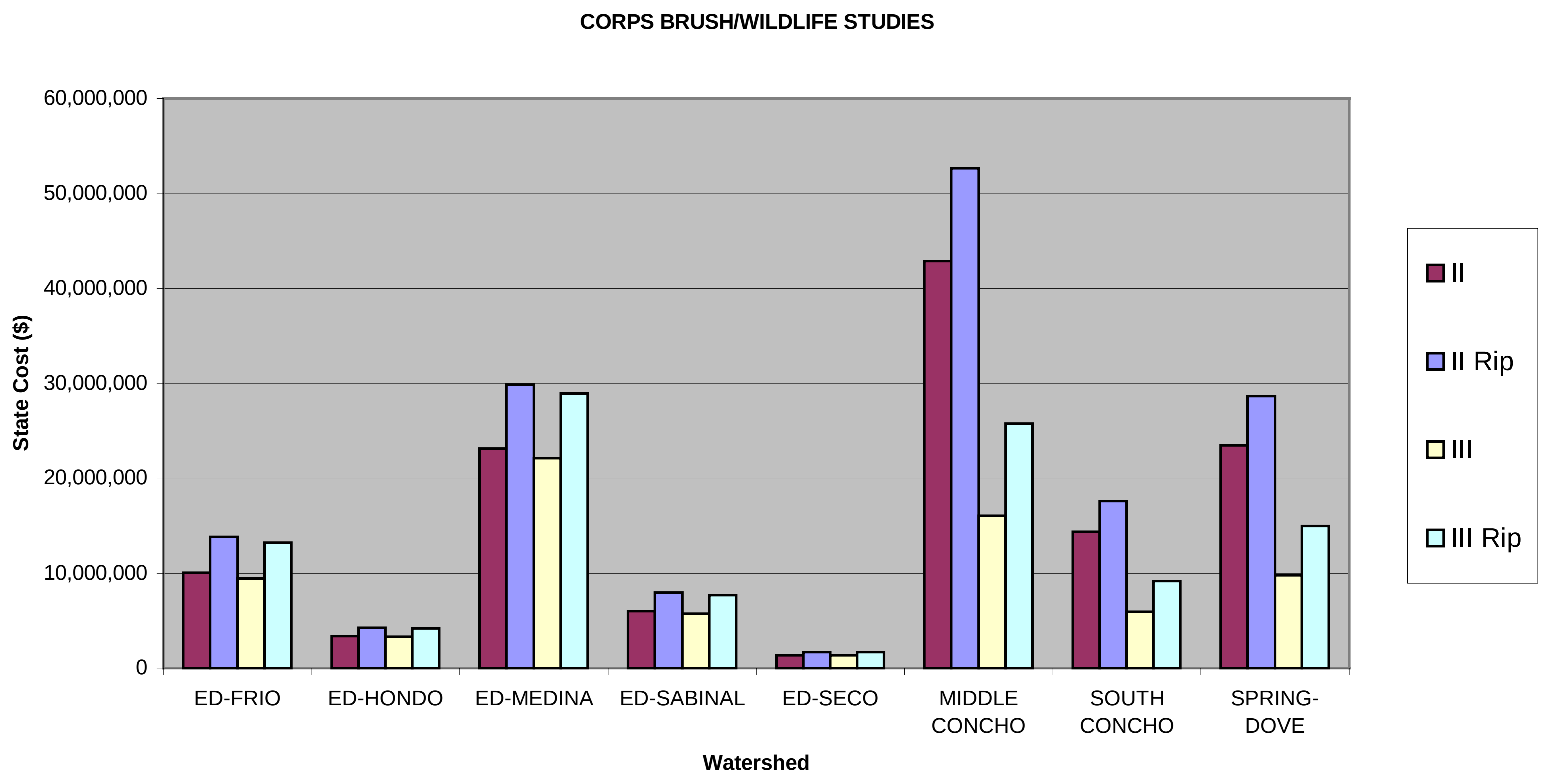


**Figure A1.** **Comparison of total society costs for restoration Scenarios II, II Rip, III, and III Rip.**

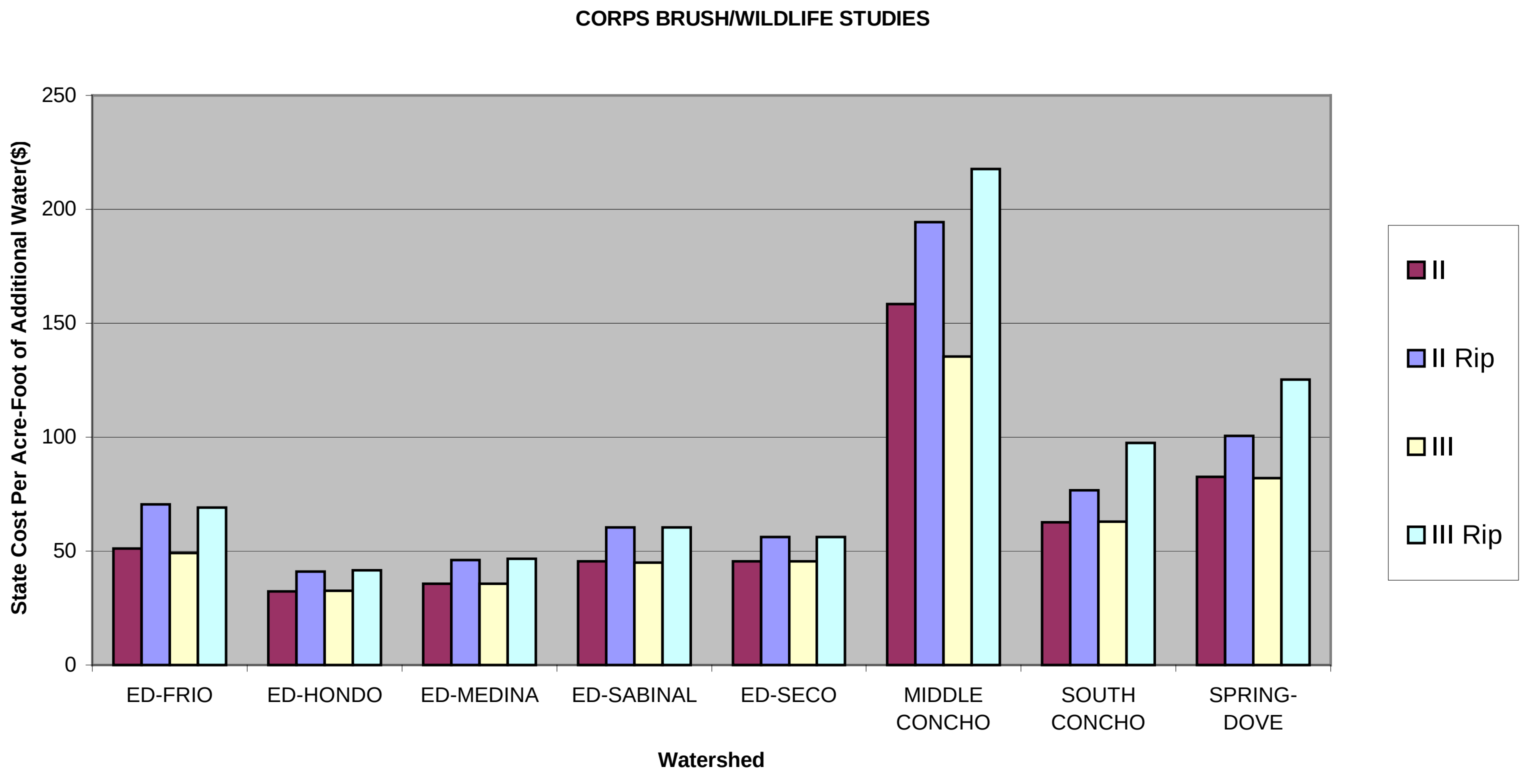


**Figure A2. Comparison of society costs per acre-foot of water saved, Scenarios II, II Rip, III, and III Rip.**

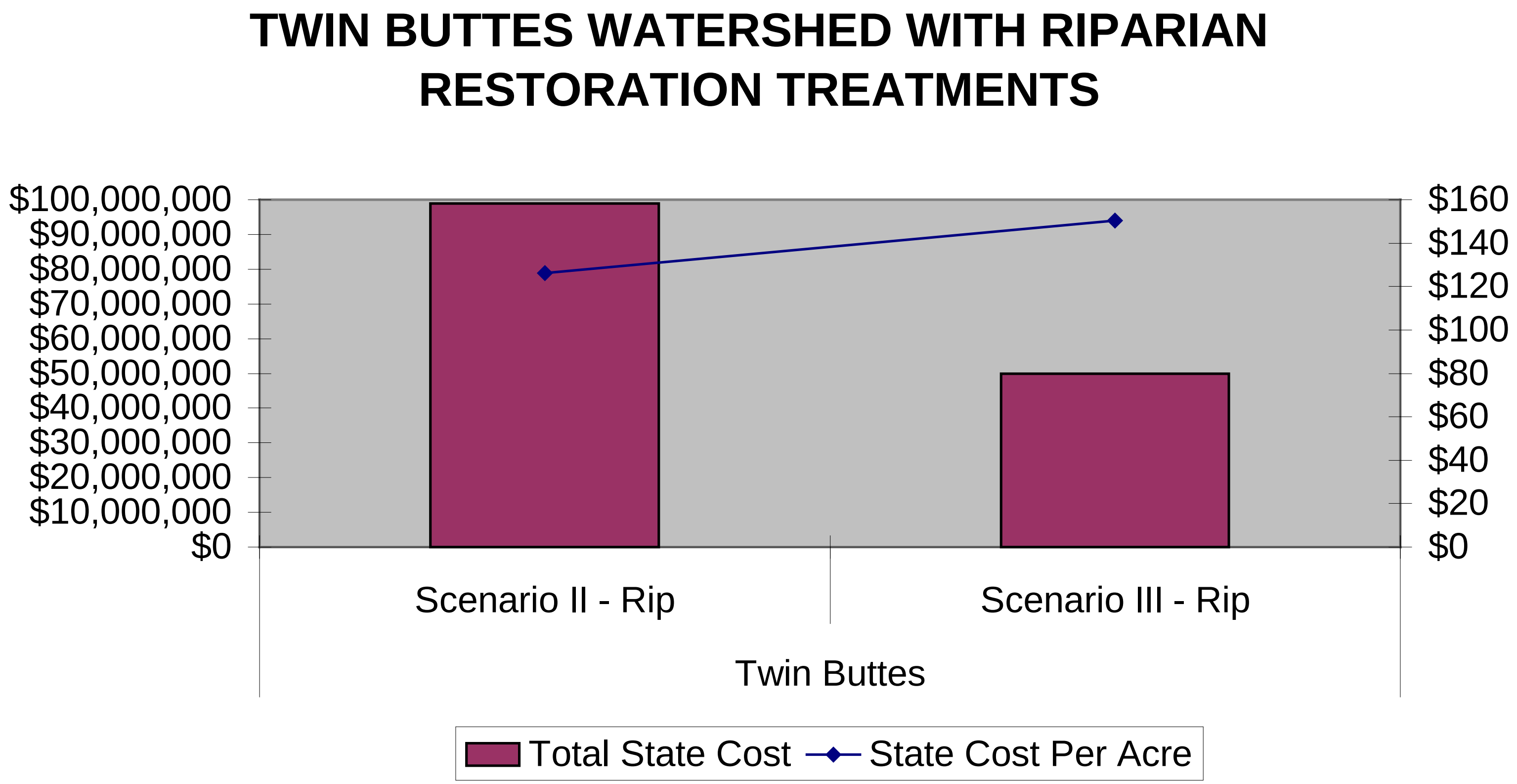


**Figure A3. Comparison of total society costs and costs per acre-foot of water saved, Twin Buttes.**

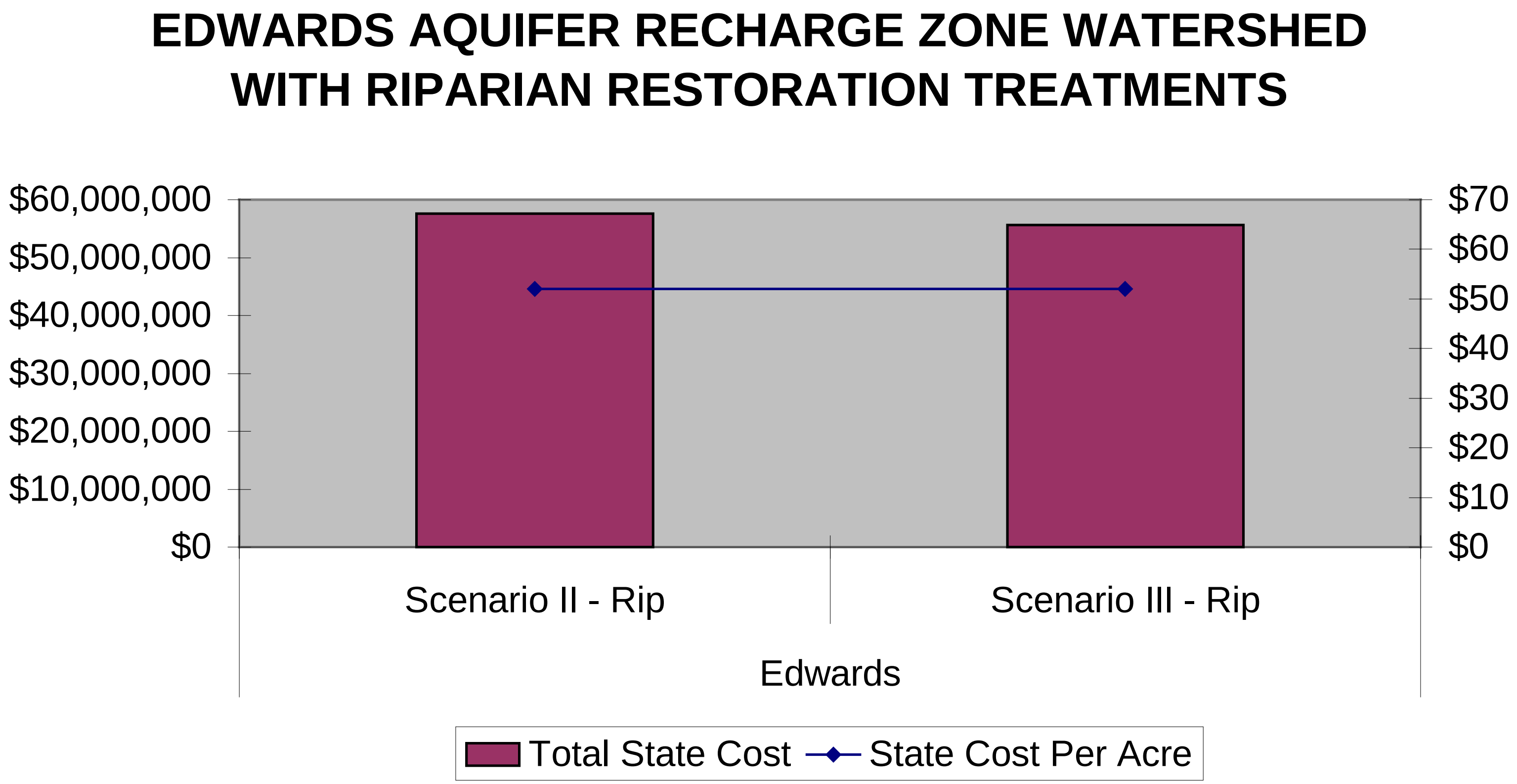


**Figure A4. Comparison of total society costs and costs per acre-foot of water saved. Edwards.**

# APPENDIX B: SPECIES DETECTED IN TWIN BUTTES AND ANALYSES

**Appendix B1:** **Species detected in Twin Buttes spring surveys. Bird species listed in descending order according to number of individuals detected. 295 survey sites sampled.**

| Common Name | Latin Name | # of Individuals | # of Sites Present |
|---|---|---|---|
| Northern Mockingbird | *Mimus polyglottos* | 435 | 215 |
| Lark Sparrow | *Chondestes grammacus* | 338 | 210 |
| Cassin's Sparrow | *Aimophila cassinii* | 311 | 173 |
| Mourning Dove | *Zenaida macroura* | 236 | 137 |
| Bewick's Wren | *Thryomanes bewickii* | 221 | 154 |
| Brown-headed Cowbird | *Molothrus ater* | 200 | 138 |
| Painted Bunting | *Passerina ciris* | 188 | 146 |
| Turkey Vulture | *Cathartes aura* | 141 | 92 |
| Ash-throated Flycatcher | *Myiarchus cinerascens* | 135 | 110 |
| Northern Bobwhite | *Colinus Virginians* | 116 | 87 |
| Northern Cardinal | *Cardinalis cardinalis* | 112 | 85 |
| Bullock's Oriole | *Icterus bullocki* | 95 | 69 |
| Canyon Towhee | *Pipilo fuscus* | 89 | 78 |
| Scissor-tailed Flycatcher | *Tyrannus forficatus* | 87 | 68 |
| Tufted Titmouse | *Baeolophus bicolor* | 82 | 59 |
| Common Nighthawk | *Chordeiles minor* | 69 | 50 |
| Black-throated Sparrow | *Amphispiza bilineata* | 64 | 54 |
| Golden-fronted Woodpecker | *Melanerpes aurifrons* | 57 | 50 |
| Scaled Quail | *Callipepla squamata* | 56 | 37 |
| House Finch | *Carpodacus mexicanus* | 53 | 31 |
| Western Meadowlark | *Sturnella neglecta* | 51 | 36 |
| Cactus Wren | *Campylorhynchus brunneicapillus* | 49 | 45 |
| Ladder-backed Woodpecker | *Picoides scalaris* | 44 | 42 |
| Vermillion Flycatcher | *Pyrocephalus rubinus* | 42 | 38 |
| Bell's Vireo | *Vireo bellii* | 37 | 25 |
| Horned Lark | *Eremophila alpestris* | 34 | 12 |
| Great-tailed Grackle | *Quiscalus mexicanus* | 33 | 7 |
| Rufous-crowned Sparrow | *Aimophila ruficeps* | 32 | 26 |
| Wild Turkey | *Meleagris gallopavo* | 32 | 16 |
| Killdeer | *Charadrius vociferus* | 27 | 20 |
| Scott's Oriole | *Icterus parisorum* | 27 | 26 |
| Western Scrub Jay | *Aphelocoma californica* | 27 | 20 |
| Western Kingbird | *Tyrannus verticalis* | 26 | 20 |
| Yellow-billed Cuckoo | *Coccyzus americanus* | 25 | 21 |
| Common Raven | *Corvus corax* | 24 | 20 |
| White-winged Dove | *Zenaida asiatica* | 24 | 11 |
| Blue Grosbeak | *Guiraca caerulea* | 21 | 20 |
| Black-chinned Hummingbird | *Archilochus alexandri* | 20 | 18 |
| Blue-grey Gnatcatcher | *Polioptila caerulea* | 18 | 14 |
| Grasshopper Sparrow | *Ammodramus savannarum* | 18 | 11 |

| | | | |
|---|---|---|---|
| House Sparrow | *Passer domesticus* | 18 | 8 |
| Chipping Sparrow | *Spizella passerina* | 16 | 13 |
| Red-tailed Hawk | *Buteo jamaicensis* | 15 | 12 |
| Greater Roadrunner | *Geococcyx californianus* | 14 | 13 |
| Summer Tanager | *Piranga rubra* | 14 | 11 |
| Orchard Oriole | *Icterus spurius* | 12 | 9 |
| Great-horned Owl | *Bubo virginianus* | 10 | 4 |
| Red-winged Blackbird | *Agelaius phoeniceus* | 9 | 5 |
| Pyrrhuloxia | *Cardinalis sinuatus* | 8 | 7 |
| Loggerhead Shrike | *Lanius ludovicianus* | 7 | 3 |
| Bank Swallow | *Riparia riparia* | 6 | 1 |
| Curve-billed Thrasher | *Toxostoma curvirostre* | 5 | 4 |
| Eastern Phoebe | *Sayornis phoebe* | 5 | 5 |
| Yellow-breasted Chat | *Icteria virens* | 5 | 3 |
| Bushtit | *Psaltriparus minimus* | 4 | 3 |
| Great Blue Heron | *Ardea herodias* | 4 | 4 |
| Green Heron | *Butorides virescens* | 4 | 2 |
| Yellow-throated Vireo | *Vireo flavifrons* | 3 | 2 |
| Eastern Wood-Pewee | *Contopus virens* | 2 | 2 |
| Field Sparrow | *Spizella pusilla* | 2 | 1 |
| Gray Vireo | *Vireo vicinior* | 2 | 2 |
| Inca Dove | *Columbina inca* | 2 | 2 |
| American Redstart | *Setophaga ruticilla* | 1 | 1 |
| Black Vulture | *Coragyps atratus* | 1 | 1 |
| Carolina Chickadee | *Poecile carolinensis* | 1 | 1 |
| Chihuahuan Raven | *Corvus cryptoleucus* | 1 | 1 |
| Cliff Swallow | *Petrochelidon pyrrhonota* | 1 | 1 |
| Great-crested Flycatcher | *Myiarchus crinitus* | 1 | 1 |
| Lesser Goldfinch | *Carduelis psaltria* | 1 | 1 |
| Swainson's Hawk | *Buteo swaonsoni* | 1 | 1 |
| White-eyed Vireo | *Vireo griseus* | 1 | 1 |
| Wilson's Warbler | *Wilsonia pusilla* | 1 | 1 |
| Yellow Warbler | *Dendroica petechia* | 1 | 1 |
| Grand Total | | 3874 | |

**Appendix B2: Species detected during Twin Buttes winter surveys. 135 survey sites sampled.**

| Common Name | Latin Name | # of Individuals | # of Sites Present |
|---|---|---|---|
| Western Meadowlark | *Sturnella neglecta* | 378 | 28 |
| White-crowned Sparrow | *Zonotrichia leucophrys* | 343 | 34 |
| Lark Bunting | *Calamospiza melanocorys* | 228 | 10 |
| Northern Mockingbird | *Mimus polyglottos* | 195 | 64 |
| Cedar Waxwing | *Bombycilla cedrorum* | 172 | 4 |
| Vesper Sparrow | *Pooecetes gramineus* | 115 | 21 |
| Chipping Sparrow | *Spizella passerina* | 106 | 12 |
| Bewick's Wren | *Thryomanes bewickii* | 93 | 57 |
| Tufted Titmouse | *Baeolophus bicolor* | 90 | 21 |
| Scaled Quail | *Callipepla squamata* | 71 | 2 |
| Morning Dove | *Zenaida macroura* | 69 | 24 |
| Great-tailed Grackle | *Quiscalus mexicanus* | 60 | 1 |
| Wild Turkey | *Meleagris gallopavo* | 52 | 6 |
| Cassin's Sparrow | *Aimophila cassinii* | 51 | 18 |
| Northern Cardinal | *Cardinalis cardinalis* | 51 | 22 |
| Mallard | *Anas platyrhynchos* | 46 | 3 |
| Canyon Towhee | *Pipilo fuscus* | 39 | 28 |
| Golden-fronted Woodpecker | *Melanerpes aurifrons* | 37 | 23 |
| Horned Lark | *Eremophila alpestris* | 33 | 2 |
| House Finch | *Carpodacus mexicanus* | 32 | 17 |
| Turkey Vulture | *Cathartes aura* | 31 | 7 |
| Field Sparrow | *Spizella pusilla* | 27 | 11 |
| Cactus Wren | *Campylorhynchus brunneicapillus* | 24 | 14 |
| Ruby-crowned Kinglet | *Regulis calendula* | 24 | 17 |
| Red-tailed Hawk | *Buteo jamaicensis* | 21 | 15 |
| Savanna Sparrow | *Passerculus sandwichensis* | 20 | 5 |
| Common Raven | *Corvus corax* | 19 | 16 |
| Killdeer | *Charadrius vociferus* | 19 | 14 |
| European Starling | *Sturnus vulgaris* | 17 | 2 |
| Ladder-backed Woodpecker | *Picoides scalaris* | 17 | 13 |
| Yellow-rumped Warbler | *Dendroica coronata* | 14 | 8 |
| Lincoln Sparrow | *Melospiza lincolnii* | 13 | 6 |
| Western Scrub Jay | *Aphelocoma californica* | 12 | 7 |
| Brown-headed Cowbird | *Molothrus ater* | 11 | 3 |
| Lark Sparrow | *Chondestes grammacus* | 11 | 3 |
| Black-throated Sparrow | *Amphispiza bilineata* | 10 | 7 |
| Loggerhead Shrike | *Lanius ludovicianus* | 10 | 8 |
| Song Sparrow | *Melospiza melodia* | 10 | 6 |
| Spotted Towhee | *Pipilo maculatus* | 9 | 6 |
| Dark-eyed Junco | *Junco hyemalis* | 8 | 1 |
| Double-crested Cormerant | *Phalacrocorax auritus* | 8 | 1 |
| Curve-billed Thrasher | *Toxostoma curvirostre* | 7 | 4 |
| Eastern Phoebe | *Sayornis phoebe* | 7 | 5 |

| | | | |
|---|---|---|---|
| Pyrrhuloxia | *Cardinalis sinuatus* | 7 | 5 |
| Black Vulture | *Coragyps atratus* | 6 | 2 |
| Bushtit | *Psaltriparus minimus* | 6 | 2 |
| Northern Harrier | *Circus cyaneus* | 6 | 5 |
| Rufous-crowned Sparrow | *Aimophila ruficeps* | 6 | 3 |
| Sage Thrasher | *Oreoscoptes montanus* | 6 | 5 |
| Grasshopper Sparrow | *Ammodramus savannarum* | 5 | 4 |
| Lesser Goldfinch | *Carduelis psaltria* | 5 | 1 |
| American Kestrel | *Falco sparverius* | 4 | 4 |
| American Robin | *Turdus migratorius* | 4 | 1 |
| American Widgeon | *Anas americana* | 4 | 1 |
| Greater Roadrunner | *Geococcyx californianus* | 4 | 4 |
| Orange-crowned Warbler | *Vermivora celata* | 4 | 3 |
| Wood Duck | *Aix sponsa* | 4 | 1 |
| Vermilion Flycatcher | *Pyrocephalus rubinus* | 3 | 3 |
| Brown Creeper | *Certhia americana* | 2 | 2 |
| House Wren | *Troglodytes aedon* | 2 | 2 |
| Marsh Wren | *Cistothorus palustris* | 2 | 2 |
| American Goldfinch | *Carduelis tristis* | 1 | 1 |
| Belted Kingfisher | *Ceryle alcton* | 1 | 1 |
| Blue-headed Vireo | *Vireo solitarius* | 1 | 1 |
| Brewer's Sparrow | *Spizella breweri* | 1 | 1 |
| Brown Thrasher | *Toxostoma rufum* | 1 | 1 |
| Carolina Wren | *Thryothorus ludovicianus* | 1 | 1 |
| Great-horned Owl | *Bubo virginianus* | 1 | 1 |
| House Sparrow | *Passer domesticus* | 1 | 1 |
| Lesser Scaup | *Aythya affinis* | 1 | 1 |
| Long-billed Dowitcher | *Limnodromus griseus* | 1 | 1 |
| Rock Wren | *Salpinctus obsoletus* | 1 | 1 |
| Say's Phoebe | *Sayornis saya* | 1 | 1 |
| Grand Total | | 2702 | |

**Appendix B3: Logistic regression models for all Twin Buttes breeding guilds (*** = p<0.01, ** = p<0.05, * = p<0.1).**

| | N | Rho2 | Loglikelihood | df | Ln+1 Juniper Cover | Ln+1 Mesquite Cover | Ln+1 Mix Cover | Ln+1 Oak Cover |
|---|---|---|---|---|---|---|---|---|
| Deciduous Guild | 14 | 0.396 | -56.382 | 4 | - | + | - | +*** |
| Grassland Facultative | 293 | 0.178 | -16.760 | 4 | + | +* | + | - |
| Grassland Guild | 266 | 0.146 | -97.100 | 4 | -* | -* | - | -*** |
| Grassland Obligates | 177 | 0.125 | -199.452 | 4 | -*** | - | - | -*** |
| **Brush Guild** | 239 | 0.119 | -145.018 | 4 | +*** | + | + | +*** |
| Riparian | 91 | 0.060 | -182.641 | 4 | - | + | - | +*** |
| Generalist Guild | 223 | 0.049 | -165.344 | 4 | +*** | - | - | + |
| Woodland Guild | 242 | 0.041 | -140.618 | 4 | + | + | + | +** |
| Scrub Guild | 209 | 0.024 | -179.265 | 4 | +** | + | + | + |
| Savanna Guild | 246 | 0.018 | -34.434 | 4 | - | + | + | - |

**Appendix B4: Logistic regression models for Twin Buttes breeding species with N>15 (*** = p<0.01, ** = p<0.05, * = p<0.1).`**

| | N | Partners in Flight Priority | Rho2 | Loglikelihood | df | Ln+1 Juniper Cover | Ln+1 Mesquite Cover | Ln+1 Mix Cover | Ln+1 Oak Cover |
|---|---|---|---|---|---|---|---|---|---|
| Black-chinned Hummingbird | 18 | High | 0.252 | -67.841 | 4 | + | - | + | +*** |
| **Tufted Titmouse** | 59 | | 0.170 | -147.841 | 4 | + | -* | +*** | +*** |
| Western Scrub Jay | 20 | | 0.159 | -73.201 | 4 | +*** | + | + | - |
| Yellow-billed Cuckoo | 21 | High | 0.157 | -75.799 | 4 | - | - | - | +*** |
| **Cassin's Sparrow** | 173 | High | 0.112 | -200.928 | 4 | -** | + | - | -*** |
| **Lark Sparrow** | 210 | Physiographic | 0.111 | -178.380 | 4 | -** | - | - | -*** |
| Western Meadowlark | 36 | | 0.103 | -109.562 | 4 | -*** | + | - | - |
| Northern Cardinal | 85 | | 0.087 | -177.479 | 4 | +** | +** | + | +*** |
| Bell's Vireo | 25 | Highest | 0.085 | -85.700 | 4 | - | +* | -* | +** |
| Black-throated Sparrow | 54 | | 0.075 | -140.618 | 4 | +*** | + | - | - |
| Bewick's Wren | 154 | Physiographic | 0.073 | -204.928 | 4 | +*** | + | + | +*** |
| Painted Bunting | 146 | High | 0.071 | -205.145 | 4 | +** | + | +* | +** |
| Scaled Quail | 37 | | 0.049 | -111.524 | 4 | + | - | + | -** |
| Northern Mockingbird | 215 | | 0.048 | -173.709 | 4 | +*** | - | -* | + |
| Vermillion Flycatcher | 38 | Physiographic | 0.046 | -113.455 | 4 | -** | - | + | +* |
| Blue Grosbeak | 20 | | 0.036 | -73.201 | 4 | + | + | + | - |
| Canyon Towhee | 78 | | 0.035 | -170.703 | 4 | +** | + | -* | - |
| Scissor-tailed Flycatcher | 68 | Global | 0.034 | -159.529 | 4 | -** | + | + | -** |
| Bullock's Oriole | 69 | | 0.032 | -160.729 | 4 | - | +* | - | -*** |
| Rufous-crowned Sparrow | 26 | High | 0.032 | -88.062 | 4 | +** | + | + | - |
| Common Raven | 20 | | 0.030 | -73.201 | 4 | -** | + | + | - |
| Scott's Oriole | 26 | | 0.029 | -88.062 | 4 | +* | - | + | + |
| Western Kingbird | 20 | | 0.029 | -73.201 | 4 | - | - | - | + |
| Cactus Wren | 45 | | 0.027 | -126.158 | 4 | + | +** | - | - |
| Common Nighthawk | 50 | | 0.025 | -134.434 | 4 | -** | + | - | - |
| Ladderbacked Woodpecker | 42 | Physiographic | 0.025 | -120.881 | 4 | - | + | - | + |
| Mourning Dove | 137 | | 0.022 | -204.353 | 4 | - | + | + | + |
| Brown-headed Cowbird | 138 | | 0.020 | -204.495 | 4 | + | - | -** | +** |
| Killdeer | 20 | | 0.018 | -73.201 | 4 | - | + | - | + |
| Ash-throated Flycatcher | 110 | | 0.017 | -195.305 | 4 | - | + | +* | - |
| House Finch | 31 | | 0.017 | -99.264 | 4 | + | + | - | + |
| Wild Turkey | 16 | Physiographic | 0.010 | -62.244 | 4 | - | + | + | - |
| Golden-fronted Woodpecker | 50 | | 0.009 | -134.434 | 4 | - | + | - | + |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Turkey Vulture | 92 | | 0.005 | -183.445 | 4 | + | - | + | - |
| Northern Bobwhite | 87 | High | 0.002 | -179.265 | 4 | + | - | + | + |

**Appendix B5: Twin Buttes logistic regression model estimates.**

| | Constant | | ln+1 Juniper Cover | | ln+1 Mesquite Cover | | ln+1 Mix Cover | | Ln+1 Oak Cover | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate | S.E. | Estimate | S.E. | Estimate | S.E. | Estimate | S.E. | Estimate | S.E. |
| Grassland Obligates | 3.11 | 0.744 | -0.738 | 0.245 | -0.049 | 0.229 | -0.392 | 0.273 | -1.133 | 0.246 |
| Brush Guild | -1.967 | 0.781 | 1.028 | 0.291 | 0.343 | 0.27 | 0.159 | 0.379 | 0.946 | 0.351 |
| Black-chinned Hummingbird | -3.374 | 1.476 | 0.057 | 0.456 | -0.86 | 0.568 | 0.314 | 0.555 | 2.172 | 0.498 |
| Tufted Titmouse | -2.067 | 0.856 | 0.032 | 0.292 | -0.536 | 0.311 | 1.084 | 0.315 | 1.259 | 0.285 |
| Western Scrub Jay | -8.968 | 1.771 | 2.257 | 0.548 | 0.416 | 0.449 | 0.573 | 0.429 | -0.275 | 0.452 |
| Yellow-billed Cuckoo | -2.795 | 1.282 | -0.364 | 0.413 | -0.144 | 0.461 | -0.496 | 0.538 | 1.648 | 0.416 |
| Cassin's Sparrow | 2.314 | 0.703 | -0.501 | 0.236 | 0.063 | 0.226 | -0.418 | 0.27 | -1.145 | 0.247 |
| Lark Sparrow | 3.731 | 0.814 | -0.538 | 0.256 | -0.316 | 0.248 | -0.323 | 0.28 | -0.935 | 0.243 |
| Western Meadowlark | 1.156 | 0.871 | -1.448 | 0.349 | 0.023 | 0.315 | -0.414 | 0.469 | -0.395 | 0.361 |

# APPENDIX C: SPECIES DETECTED IN EDWARDS AND ANALYSES

**Appendix C1: Species detected in Edwards spring surveys. 201 survey sites sampled.**

| Common Name | Latin Name | # of Individuals | # of Sites Present |
|---|---|---|---|
| Tufted Titmouse | *Baeolophus bicolor* | 233 | 147 |
| Northern Cardinal | *Cardinalis cardinalis* | 225 | 157 |
| Bewick's Wren | *Thryomanes bewickii* | 160 | 122 |
| Brown-headed Cowbird | *Molothrus ater* | 157 | 91 |
| Cedar Waxwing | *Bombycilla cedrorum* | 145 | 3 |
| Mourning Dove | *Zenaida macroura* | 137 | 79 |
| Cliff Swallow | *Petrochelidon pyrrhonota* | 120 | 9 |
| Golden-cheeked Warbler | *Dendroica chrysoparia* | 101 | 70 |
| Ash-throated Flycatcher | *Myiarchus cinerascens* | 95 | 79 |
| Carolina Chickadee | *Poecile carolinensis* | 87 | 58 |
| White-eyed Vireo | *Vireo griseus* | 79 | 63 |
| Summer Tanager | *Piranga rubra* | 77 | 67 |
| Turkey Vulture | *Cathartes aura* | 71 | 49 |
| Blue-grey Gnatcatcher | *Polioptila caerulea* | 69 | 53 |
| Lark Sparrow | *Chondestes grammacus* | 69 | 45 |
| Western Scrub Jay | *Aphelocoma californica* | 65 | 49 |
| Black-and-white Warbler | *Mniotilta varia* | 63 | 51 |
| Rufous-crowned Sparrow | *Aimophila ruficeps* | 59 | 47 |
| House Finch | *Carpodacus mexicanus* | 57 | 40 |
| Ladder-backed Woodpecker | *Picoides scalaris* | 55 | 48 |
| Black-chinned Hummingbird | *Archilochus alexandri* | 48 | 43 |
| Chipping Sparrow | *Spizella passerina* | 47 | 35 |
| Northern Mockingbird | *Mimus polyglottos* | 47 | 38 |
| Carolina Wren | *Pipilo fuscus* | 41 | 34 |
| Painted Bunting | *Passerina ciris* | 40 | 36 |
| Bushtit | *Psaltriparus minimus* | 38 | 13 |
| Field Sparrow | *Spizella pusilla* | 34 | 24 |
| Blue Grosbeak | *Guiraca caerulea* | 33 | 29 |
| Wild Turkey | *Meleagris gallopavo* | 32 | 28 |
| Yellow-billed Cuckcoo | *Coccyzus americanus* | 31 | 28 |
| Lesser Goldfinch | *Carduelis psaltria* | 30 | 19 |
| Vermillion Flycatcher | *Pyrocephalus rubinus* | 27 | 22 |
| Eastern Phoebe | *Sayornis phoebe* | 26 | 21 |
| Red-eyed Vireo | *Vireo olivaceus* | 25 | 24 |
| Scissor-tailed Flycatcher | *Scissor-tailed Flycatcher* | 25 | 18 |
| Canyon Wren | *Catherpes mexicanus* | 24 | 22 |
| Northern Bobwhite | *Colinus virginianus* | 20 | 15 |
| Great-tailed Grackle | *Quiscalus mexicanus* | 17 | 12 |
| Indigo Bunting | *Passerina cyanea* | 17 | 14 |
| Greater Roadrunner | *Geococcyx californianus* | 15 | 15 |
| Yellow-throated Vireo | *Vireo flavifrons* | 14 | 13 |
| Scott's Oriole | *Scott's Oriole* | 13 | 12 |

| | | | |
|---|---|---|---|
| Black Vulture | *Coragyps atratus* | 12 | 12 |
| Nashville Warbler | *Vermivora ruficapilla* | 12 | 10 |
| Black-capped Vireo | *Vireo atricapillus* | 11 | 7 |
| Common Raven | *Corvus corax* | 11 | 7 |
| Eastern Wood Pewee | *Contopus virens* | 11 | 10 |
| Acadian Flycatcher | *Empidonax virescens* | 10 | 9 |
| Barn Swallow | *Hirundo rustica* | 9 | 7 |
| Cassin's Sparrow | *Aimophila cassinii* | 9 | 7 |
| Golden-fronted Woodpecker | *Melanerpes aurifrons* | 7 | 7 |
| Orange-crowned Warbler | *Vermivora celata* | 7 | 4 |
| Ruby-crowned Kinglet | *Regulis calendula* | 7 | 6 |
| White-winged Dove | *Zenaida asiatica* | 6 | 4 |
| Eastern Bluebird | *Sialia sialis* | 5 | 3 |
| Orchard Oriole | *Icterus spurius* | 5 | 4 |
| Red-shouldered Hawk | *Buteo lineatus* | 5 | 5 |
| Common Ground Dove | *Columbina passerina* | 4 | 4 |
| Grasshopper Sparrow | *Ammodramus savannarum* | 4 | 3 |
| American Kestrel | *Falco sparverius* | 3 | 3 |
| Belted Kingfisher | *Ceryle alcton* | 3 | 2 |
| Killdeer | *Charadrius vociferus* | 3 | 2 |
| Lincoln's Sparrow | *Melospiza lincolnii* | 3 | 2 |
| Red-tailed Hawk | *Buteo jamaicensis* | 3 | 3 |
| Yellow Warbler | *Dendroica petechia* | 3 | 3 |
| Yellow-throated Warbler | *Dendroica dominica* | 3 | 3 |
| Cave Swallow | *Petrochelidon fulva* | 2 | 2 |
| Great-crested Flycatcher | *Myiarchus crinitus* | 2 | 2 |
| Purple Martin | *Progne subis* | 2 | 2 |
| Yellow-bellied Flycatcher | *Empidonax flaviventris* | 2 | 1 |
| Clay-colored Sparrow | *Spizella pallida* | 1 | 1 |
| Common Nighthawk | *Chordeiles minor* | 1 | 1 |
| Cooper's Hawk | *Accipiter cooperii* | 1 | 1 |
| Great-blue Heron | *Ardea herodias* | 1 | 1 |
| Green Heron | *Butorides virescens* | 1 | 1 |
| House Wren | *Troglodytes aedon* | 1 | 1 |
| Swainson's Hawk | *Buteo swaonsoni* | 1 | 1 |
| Wilson's Warbler | *Wilsonia pusilla* | 1 | 1 |
| Yellow-headed Blackbird | *Xanthocephalus xanthocephalus* | 1 | 1 |
| Grand Total | | 2941 | |

**Appendix C2: Species detected in Edwards winter surveys. 147 survey sites sampled.**

| Common Name | Latin Name | # of Individuals | # of Sites Present |
|---|---|---|---|
| Chipping Sparrow | *Spizella passerina* | 691 | 25 |
| Tufted Titmouse | *Baeolophus bicolor* | 188 | 68 |
| Morning Dove | *Zenaida macroura* | 136 | 25 |
| Field Sparrow | *Spizella pusilla* | 116 | 20 |
| Cedar Waxwing | *Bombycilla cedrorum* | 114 | 7 |
| Ruby-crowned Kinglet | *Regulis calendula* | 98 | 51 |
| Northern Cardinal | *Cardinalis cardinalis* | 88 | 56 |
| Vesper Sparrow | *Pooecetes gramineus* | 87 | 11 |
| Carolina Chickadee | *Poecile carolinensis* | 83 | 29 |
| Bewick's Wren | *Thryomanes bewickii* | 48 | 42 |
| Eastern Phoebe | *Sayornis phoebe* | 41 | 32 |
| Lincoln's Sparrow | *Melospiza lincolnii* | 40 | 15 |
| Western Scrub Jay | *Aphelocoma californica* | 40 | 24 |
| House Finch | *Carpodacus mexicanus* | 37 | 23 |
| Ladder-backed Woodpecker | *Picoides scalaris* | 37 | 33 |
| American Robin | *Turdus migratorius* | 32 | 7 |
| Common Raven | *Corvus corax* | 31 | 23 |
| Savannah Sparrow | *Passerculus sandwichensis* | 25 | 11 |
| Spotted Towhee | *Pipilo maculatus* | 24 | 16 |
| Bushtit | *Psaltriparus minimus* | 23 | 4 |
| Black Vulture | *Coragyps atratus* | 20 | 11 |
| Rufous-crowned Sparrow | *Aimophila ruficeps* | 19 | 11 |
| Northern Mockingbird | *Mimus polyglottos* | 18 | 16 |
| Orange-crowned Warbler | *Vermivora celata* | 18 | 11 |
| Canyon Wren | *Catherpes mexicanus* | 11 | 9 |
| Dark-eyed Junco | *Junco hyemalis* | 10 | 2 |
| Greater Roadrunner | *Geococcyx californianus* | 9 | 8 |
| Red-tailed Hawk | *Buteo jamaicensis* | 9 | 8 |
| Carolina Wren | *Pipilo fuscus* | 6 | 4 |
| Hermit Thrush | *Catharus guttatus* | 6 | 4 |
| Lesser Goldfinch | *Carduelis psaltria* | 6 | 2 |
| American Kestrel | *Falco sparverius* | 5 | 5 |
| Golden-crowned Kinglet | *Regulus satrapa* | 5 | 3 |
| Golden-fronted Woodpecker | *Melanerpes aurifrons* | 5 | 5 |
| Grasshopper Sparrow | *Ammodramus savannarum* | 5 | 4 |
| Killdeer | *Charadrius vociferus* | 5 | 4 |
| Yellow-bellied Sapsucker | *Sphyrapicus varius* | 5 | 4 |
| Yellow-rumped Warbler | *Dendroica coronata* | 5 | 4 |
| Eastern Meadowlark | *Sturnella neglecta* | 4 | 1 |
| White-eyed Vireo | *Vireo griseus* | 4 | 3 |
| Leconte's Sparrow | *Ammodramus leconteii* | 3 | 3 |
| Northern Harrier | *Circus cyaneus* | 3 | 3 |
| Song Sparrow | *Melospiza melodia* | 3 | 2 |

| | | | |
|---|---|---|---|
| Eastern Bluebird | *Sialia sialis* | 2 | 1 |
| Barred Owl | *Strix varia* | 1 | 1 |
| Belted Kingfisher | *Ceryle alcton* | 1 | 1 |
| Black Phoebe | *Sayornis nigricans* | 1 | 1 |
| Blue-headed Vireo | *Vireo solitarius* | 1 | 1 |
| Canyon Towhee | *Pipilo fuscus* | 1 | 1 |
| Great-blue Heron | *Ardea herodias* | 1 | 1 |
| Green Kingfisher | *Butorides virescens* | 1 | 1 |
| Loggerhead Shrike | *Lanius ludovicianus* | 1 | 1 |
| Merlin | *Falco columbarius* | 1 | 1 |
| Peregrine Falcon | *Falco pergrinus* | 1 | 1 |
| Red-winged Blackbird | *Agelaius phoeniceus* | 1 | 1 |
| White-crowned Sparrow | *Zonotrichia leucophrys* | 1 | 1 |
| Grand Total | | 2177 | |

**Appendix C3: Logistic regression for all Edwards breeding bird guilds (*** = p<0.01, ** = p<0.05, * = p<0.1).**

| | N | Rho2 | Loglikelihood | df | Ln+1 Cedar Cover | Oak Cover | Mix Cover | Ln+1 Mesquite Cover |
|---|---|---|---|---|---|---|---|---|
| **Grassland Guild** | 56 | 0.295 | -118.918 | 4 | - *** | - * | - *** | - * |
| Grassland Facultative | 183 | 0.269 | -60.602 | 4 | -*** | + | - | + |
| Grassland Obligate | 8 | 0.255 | -33.63 | 4 | - | - | - | - |
| Savanna Guild | 167 | 0.097 | -91.363 | 4 | -*** | +** | - | +* |
| Deciduous Guild | 134 | 0.074 | -127.939 | 4 | + | +*** | +** | + |
| Generalist Guild | 90 | 0.049 | -138.224 | 4 | -** | +** | - | - |
| Woodland Guild | 194 | 0.029 | -30.378 | 4 | - | + | - | - |
| Riparian | 130 | 0.024 | -130.535 | 4 | + | - | - | + |
| Scrub Guild | 116 | 0.011 | -136.922 | 4 | + | - | + | - |

**Appendix C4: Logistic regression models for Edwards breeding bird species with N>15 (*** = p<0.01, ** = P<0.05, * = p<0.1).**

| Species | N | Partners in Flight Priority | Rho2 | Loglikelihood | df | Ln+1 Cedar Cover | Oak Cover | Mix Cover | Ln+1 Mesquite Cover |
|---|---|---|---|---|---|---|---|---|---|
| Golden-cheeked Warbler | 70 | Highest | 0.319 | -129.92 | 4 | + *** | + *** | + *** | - |
| Northern Mockingbird | 38 | | 0.288 | -97.455 | 4 | -** | + | -*** | - |
| Scissortail Flycatcher | 18 | Global | 0.277 | -60.602 | 4 | - | - | - *** | - |
| Vermillion Flycatcher | 22 | Physiographic | 0.270 | -69.419 | 4 | - * | - ** | - ** | - |
| **Lark Sparrow** | 45 | Physiographic | 0.245 | -106.887 | 4 | - ** | - | - *** | - |
| Black-and-white Warbler | 51 | | 0.203 | -113.85 | 4 | + *** | + *** | + ** | - |
| Northern Bobwhite | 15 | High | 0.179 | -53.355 | 4 | - *** | - | + | - |
| **Red-eyed Vireo** | 24 | | 0.162 | -73.512 | 4 | +** | +** | +* | +* |
| Canyon Wren | 22 | | 0.153 | -69.419 | 4 | + | +** | +* | - |
| Western Scrub Jay | 49 | | 0.114 | -111.635 | 4 | +*** | - | + | - |
| **White-eyed Vireo** | 63 | | 0.106 | -124.986 | 4 | + * | + | + *** | + |
| Blue-gray Gnatcatcher | 53 | | 0.102 | -115.951 | 4 | + | +*** | +** | + |
| Lesser Goldfinch | 19 | Physiographic | 0.101 | -62.891 | 4 | - ** | + * | - | + |
| Carolina Wren | 34 | | 0.084 | -91.363 | 4 | + | +* | +*** | + |
| Chipping Sparrow | 35 | | 0.079 | -92.937 | 4 | - | - | -** | + |
| Mourning Dove | 79 | | 0.078 | -134.687 | 4 | -*** | +** | - | + |
| House Finch | 40 | | 0.068 | -100.303 | 4 | - | + | -** | - |
| Wild Turkey | 28 | Physiographic | 0.065 | -81.143 | 4 | - | + | -** | + |
| Yellow-billed Cuckoo | 28 | High | 0.064 | -81.143 | 4 | -*** | +* | + | - |
| Eastern Phoebe | 21 | | 0.055 | -67.297 | 4 | - | + | - | +* |
| Tufted Titmouse | 147 | | 0.051 | -116.966 | 4 | + | +* | + | + |
| Ladderbacked Woodpecker | 48 | Physiographic | 0.050 | -110.49 | 4 | + | +*** | - | + |
| Greater Roadrunner | 15 | | 0.049 | -53.355 | 4 | - | + | - | + |
| Blue Grosbeak | 29 | | 0.047 | -82.944 | 4 | + | + | - | +* |
| Brown-headed Cowbird | 91 | | 0.047 | -138.423 | 4 | - | + | - | - |
| Field Sparrow | 24 | Physiographic | 0.046 | -73.512 | 4 | - | + | - | - |
| Painted Bunting | 36 | High | 0.043 | -94.477 | 4 | - | + | - | + |
| Northern Cardinal | 157 | | 0.036 | -105.629 | 4 | + | + | + | - |
| Carolina Chickadee | 49 | | 0.028 | -111.635 | 4 | - | + | +** | + |
| Summer Tanager | 67 | | 0.027 | -127.939 | 4 | - | + | - | + |
| Ash-throated Flycatcher | 79 | | 0.022 | -134.687 | 4 | + | +* | - | + |
| Rufous-crowned Sparrow | 47 | High | 0.021 | -109.317 | 4 | + | + | + | - |
| Turkey Vulture | 49 | | 0.019 | -111.635 | 4 | -* | + | + | - |
| Black-chinned Hummingbird | 43 | High | 0.018 | -104.343 | 4 | + | + | + | - |
| Bewick's Wren | 122 | Physiographic | 0.014 | -134.687 | 4 | -* | + | + | + |

**Appendix C5: Edwards logistic regression model estimates.**

| | Constant | | ln+1 Cedar Cover | | Oak Cover | | Mix Cover | | ln+1 Mesquite Cover | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate | S.E | Estimate | S.E | Estimate | S.E | Estimate | S.E | Estimate | S.E |
| Grassland Guild | 3.964 | 0.859 | -0.841 | 0.236 | -0.082 | 0.045 | -0.101 | 0.028 | -0.774 | 0.438 |
| Golden-cheeked Warbler | -7.580 | 1.373 | 1.297 | 0.291 | 0.131 | 0.050 | 0.103 | 0.028 | -0.003 | 0.375 |
| Northern Mockingbird | 2.020 | 0.807 | -0.568 | 0.268 | 0.021 | 0.048 | -0.174 | 0.041 | -0.054 | 0.458 |
| Scissortail Flycatcher | 1.755 | 1.001 | -0.621 | 0.387 | -0.052 | 0.064 | -0.158 | 0.058 | -0.335 | 0.618 |
| Vermillion Flycatcher | 2.105 | 0.941 | -0.595 | 0.355 | -0.152 | 0.064 | -0.095 | 0.043 | -0.205 | 0.570 |
| Lark Sparrow | 2.803 | 0.798 | -0.626 | 0.245 | -0.072 | 0.046 | -0.108 | 0.031 | -0.348 | 0.438 |
| Black-and-white Warbler | -5.871 | 1.229 | 0.846 | 0.271 | 0.132 | 0.050 | 0.060 | 0.027 | -0.272 | 0.376 |
| Northern Bobwhite | 0.842 | 1.107 | -1.199 | 0.386 | -0.057 | 0.066 | 0.008 | 0.034 | -1.129 | 0.709 |
| Red-eyed Vireo | -8.341 | 1.904 | 0.975 | 0.420 | 0.136 | 0.067 | 0.067 | 0.037 | 0.779 | 0.462 |
| Canyon Wren | -6.112 | 1.700 | 0.388 | 0.344 | 0.164 | 0.068 | 0.063 | 0.037 | -0.686 | 0.528 |
| Western Scrub Jay | -3.340 | 0.913 | 0.988 | 0.270 | -0.032 | 0.045 | 0.020 | 0.023 | -0.169 | 0.361 |
| White-eyed Vireo | -3.780 | 0.860 | 0.383 | 0.215 | 0.049 | 0.041 | 0.072 | 0.022 | 0.097 | 0.334 |
| Blue-gray Gnatcatcher | -4.250 | 0.936 | 0.026 | 0.216 | 0.159 | 0.046 | 0.054 | 0.024 | 0.062 | 0.349 |
| Lesser Goldfinch | -1.527 | 0.998 | -0.752 | 0.309 | 0.106 | 0.059 | -0.043 | 0.038 | 0.113 | 0.531 |

# APPENDIX D: BIRD GUILDS

Appendix D1: TWIN BUTTES BREEDING BIRD GUILDS
**(F=Grassland Facultative, O=Grassland Obligate, R= Riparian Associated)**

## *GRASSLAND*

| | | | |
|---|---|---|---|
| Bobwhite Quail | F | | |
| Cassin's Sparrow | | O | |
| Chihuahuan Raven | | F | |
| Grasshopper Sparrow | | O | |
| Horned Lark | | O | |
| Killdeer | F | | |
| Lark Sparrow | | F | |
| Western Meadowlark | | O | |

## *SAVANNA*

| | | | |
|---|---|---|---|
| Bank Swallow | | | R |
| Black Vulture | | | |
| Cliff Swallow | | | R |
| Common Nighthawk | | F | |
| Ladder-backed Woodpecker | | | |
| Lesser Goldfinch | | | |
| Loggerhead Shrike | | F | |
| Mourning Dove | F | | |
| Scaled Quail | | F | |
| Scissor-tailed Flycatcher | F | | |
| Swainson's Hawk | | O | |
| Turkey Vulture | F | | |
| Western Kingbird | | F | |

## HUMAN

Great-tailed Grackle
House Sparrow

## *MARSH / RIVER*

| | | | |
|---|---|---|---|
| Great Blue Heron | | | R |
| Red-winged Blackbird | F | R | |
| Green Heron | | | R |

## *SCRUB*

| | | |
|---|---|---|
| Ash-throated Flycatcher | | |
| Black-throated Sparrow | | |
| Cactus Wren | | |
| Greater Roadrunner | | |
| Grey Vireo | | |
| House Finch | | |
| Orchard Oriole | | |
| Rufous-crowned Sparrow | | F |
| Scott's Oriole | | |
| Scrub Jay | | |

## *WOODLAND*

| | | | |
|---|---|---|---|
| Black-chinned Hummingbird | | | |
| Blue Grosbeak | | | |
| Brown-headed Cowbird | F | | |
| Bullock's Oriole | | | |
| Bushtit | | | |
| Chipping Sparrow | | | |
| Eastern Phoebe | | R | |
| Golden-fronted Woodpecker | | | |
| Great-horned Owl | | | |
| Inca Dove | | | |
| Red-tailed Hawk | | | |
| Tufted Titmouse | | | |
| Vermillion Flycatcher | | | R |
| White-winged Dove | | | R |
| Wild Turkey | | | |
| Yellow-billed Cuckoo | | | |

## DECIDUOUS WOODLAND

| | | | |
|---|---|---|---|
| Carolina Chickadee | | | R |
| Eastern Wood-Pewee | | | |
| Great-crested Flycatcher | | | |
| Summer Tanager | | | |
| Yellow-throated Vireo | | | |

## *BRUSH*

| | | | |
|---|---|---|---|
| Bell's Vireo | | | R |
| Bewick's Wren | | | |
| Canyon Towhee | | F | |
| Curve-billed Thrasher | | | |
| Field Sparrow | | | |
| Northern Cardinal | | | |
| Painted Bunting | | | |
| Pyrrhuloxia | | | |
| White-eyed Vireo | | | R |
| Yellow-breasted Chat | | | R |

## *GENERALIST*

Blue-gray Gnatcatcher
Common Raven
Northern Mockingbird

## *MIGRATION*

American Redstart
Wilson's Warbler
Yellow Warbler

**Appendix D2: TWIN BUTTES WINTER BIRD GUILDS**
**(F=Grassland Facultative, O=Grassland Obligate)**

## GROUND GLEANS SEEDS (GRASS OR FORB)

| | |
|---|---|
| Black-throated Sparrow | |
| Brewer's Sparrow | |
| Brown-headed Cowbird | F |
| Canyon Towhee | F |
| Cassin's Sparrow | O |
| Chipping Sparrow | |
| Dark-eyed Junco | |
| Field Sparrow | |
| Grasshopper Sparrow | O |
| Horned Lark | O |
| House Finch | |
| House Sparrow | |
| Killdeer | F |
| Lark Bunting | O |
| Lark Sparrow | F |
| Lincoln Sparrow | |
| Morning Dove | F |
| Rufous-crowned Sparrow | F |
| Savanna Sparrow | O |
| Scaled Quail | F |
| Song Sparrow | |
| Spotted Towhee | |
| Vesper Sparrow | O |
| Western Meadowlark | O |
| White-crowned Sparrow | |

## GROUND GLEANS FRUIT OR BERRIES

American Robin
Cactus Wren
Curve-billed Thrasher
Greater Roadrunner
Northern Cardinal
Northern Mockingbird
Pyrrhuloxia
Sage Thrasher
Scrub Jay
Starling

## FLYCATCH

| | |
|---|---|
| Eastern Phoebe | |
| Say's Phoebe | F |
| Vermilion Flycatcher | |

## GROUND GLEANS OTHER

Bewick's Wren
Brown Thrasher
Carolina Wren
Common Raven
Great-tailed Grackle
House Wren
Marsh Wren
Rock Wren
Wild Turkey

*FOLIAGE GLEAN*

American Goldfinch
Blue-headed Vireo
Bushtit
Cedar Waxwing
Lesser Goldfinch
Orange-crowned Warbler
Ruby-crowned Kinglet
Tufted Titmouse
Yellow-rumped Warbler

*BIRDS OF PREY*

| | |
|---|---|
| American Kestrel | F |
| Black Vulture | |
| Great Horned Owl | |
| Loggerhead Shrike | F |
| Northern Harrier | O |
| Red-tailed Hawk | |
| Turkey Vulture | F |

*BARK GLEAN*

Brown Creeper
Golden-fronted Woodpecker
Ladder-backed Woodpecker

*AQUATIC*

| | |
|---|---|
| American Wigeon | F |
| Belted Kingfisher | |
| Double-crested Cormorant | |
| Lesser Scaup | |
| Long-billed Dowitcher | F |
| Mallard | F |
| Wood Duck | |

**Appendix D3: EDWARDS BREEDING BIRD GUILDS**
**(F=Grassland Facultative, O=Grassland Obligate, R= Riparian Associated)**

### GRASSLAND GUILD

Cassin’s Sparrow O
Grasshopper Sparrow O
Killdeer F
Lark Sparrow F
Northern Bobwhite F

### SAVANNA GUILD

American Kestrel F
Barn Swallow R
Black Vulture
Cave Swallow R
Cliff Swallow R
Common Nighthawk F
Eastern Bluebird F
Ladder-backed Woodpecker
Lesser Goldfinch
Mourning Dove
Purple Martin R
Scissor-tailed Flycatcher F
Swainson’s Hawk O
Turkey Vulture F

### MARSH/RIVER GUILD

Belted Kingfisher R
Great-blue Heron R

### MIGRATION

Cedar Waxwing
Clay-colored Sparrow
House Wren
Lincoln’s Sparrow
Nashville Warbler
Orange-crowned Warbler
Ruby-crowned Kinglet
Wilson’s Warbler
Yellow Warbler
Yellow-bellied Flycatcher
Yellow-headed Blackbird

### GENERALIST GUILD

Blue-gray Gnatcatcher
Common Raven
Northern Mockingbird

### HUMAN AND OTHER

Canyon Wren
Great-tailed Grackle

### WOODLAND GUILD

Black-chinned Hummingbird
Blue Grosbeak R
Brown-headed Cowbird F
Bushtit
Chipping Sparrow
Common Ground Dove
Eastern Phoebe R
Golden-cheeked Warbler
Golden-fronted Woodpecker
Red-shouldered Hawk R
Red-tailed Hawk
Tufted Titmouse
Vermillion Flycatcher R
White-winged Dove R
Wild Turkey
Yellow-billed Cuckoo

### DECIDUOUS GUILD

Acadian Flycatcher R
Black-and-white Warbler
Carolina Chickadee R
Carolina Wren
Cooper’s Hawk R
Eastern Wood Pewee
Great-crested Flycatcher
Indigo Bunting
Red-eyed Vireo
Summer Tanager
Yellow-throated Vireo
Yellow-throated Warbler R

### BRUSH GUILD

Bewick’s Wren
Field Sparrow

### SCRUB GUILD

Ash-throated Flycatcher F
Black-capped Vireo
Greater Roadrunner
House Finch
Orchard Oriole
Rufous-crowned Sparrow F
Scott’s Oriole
Western Scrub Jay

## Appendix D4: EDWARDS WINTER BIRD GUILDS
## (F=Grassland Facultative, O=Grassland Obligate)

### GROUND GLEANS SEEDS (GRASS OR FORB)

Canyon Towhee F[T]
Carolina Wren
Chipping Sparrow
Common Ground Dove F
Dark-eyed Junco
Eastern Meadowlark O
Field Sparrow
Grasshopper Sparrow O
House Finch
Killdeer F
Le Conte's Sparrow O
Lincoln's Sparrow
Mourning Dove F
Red-winged Blackbird F
Rufous-crowned Sparrow F
Savannah Sparrow O
Song Sparrow
Spotted Towhee
Vesper Sparrow O
White-crowned Sparrow

### GROUND GLEANS FRUIT OR BERRIES

American Robin
Greater Roadrunner
Hermit Thrush
Northern Cardinal
Northern Mockingbird
Scrub Jay

### GROUND GLEANS OTHER

Common Raven
Bewick's Wren
Canyon wren

### FLYCATCH

Black Phoebe
Eastern Bluebird
Eastern Phoebe

### *FOLIAGE GLEAN*

Blue-headed Vireo
Bushtit
Carolina Chickadee
Cedar Waxwing
Golden-crowned Kinglet
Lesser Goldfinch
Orange-crowned Warbler
Ruby-crowned Kinglet
Tufted Titmouse
White-eyed Vireo
Yellow-rumped Warbler

### *BIRDS OF PREY*

American kestrel F
Barred Owl
Black Vulture
Loggerhead Shrike F
Merlin F
Northern Harrier O
Peregrine Falcon F
Red-tailed Hawk

### *BARK GLEAN*

Golden-fronted Woodpecker
Ladder-backed Woodpecker
Yellow-bellied Sapsucker

### *AQUATIC*

Belted Kingfisher
Canada Goose
Great Blue Heron
Green Kingfisher
Lesser Scaup

# Appendix: E

**Appendix E1. List of birds sighted in Edwards and Twin Buttes watersheds according to current field check lists.**

| Species | Lost Maples State Natural Area[1] | H. E. Butt Foundation Camp[1] | Texas Hill Country River Region[1] | Garner State Park[1] | San Angelo State Park[1] | Concho Valley Region[1] | Habitat | Comments[2] |
|---|---|---|---|---|---|---|---|---|
| | Edward's Watershed | | | | Twin Buttes Watershed | | | |
| | | | | | | | | |
| LOONS | | | | | | | | |
| Common Loon *(Gavia immer)* | | | | | T | I, Rg, S, T | forested lakes and rivers; oceans and bays in winter | |
| | | | | | | | | |
| GREBES | | | | | | | | |
| Pied-billed Grebe *(Podilymbus podiceps)* | B, R | R | U | U | T | I, Rg, S, T | marshes, ponds; salt water in winter if freshwater habitats freeze | |
| Horned Grebe *(Podiceps auritus)* | | | | | T | I, Rg, S, T | marshes and lakes in summer; in winter, mainly on salt water but also on the Great Lakes | |
| Red-necked Grebe *(Podiceps grisegena)* | | | | | T | | ponds and lakes in summer; bays and estuaries in winter | |
| Eared Grebe *(Podiceps nigricollis)* | | | U | | T | I, Rg, S, T | marshy lakes and ponds; open bays and ocean in winter | |
| Western Grebe *(Aechmophorus occidentalis)* | | | | | T | I, Rg, S, T | breeds on large lakes with tules of rushes; winters mainly on shallow coastal bay and estuaries | |
| Clark's Grebe *(Aechmophorus clarkii)* | | | | | T | I, Rg, S, T | breeds on large lakes with tules of rushes; winters mainly on shallow coastal bay and estuaries | |
| | | | | | | | | |
| PELICANS | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| American White Pelican *(Pelecanus erythrorhynchos)* | | | | | T | I, Rg, S, T | shallow lakes and coastal lagoons | |
| Brown Pelican *(Pelecanus occidentalis)* | | | | | T | I, Rg, S, T | sandy coastal beaches and lagoons | SE, FE |
| | | | | | | | | |
| CORMORANTS | | | | | | | | |
| Double-crested Cormorant *(Phalacrocorax auritus)* | | R | U | | T | I, Rg, S, T | lakes, rivers, swamps, and coasts | |
| Neotropic Cormorant (*Phalacrocorax brasilianus*) | | | | | T | I, Rg, S, T | brackish and fresh water | |
| | | | | | | | | |
| BITTERNS AND HERONS | | | | | | | | |
| American Bittern *(Botaurus lentiginosus)* | | | | | T | I, Rg, S, T | freshwater and brackish marshes and marshy lake shores | |
| Least Bittern *(Ixobrychus exilis)* | | | | | | I, Rg, S, T | freshwater marshes where cattails and reeds predominate | |
| Great Blue Heron *(Ardea herodias)* | B, R | R | U | U | T | I, Rg, S, T | lakes, ponds, rivers, and marshes | |
| Great Egret *(Ardea alba)* | | R | U | | T | I, Rg, S, T | freshwater and salt marshes, marshy ponds, and tidal flats | |
| Snowy Egret *(Egretta thula)* | | | U | | T | I, Rg, S, T | salt marshes, ponds, rice fields, and shallow coastal bays | |
| Little Blue Heron *(Egretta caerulea)* | B, R | | U | | T | I, Rg, S, T | Freshwater swamps and lagoons in the South; coastal thickets on islands in the North | |
| Tricolored Heron *(Egetta tricolor)* | | | | | | I, Rg, S, T | swamps, bayous, coastal ponds, salt marshes, mangrove islands, mud flats, and lagoons | |
| Reddish Egret *(Egretta rufescens)* | | | | | | I, Rg, S, T | salt and brackish waters, breeding in shallow bays and lagoons; in mangroves (Florida); among cacti, willows and other shrubs (Texas) | ST |
| Cattle Egret *(Bubulcus ibis)* | B, R | | U | | T | I, Rg, S, T | dry land in open fields where it feeds alongside livestock, but breeds near water with other herons | |
| Green Heron *(Butorides virescens)* | B, R | R | U | U | T | I, Rg, S, T | breeds mainly in freshwater or brackish marshes with clumps of trees; feeds along margin of any | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | body of water | |
| Black-crowned Night-Heron *(Nycticorax nycticorax)* | | R | | | T | I, Rg, S, T | marshes, swamps, and wooded streams | |
| Yellow-crowned Night-Heron *(Nycticorax violacea)* | | | | | | I, Rg, S, T | wooded swamp and coastal thickets | |
| | | | | | | | | |
| IBISES AND SPOONBILLS | | | | | | | | |
| White-faced Ibis *(Plegadis chihi)* | | | U | | T | I, Rg, S, T | salt marshes and brushy coastal islands in Louisiana and Texas, freshwater marshes in the West | ST |
| Roseate Spoonbill *(Ajaia ajaja)* | | | | | | I, Rg, S, T | mangroves | |
| | | | | | | | | |
| STORKS | | | | | | | | |
| Wood Stork *(Mycteria americana)* | | | | | | I, Rg, S, T | on or near the coast, breeding chiefly in cypress swamps; also in mangroves | ST |
| | | | | | | | | |
| AMERICAN VULTURES | | | | | | | | |
| Black Vulture *(Coragyps altratus)* | B, R | R | U | U | T | I, Rg, S, T | open country wherever carrion is present, but breeds in light woodlands and thickets | |
| Turkey Vulture *(Cathartes aura)* | B, R | R | U | U | T | I, Rg, S, T | mainly deciduous forests and woodlands; often seen over adjacent farmland | |
| | | | | | | | | |
| SWANS, GEESE, AND DUCKS | | | | | | | | |
| Black-bellied Whistling-Duck *(Dendrocygna autumnalis)* | | | U | | | I, Rg, S, T | wooded streams and ponds | |
| Greater White-fronted Goose *(Anser albifrons)* | | | | | T | I, Rg, S, T | breeds on marshy tundra; winters on marshes and bays | G |
| Snow Goose *(Chen caerulescens)* | | | | | T | I, Rg, S, T | breeds on the tundra and winters in salt marshes and marshy coastal bays; less commonly in freshwater marshes and adjacent grain fields | G |
| Ross's Goose *(Chen rossii)* | | | | | | I, Rg, S, T | Arctic tundra in the breeding season, salt or fresh marshes in the winter | G |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Canada Goose *(Branta canadensis)* | | | | | T | I, Rg, S, T | lakes, bays, rivers, and marshes; often feeds in open grassland and stubble fields | G |
| Tundra Swan *(Cygnus columbianus)* | | | | | T | I, Rg, S, T | Arctic tundra; winters on marshy lakes and bays | |
| Wood Duck *(Aix sponsa)* | B, R | R | U | U | T | I, Rg, S, T | wooded rivers and ponds; wooded swamps; visits freshwater marshes in late summer and fall | G |
| Gadwall *(Anas strepera)* | | | U | | T | I, Rg, S, T | freshwater marshes, ponds, and rivers; locally in salt marshes | G |
| American Wigeon *(Anas americana)* | B, R | R | U | | T | I, Rg, S, T | marshes, ponds, and shallow lakes | G |
| Mallard *(Anas platyrhynchos)* | | R | U | | T | I, Rg, S, T | ponds, lakes, and marshes; semi-domesticated birds may be found on almost any body of water | G |
| Blue-winged Teal *(Anas discors)* | B, R | R | U | U | T | I, Rg, S, T | marshes, shallow ponds, and lakes | G |
| Cinnamon Teal *(Anas cyanoptera)* | | | U | | T | I, Rg, S, T | prairie marshes, ponds, slow-moving streams bordered with reeds | G |
| Northern Shoveler *(Anas clypeata)* | | | | | T | I, Rg, S, T | marshes and prairie potholes; sometimes on salt or brackish marshes | G |
| Northern Pintail *(Anas acuta)* | | | | | T | I, Rg, S, T | marshes , prairie potholes, and tundra; sometimes salt marshes in winter | G |
| Green-winged Teal *(Anas crecca)* | B, R | | | | T | I, Rg, S, T | marshes, ponds, and marshy lakes | G |
| Canvasback *(Aythya valisineria)* | | | | | T | I, Rg, S, T | nests on marshes; winters on lakes, bays and estuaries | G |
| Redhead *(Aythya americana)* | | | | | T | I, Rg, S, T | nests in marshes, but at other times is found on lakes and bays; often on salt water in winter | G |
| Ring-necked Duck *(Aythya collaris)* | | R | | | T | I, Rg, S, T | wooded lakes, ponds, and rivers; seldom on salt water except except in the southern states | G |
| Greater Scaup *(Aythya marila)* | | | | | | I, Rg, S, T | lakes, bays, and ponds; in winter, often on salt water | G |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lesser Scaup *(Aythya affinis)* | | R | U | | T | I, Rg, S, T | ponds and marshes; in migration and winter it occurs on lakes, rivers, and ponds, and in the southern states on salt water | G |
| Bufflehead *(Bucephala albeola)* | | R | | | T | I, Rg, S, T | northern lakes and ponds; in winter, mainly on salt bays and estuaries | G |
| Common Goldeneye *(Bucephala clangula)* | | | | | T | I, Rg, S, T | nests on lakes and ponds in the North; in migration and winter mainly along the coast in bays and inlets | G |
| Hooded Merganser *(Lophodytes cucullatus)* | | | | | | I, Rg, S, T | wooded ponds, lakes, and rivers; sometimes in tidal channels in winter | G |
| Red-breasted Merganser *(Mergus serrator)* | | | | | T | I, Rg, S, T | northern lakes and tundra ponds; in winter, principally on the ocean and in salt bays | G |
| Common Merganser *(Mergus merganser)* | | | | | T | I, Rg, S, T | wooded rivers and ponds; in winter, also on salt bays | G |
| Ruddy Duck *(Oxyura jamaicensis)* | | | | | T | I, Rg, S, T | freshwater marshes, marshy lakes and ponds; sometimes shallow salt bays and rivers in winter | G |
| | | | | | | | | |
| KITES, HAWKS, EAGLES, AND ALLIES | | | | | | | | |
| Osprey *(Pandion haliaetus)* | B, R | | U | | T | I, Rg, S, T | lakes, rivers, and seacoasts | |
| White-tailed Kite *(Elanus leucurus)* | | | | | | I, Rg, S, T | farmlands and prairies with scattered trees or fencerows; mesquite grasslands | |
| Mississippi Kite *(Ictinia mississippiensis)* | B, R | R | | | T | I, Rg, S, T | open woodland and mixed scrub near water | |
| Bald Eagle *(Haliaeetus leucocephalus)* | B, R | R | | | T | I, Rg, S, T | lakes, rivers, marshes, and seacoasts | ST, FT(PDL) |
| Northern Harrier *(Circus cyaneus)* | B, R | R | U | U | T | I, Rg, S, T | marshes and open grasslands | |
| Sharp-shinned Hawk *(Accipiter striatus)* | B, R | R | U | U | T | I, Rg, S, T | dense coniferous forests, less often in deciduous forests; in migration and winter it may be seen in almost any habitat | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Cooper's Hawk<br>*(Accipiter cooperii)* | B, R | R | U | U | T | I, Rg, S, T | deciduous and, less often, coniferous forests, especially where these are interrupted by meadows and clearings | |
| Common Black-Hawk<br>(Buteogallus anthracinus) | | | | | | I, Rg, S, T | wooded canyons and riverside woodlands | ST |
| Harris's Hawk<br>*(Parabuteo unicinctus)* | | | | U | T | I, Rg, S, T | semi-arid regions in scrub with mesquite, cacti,<br>and yucca | |
| Red-shouldered Hawk<br>*(Buteo lineatus)* | B, R | R | U | U | | I, Rg, S, T | deciduous woodlands, especially where there is<br>standing water | |
| Broad-winged Hawk<br>*(Buteo platypterus)* | B, R | | U | U | | I, Rg, S, T | chiefly deciduous woodland | |
| Short-tailed Hawk<br>*(Buteo brachyurus)* | B, R | | | | | | chiefly cypress and mangrove swamps | |
| Swainson's Hawk<br>*(Buteo swainsoni)* | B, R | | U | U | T | I, Rg, S, T | open plains, grasslands, and prairie | |
| Zone-tailed Hawk<br>(Buteo albonotatus) | B, R | R | U | U | | I, Rg, S, T | forested canyons and riverside woodlands | ST |
| Red-tailed Hawk<br>*(Buteo jamaicensis)* | B, R | R | U | U | T | I, Rg, S, T | mainly deciduous forest and adjacent open country; habitat more variable in the West | |
| Ferruginous Hawk<br>(Buteo regalis) | B, R | | U | U | T | I, Rg, S, T | prairies, brushy open country, badlands | |
| Rough-legged Hawk<br>*(Buteo lagopus)* | | | | | T | I, Rg, S, T | tundra; winters on open plains, agricultural areas, and marshes | |
| Golden Eagle<br>*(Aquila chrysaetos)* | B, R | R | | | T | I, Rg, S, T | mainly deciduous forests and woodlands; often seen over adjacent farmland | |
| | | | | | | | | |
| CARACARAS AND FALCONS | | | | | | | | |
| Crested Caracara<br>*(Caracara cheriway)* | | R | U | | | | prairies, savannahs, desrt scrub, and seashores | |
| American Kestrel<br>*(Falco sparverius)* | B, R | R | U | U | T | I, Rg, S, T | towns and cities, parks, farmlands, and open country | |
| Merlin<br>*(Falco columbarius)* | B, R | | U | U | T | I, Rg, S, T | coniferous forests; more widespread in winter | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Peregrine Falcon - American Peregrine Falcon, E; Arctic Peregrine Falcon, T - *(Falco peregrinus)* | B, R | | U | | T | I, Rg, S, T | open country, especially along rivers, also near lakes, and the coast; migrates chiefly along the coast | SE (American), ST (Arctic) |
| Prairie Falcon (Falco mexicanus) | | | U | | | I, Rg, S, T | barren mountains, dry plains, and prairies | |
| | | | | | | | | |
| GROUSE, AND TURKEYS | | | | | | | | |
| Wild Turkey *(Meleagris gallopavo)* | B, R | R | U | U | T | I, Rg, S, T | open woodlands, pine-oak forests | G |
| | | | | | | | | |
| NEW WORLD QUAIL | | | | | | | | |
| Scaled Quail *(Callipela squamata)* | | | U | | T | I, Rg, S, T | dry grasslands and brushy deserts | G |
| Northern Bobwhite *(Colinus virginianus)* | B, R | R | U | U | T | I, Rg, S, T | brusht pastures, grassy roadsides, farmlands, and open woodlands | G |
| | | | | | | | | |
| RAILS, GALLINULES, AND COOTS | | | | | | | | |
| Clapper Rail *(Rallus longirostris)* | | | | | | I, Rg, S, T | salt marshes | G |
| Virginia Rail *(Rallus limicola)* | | | | | T | I, Rg, S, T | freshwater and brackish marshes; may visit salt marshes in winter | G |
| Sora *(Porzana carolina)* | | | | | T | I, Rg, S, T | chiefly freshwater marshes and marshy ponds; rice fields and salt marshes in winter | G |
| Purple Gallinule *(Porphyrula martinica)* | B, R | | | | | I, Rg, S, T | freshwater marshes with lily pads, pickerelweed, and other aquatic vegetation | G |
| Common Moorhen *(Gallinula chloropus)* | | | | | | I, Rg, S, T | freshwater marshes and ponds with cattails and other aquatic vegetation | G |
| American Coot *(Fulica americana)* | | R | U | | T | I, Rg, S, T | open ponds and marshes; in winter, also in saltwater bays and inlets | |
| | | | | | | | | |
| CRANES | | | | | | | | |
| Sandhill Crane *(Grus canadensis)* | B, R | | | U | T | I, Rg, S, T | large freshwater marshes, prairie ponds, and marshy tundra; also | G |

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|---|---|---|---|---|---|---|---|---|
| | | | | | | | on prairies and grainfields during migration and in winter | |
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| PLOVERS | | | | | | | | |
| Black-bellied Plover *(Pluvialis squatarola)* | | | | | T | I, Rg, S, T | tundra; in migration and in winter it occurs on beaches and coastal marshes, less commonly on inland marshes, lakeshores, and plowed fields | |
| American Golden-Plover *(Pluvialis dominica)* | | | | | T | I, Rg, S, T | tundra; in migration, on coastal beaches and mudflats and inland on prairies and plowed fields | |
| Snowy Plover *(Charadrius alexandrinus)* | | | | | T | I, Rg, S, T | flat, sandy beaches; alkali beds; and sandy areas with little vegetation | |
| Wilson's Plover *(Charadrius wilsonia)* | | | | | | I, Rg, S, T | sand beaches and mud flats | |
| Semipalmated Plover *(Charadrius semipalmatus)* | | | | | T | I, Rg, S, T | beaches and tidal flats, shallow pools in salt marshes; lakeshores in the interior during migration | |
| Killdeer *(Charadrius vociferus)* | B, R | R | U | U | T | I, Rg, S, T | open country generally--plowed fields, golf courses, and short-grass prairies | |
| Mountain Plover (Charadrius montanus) | | | | | | I, Rg, S, T | arid plains, short-grass prairies, and fields | FPT |
| | | | | | | | | |
| STILTS AND AVOCETS | | | | | | | | |
| Black-necked Stilt *(Himantopus mexicanus)* | | | U | | T | I, Rg, S, T | salt marshes and shallow coastal bays in the East; also freshwater marshes in the West | |
| American Avocet *(Recurvirostra americana)* | | R | | | T | I, Rg, S, T | freshwater marshes and shallow marshy lakes; breeds locally in salt or brackish marshes; many move to the coast in winter | |
| | | | | | | | | |
| SANDPIPERS AND ALLIES | | | | | | | | |
| Greater Yellowlegs *(Tringa melanoleuca)* | | R | U | | T | I, Rg, S, T | prefers pool, lakeshores, and tidal mud flats in migration, but open wet tundra and marshy ground in the breeding season | |

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|---|---|---|---|---|---|---|---|---|
| Lesser Yellowlegs<br>*(Tringa flavipes)* | | R | | | T | I, Rg, S, T | marshy ponds, lake and river shores, mud flat; in the breeding season, boreal bogs | |
| Solitary Sandpiper<br>*(Tringa solitaria)* | B, R | R | U | | T | I, Rg, S, T | inland ponds and bogs, wet swampy places, and woodland streams | |
| Willet<br>*(Catoptrophorus semipalmatus)* | | | | | | I, Rg, S, T | coastal beaches, freshwater and salt marshes, lakeshores, and wet prairies | |
| Spotted Sandpiper<br>*(Actitis macularia)* | B, R | R | U | U | T | I, Rg, S, T | almost anyplace with water nearby, both in open country and in wooded areas | |
| Upland Sandpiper<br>*(Bartramia longicauda)* | B, R | | | | T | I, Rg, S, T | open grassland, prairies, and hayfields in breeding season; also, while on migration, open country generally | |
| Whimbrel<br>*(Numenius phaeopus)* | | | | | | I, Rg, S, T | Arctic tundra, preferring freshwater pools near the coast; on migration, chiefly coastal salt meadows, mud flats, and grassy slopes along the coast | |
| Long-billed Curlew<br>*(Numenius americanus)* | | | | | T | I, Rg, S, T | chiefly grass plains and prairies; in migration, lake and river shores, mud flats, salt marshes, and sand beaches | |
| Hudsonian Godwit<br>*(Limosa haemastica)* | | | | | | I, Rg, S, T | tundra; chiefly mud flats on migration | |
| Marbled Godwit<br>*(Limosa fedoa)* | | | | | | I, Rg, S, T | extensive grasslands; on migration, salt marshes, tidal creeks, mud flats, and sea beaches | |
| Ruddy Turnstone<br>*(Arenaria interpres)* | | | | | | I, Rg, S, T | coastal tundra; in winter on rocky, pebbly, and sandy coasts and beaches | |
| Sanderling<br>*(Calidris alba)* | | | | | | I, Rg, S, T | ocean beaches, sandbars, occasionally mud flats; inland lake and river shores | |
| Semipalmated Sandpiper<br>*(Calidris pusilla)* | | | | | T | I, Rg, S, T | coastal beaches, lake and river shores, flats, and pools in salt marshes | |

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| Western Sandpiper<br>*(Calidris mauri)* | | | U | | T | I, Rg, S, T | shores, mud flats, grassy pools, and wet meadows | |
| Least Sandpiper<br>*(Calidris minutilla)* | | | U | | T | I, Rg, S, T | grassy pools, bogs, and marshes with open areas; also flooded fields and mud flats | |
| White-rumped Sandpiper<br>*(Calidris fuscicollis)* | | | | | | I, Rg, S, T | tundra; flats, grassy pools, wet meadows, and shores in winter | |
| Baird's Sandpiper<br>*(Calidris bairdii)* | | | | | T | I, Rg, S, T | chiefly inland areas with grassy pools, wet meadows, and lake and river shores; in summer on the tundra | |
| Pectoral Sandpiper<br>*(Calidris melanotos)* | | | | | T | I, Rg, S, T | wet, short-grass areas; grassy pools; golf courses and airports after heavy rains; and salt creeks and meadows | |
| Dunlin<br>*(Calidris alpina)* | | | | | T | I, Rg, S, T | beaches, extensive mud and sand flats, tidal inlets and lagoons; also inland lake and river shores | |
| Stilt Sandpiper<br>*(Micropalama himantopus)* | | | | | | I, Rg, S, T | grassy pools and shores of ponds and lakes | |
| Buff-breasted Sandpiper<br>*(Tryngites subruficollis)* | | | | | | I, Rg, S, T | short-grass fields, meadows, and prairies; breeds in dry tundra | |
| Long-billed Dowitcher<br>*(Limnodromus scolopaceus)* | | | | | T | I, Rg, S, T | breeds in muskeg; in migration and winter occurs on mud flats, marshy pools, and margins of freshwater ponds | |
| Common Snipe<br>*(Gallinago gallinago)* | B, R | R | U | U | T | I, Rg, S, T | freshwater marshes, ponds, flooded meadows, and fields; more rarely in salt marshes | G |
| American Woodcock<br>*(Scolopax minor)* | | | | | T | I, Rg, S, T | moist woodland and thickets near open fields | G |
| Wilson's Phalarope<br>*(Phalaropus tricolor)* | | | | | T | I, Rg, S, T | prairie pools and marshes, lake and river shores, marshy pools along the coast | |
| Red-necked Phalarope<br>*(Phalaropus lobatus)* | | | | | T | I, Rg, S, T | open ocean, beaches, flats, lake and river shores | |
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| GULLS, TERNS, AND SKIMMERS | | | | | | | | |
| Laughing Gull<br>*(Larus atricilla)* | | | | | T | I, Rg, S, T | salt marshes, bays, and estruaries; very rare inland | |

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| Franklin's Gull<br>*(Larus pipixcan)* | | | | | T | I, Rg, S, T | prairie marshes and sloughs; often feeds in plowed fields | |
| Bonaparte's Gull<br>*(Larus philadelphia)* | | | | | T | I, Rg, S, T | forested lakes and rivers; winters along the coast, in estuaries, and at the mouth of large rivers | |
| Ring-billed Gull<br>*(Larus delawarensis)* | | | | | T | I, Rg, S, T | lakes and rivers; many move to salt water in the winter | |
| Herring Gull<br>*(Larus argentatus)* | | | | | T | I, Rg, S, T | lakes, rivers, estuaries, and beaches; common in all aquatic habitats | |
| Common Tern<br>*(Sterna hirundo)* | | | | | T | I, Rg, S, T | lakes, ponds, rivers, coastal beaches, and islands | |
| Forster's Tern<br>*(Sterna forsteri)* | | | | | T | I, Rg, S, T | salt marshes in the East; freshwater marshes in the West | |
| Least Tern ("Interior")<br>*(Sterna antillarum)* | | | | | T | I, Rg, S, T | sandy and pebbly beaches along the coast; sandbars in large rivers; often on land fills | SE, FE |
| Black Tern<br>*(Chlidonias nigra)* | | | | | T | I, Rg, S, T | freshwater marshes and marshy lakes in summer; sandy coasts in migration and in winter | |
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| PIGEONS AND DOVES | | | | | | | | |
| Rock Dove<br>*(Columba livia)* | | | U | U | T | I, Rg, S, T | city parks, suburban gardens, and farmland | I |
| Eurasian Collared-Dove<br>*(Streptopelia decaocto)* | | | U | | | I, Rg, S, T | prefers open, dry areas with low scrub and scattered trees | I |
| White-winged Dove<br>*(Zenaida asiatica)* | B, R | | U | U | T | I, Rg, S, T | open arid country with dense thickets of shrubs and low trees | G |
| Mourning Dove<br>*(Zenaida macroura)* | B, R | R | U | U | T | I, Rg, S, T | open fields, parks, and lawns with many trees and shrubs | G |
| Inca Dove<br>*(Columbina inca)* | B, R | R | U | U | T | I, Rg, S, T | mesquite thickets or cacti in semi-arid country; also parks, yards, and ranches | |
| Common Ground-Dove<br>*(Columbina passerina)* | | | U | | | I, Rg, S, T | open areas such as fields, gardens, farmland, and roadsides | |
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| CUCKOOS, ROADRUNNERS, AND ANIS | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|
| Yellow-billed Cuckoo *(Coccyzus americanus)* | B, R | R | U | U | T | I, Rg, S, T | moist thickets, willows, overgrown pastures, and orchards | |
| Greater Roadrunner *(Geococcyx californianus)* | B, R | R | | U | T | I, Rg, S, T | open arid country with scattered thickets | |
| Groove-billed Ani *(Crotophaga sulcirostris)* | B, R | | | | | | arid agricultural land especially where there are cattle | |
| | | | | | | | | |
| BARN OWLS | | | | | | | | |
| Barn Owl *(Tyto alba)* | | | | U | T | I, Rg, S, T | open country, forest edge and clearings, cultivated areas, and cities | |
| | | | | | | | | |
| TYPICAL OWLS | | | | | | | | |
| Eastern Screech-Owl *(Otus asio)* | B, R | R | U | U | T | I, Rg, S, T | open deciduous woods, wood lots, suburban areas, lakeshores, old orchards | |
| Western Screech-Owl *(Otus kennicottii)* | | | | | T | I, Rg, S, T | woodlands, orchards, yards with many trees | |
| Great Horned Owl *(Bubo virginianus)* | B, R | R | U | U | T | I, Rg, S, T | ubiquitous, frequently forest, desert, open country, swamps, and even city parks | |
| Elf Owl *(Micrathene whitneyi)* | | | | | | I, Rg, S, T | desert, dry open woodland, and streamside thickets with trees | |
| Burrowing Owl *(Athene cunicularia)* | | | | | T | I, Rg, S, T | plains, deserts, fields, and airports | |
| Barred Owl *(Strix varia)* | B, R | R | U | U | | I, Rg, S, T | low, wet woods and swamp forest | |
| Long-eared Owl *(Asio otus)* | | | | | T | I, Rg, S, T | deciduous and evergreen forests | |
| Short-eared Owl *(Asio flammeus)* | | | | | T | I, Rg, S, T | freshwater and salt marshes; open grassland, prairies, dunes; open country generally during migration | |
| | | | | | | | | |
| NIGHTJARS | | | | | | | | |
| Lesser Nighthawk *(Chordeiles acutipennis)* | B, R | | | U | T | I, Rg, S, T | open dry scrublands; desert valleys; prairies and pastures | |
| Common Nighthawk *(Chordeiles minor)* | B, R | R | U | U | T | I, Rg, S, T | aerial, but open country generally; also cities and towns | |

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| Common Poorwill *(Phalaenoptilus nuttallii)* | B, R | R | U | U | T | I, Rg, S, T | desert, chaparral, sagebrush, and other arid uplands | |
| Chuck-will's-widow *(Caprimulgus carolinensis)* | B, R | R | U | U | | I, Rg, S, T | open woodland and clearings near agricultural country | |
| Whip-poor-will *(Caprimulgus vociferus)* | B, R | | | | T | I, Rg, S, T | dry open woodland near fields | |
| | | | | | | | | |
| SWIFTS | | | | | | | | |
| Chimney Swift *(Chaetura pelagica)* | B, R | R | U | U | T | I, Rg, S, T | breeds and roosts in chimneys; feeds entirely on the wing | |
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| HUMMINGBIRDS | | | | | | | | |
| Green Violet-ear *(Colibri thalassinus)* | B, R | | | | | | most U. S. sightings have been in areas with dense vegetation | |
| Broad-billed Hummingbird *(Cynanthus latirostris)* | | | | | | I, Rg, S, T | desert canyons; mesquite and other thickets in arid country | |
| Blue-throated Hummingbird *(Lampornis clemenciae)* | B, R | | | | | | streamside growth in canyons | |
| Ruby-throated Hummingbird *(Archilochus colubris)* | B, R | R | U | | T | I, Rg, S, T | suburban gardens, parks, and woodlands | |
| Black-chinned Hummingbird *(Archilochus alexandri)* | B, R | R | U | U | T | I, Rg, S, T | mountain and alpine meadows, woodlands, canyons with thickets, chaparral, and orchards | |
| Anna's Hummingbird *(Calypte anna)* | | | | | | I, Rg, S, T | chaparral, brushy oak woodlands, and gardens | |
| Calliope Hummingbird *(Stellula calliope)* | | | | | | I, Rg, S, T | montane and subalpine forest clearings, brushy edges, and alpine meadows | |
| Broad-tailed Hummingbird *(Selasphorus platycercus)* | | | U | | | I, Rg, S, T | mountain meadows, pinon-juniper woodlands, dry pinderosa pines, fir or mixed forests, and canyon vegetation | |
| Rufous Hummingbird *(Selasphorus rufus)* | B, R | | | U | T | I, Rg, S, T | mountain meadows, forest edges; in migration and winter often in gardens with hummingbird feeding stations | |
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| KINGFISHERS | | | | | | | | |
| Ringed Kingfisher *(Ceryle torquata)* | | | U | | | | tree-lined rivers, streams, and lakes | |

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| Belted Kingfisher<br>*(Ceryle alcyon)* | B, R | R | U | U | T | I, Rg, S, T | rivers, lakes, and saltwater estuaries | |
| Green Kingfisher<br>*(Chloroceryle americana)* | B, R | R | U | U | | I, Rg, S, T | woodland streams and pools | |
| | | | | | | | | |
| WOODPECKERS AND ALLIES | | | | | | | | |
| Lewis's Woodpecker<br>*(Melanerpes lewis)* | | | | | | I, Rg, S, T | open pine-oak woodlands, oak or cottonwood groves in grasslands, ponderosa pine country | |
| Red-headed Woodpecker<br>*(Malanerpes erythrocephalus)* | | | | | T | I, Rg, S, T | open country, farms, rural roads, open park-like woodland, and golf courses | |
| Acorn Woodpecker<br>*(Melanerpes formicivorus)* | | R | | | T | I, Rg, S, T | open oak and pine-oak forests | |
| Golden-fronted Woodpecker<br>*(Melanerpes aurifrons)* | B, R | R | U | U | T | I, Rg, S, T | open woods in dry country and river bottoms with trees | |
| Red-bellied Woodpecker<br>*(Centurus carolinus)* | | | | | T | I, Rg, S, T | open and swamp woodland; comes into parks during migration and to feeders in winter | |
| Yellow-bellied Sapsucker<br>*(Sphyrapicus varius)* | B, R | R | U | U | T | I, Rg, S, T | young, open deciduous or mixed forest with clearings; in migration, parks, yards, gardens | |
| Red-naped Sapsucker<br>*(Sphyrapicus nuchalis)* | B, R | | | | T | I, Rg, S, T | edges of coniferous forests, woodlands, groves of aspen and alder | |
| Ladder-backed Woodpecker<br>*(Picoides scalaris)* | B, R | R | U | U | T | I, Rg, S, T | arid areas with thickets and trees | |
| Downy Woodpecker<br>*(Picoides pubescens)* | B, R | | | U | | I, Rg, S, T | wood lots, parks, and gardens; suet feeders in winter | |
| Northern Flicker<br>*(Colaptes auratus)* | B, R | R | | U | T | I, Rg, S, T | open country with trees; parks and large gardens | |
| | | | | | | | | |
| TYRANT FLYCATCHERS | | | | | | | | |
| Olive-sided Flycatcher<br>*(Contopus cooperi)* | B, R | R | | U | T | I, Rg, S, T | boreal spruce and fir forests, usually near openings, burns, ponds, and bogs | |
| Western Wood-Pewee<br>*(Contopus sordidulus)* | | | | U | T | I, Rg, S, T | open woodland and woodland edges; orchards | |

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| Eastern Wood-Pewee *(Contopus virens)* | B, R | R | U | U | T | I, Rg, S, T | forest, open woodland, orchards, and shade trees in parks and along roadsides | |
| Acadian Flycatcher *(Empidonax virescens)* | B, R | R | U | U | | I, Rg, S, T | beech-maple or hemlock forest, usually under the canopy but also in clearings; often in wooded ravines | |
| Willow Flycatcher ("Southwestern") *(Empidonax traillii)* | B, R | | | | T | I, Rg, S, T | swampy thickets, upland pastures, and old abandoned orchards | SE, FE |
| Least Flycatcher *(Empidonax minimus)* | B, R | | | | T | I, Rg, S, T | widely distributed in open country, nesting in shade trees, orchards, villages, city parks, rural roadsides, and woodland borders | |
| Black Phoebe *(Sayornis nigricans)* | B, R | R | U | U | | I, Rg, S, T | shady areas near water, streams, ponds and lake banks; in winter, city parks, open chaparral | |
| Eastern Phoebe *(Sayornis phoebe)* | B, R | R | U | U | T | I, Rg, S, T | open woodland near streams; cliffs, bridges, and buildings with ledges | |
| Say's Phoebe *(Sayornis saya)* | B, R | | U | U | T | I, Rg, S, T | plains, sparsely vegetated countryside, dry sunny locations, often near ranch houses, barns, and other buildings | |
| Vermilion Flycatcher *(Pyrocephalus rubinus)* | B, R | R | U | U | T | I, Rg, S, T | trees and shrubs in open river bottoms and along roadsides | |
| Ash-throated Flycatcher *(Myiarchus cinerascens)* | B, R | R | U | U | T | I, Rg, S, T | deserts with cactus and mesquite thickets; also dry woods | |
| Great Crested Flycatcher *(Myiarchus crinitus)* | B, R | R | U | U | | I, Rg, S, T | open forest, orchards, and large trees in farm country | |
| Brown-crested Flycatcher *(Myiarchus tyrannulus)* | | | U | | | I, Rg, S, T | arid lands in areas with cacti or large trees | |
| Great Kiskadee *(Pitangus sulphuratus)* | | | | | | I, Rg, S, T | rivers, streams, and lakes bordered with dense vegetation; also in more open country and in parks in most of its range | |
| Couch's Kingbird *(Tyrannus couchii)* | | | U | | | | borders of wooldands and brushy streamside thickets | |
| Cassin's Kingbird *(Tyrannus vociferans)* | | | | | | I, Rg, S, T | savannas, rangelands, pinon-juniper woodlands | |

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| Western Kingbird<br>*(Tryannus verticalis)* | B, R | R | U | U | T | I, Rg, S, T | open country; ranches, roadsides, streams, and ponds with trees | |
| Eastern Kingbird<br>*(Tyrannus tyrannus)* | B, R | R | U | | T | I, Rg, S, T | open country; farms, orchards, roadsides, and lake and river shores | |
| Scissor-tailed Flycatcher<br>*(Tyrannus forficatus)* | B, R | R | U | U | T | I, Rg, S, T | open country along roadsides and on ranches with scattered trees and bushes; also fence wires and posts | |

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| SHRIKES | | | | | | | | |
| Northern Shrike<br>*(Lanius excubitor)* | | | | | | I, Rg, S, T | open woodlands and brushy swamps in summer; open grasslands with fence posts and scattered trees in winter | |
| Loggerhead Shrike<br>*(Lanius ludovicianus)* | B, R | R | U | U | T | I, Rg, S, T | grasslands, orchards, and open areas, with scattered trees; open grassy woodlands; deserts in the West | |
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| VIREOS | | | | | | | | |
| White-eyed Vireo<br>*(Vireo griseus)* | B, R | R | U | U | T | I, Rg, S, T | dense swampy thickets and hillsides with blackberry and briar tangles | |
| Bell's Vireo<br>*(Vireo belii)* | B, R | R | U | U | T | I, Rg, S, T | dense bottomland thickets, willow scrub, and mesquite | |
| Black-capped Vireo<br>*(Vireo atricapillus)* | B, R | R | U | | | I, Rg, S, T | dense oak scrub and juniper thickets | SE, FE |
| Gray Vireo<br>*(Vireo vicinior)* | | | | | | I, Rg, S, T | dry brush, especially juniper in the pinon- and juniper-covered slopes of the southwestern mountains; scrub oak and other types of chaparral | |
| Yellow-throated Vireo<br>*(Vireo flavifrons)* | B, R | R | U | U | | I, Rg, S, T | tall deciduous trees at the edge of forests, along streams, roadsides, orchards, parks, and estates | |
| Blue-headed Vireo<br>*(Vireo solitarius)* | B, R | | U | U | T | I, Rg, S, T | coniferous and mixed forests | |

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| Warbling Vireo<br>*(Vireo gilvus)* | | | U | | T | I, Rg, S, T | deciduous woodland, especially near streams; in isolated groves and shade trees | |
| Philadelphia Vireo<br>*(Vireo philadelphicus)* | B, R | | | | T | I, Rg, S, T | open second-growth woodlands, old clearings and burned-over areas, and thickets along streams and lakes | |
| Red-eyed Vireo<br>*(Vireo olivaceus)* | B, R | R | U | U | T | I, Rg, S, T | deciduous forest, and shade trees in residential areas | |
| | | | | | | | | |
| JAYS, MAGPIES, AND CROWS | | | | | | | | |
| Blue Jay<br>*(Cyanocitta cristata)* | B, R | | U | | T | I, Rg, S, T | chiefly oak forest, but now also city parks and suburban yards, especially where oak trees predominate | |
| Western Scrub-Jay<br>*(Aphelocoma californica)* | B, R | R | U | U | T | I, Rg, S, T | scrub oak, woodlands, and chaparral, but does not breed in low scrub because it needs watch posts; also inhabits suburban gardens | |
| Clark's Nutcracker<br>*(Nucifraga columbiana)* | | | | | | I, Rg, S, T | stands of juniper and ponderosa pine or of whitebark pine and larch on high mountain ranges, near the tree line | |
| American Crow<br>*(Corvus brachyryhynchos)* | | R | | | | | deciduous growth along rivers and streams; orchards and city parks; also mixed and coniferous woods, but avoids closed coniferous forests and desert expanses | |
| Chihuahuan Raven<br>*(Corvus cryptoleucus)* | | R | U | U | T | I, Rg, S, T | arid grasslands and mesquite; plains and deserts | |
| Common Raven<br>*(Corvus corax)* | B, R | R | U | U | T | I, Rg, S, T | coniferous forests and rocky coasts; in the West also in deserts and arid mountains | |
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| LARKS | | | | | | | | |
| Horned Lark<br>*(Eremophila alpestris)* | | | | | T | I, Rg, S, T | plains, fields, airports, and beaches | |
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| SWALLOWS | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|
| Purple Martin<br>*(Progne subis)* | B, R | R | U | U | T | I, Rg, S, T | open woodland, residential areas, and agricultural land | |
| Tree Swallow<br>*(Tachycineta bicolor)* | | | | | T | I, Rg, S, T | lakeshores, flooded meadows, marshes, and streams | |
| Violet-green Swallow<br>*(Tachycineta thalassina)* | | | | | | I, Rg, S, T | breeds in forests, wooded foothills, mountains, suburban areas | |
| Northern Rough-winged Swallow<br>*(Stelgidopteryx serripennis)* | B, R | R | U | U | T | I, Rg, S, T | riverbanks; prefers drier sites than the Bank Swallow | |
| Bank Swallow<br>*(Riparia riparia)* | | | | | T | I, Rg, S, T | rivers and streams; especially near sandbanks; more widespread during migration | |
| Cliff Swallow<br>*(Petrochelidon pyrrhonota)* | B, R | R | U | U | T | I, Rg, S, T | open country near buildings or cliffs; lakeshores and marshes on migration | |
| Cave Swallow<br>*(Petrochelidon fulva)* | B, R | | U | | T | I, Rg, S, T | chiefly open country near caves and cliffs | |
| Barn Swallow<br>*(Hirundo rustica)* | B, R | R | U | U | T | I, Rg, S, T | agricultural land, suburban areas, marshes, lake shores | |
| | | | | | | | | |
| CHICKADEES AND TITMICE | | | | | | | | |
| Carolina Chickadee<br>*(Poecile carolinensis)* | B, R | R | U | U | T | I, Rg, S, T | deciduous woodlands and residential areas | |
| Tufted Titmouse<br>*(Baeolophus bicolor)* | B, R | R | U | U | T | I, Rg, S, T | swampy or moist woodland and shade trees in villages and city parks; in winter, at feeders | |
| | | | | | | | | |
| VERDIN | | | | | | | | |
| Verdin<br>*(Auriparus flaviceps)* | | R | U | U | T | I, Rg, S, T | brushy desert; mesquite thickets | |
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| BUSHTITS | | | | | | | | |
| Bushtit<br>*(Psaltriparus minimus)* | B, R | R | U | U | T | I, Rg, S, T | varied; deciduous growth, usually streamside; in the coastal forest, it lives in second-growth alder thickets or in edges of coniferous forests composed of maple, dogwood, and birch; also in oak woodland, chaparral, and juniper brush | |

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| NUTHATCHES | | | | | | | | |
| Red-breasted Nuthatch<br>*(Sitta canadensis)* | | R | | U | T | I, Rg, S, T | coniferous forests; more widespread in migration and winter | |
| White-breasted Nuthatch<br>*(Sitta carolinensis)* | | | U | | | I, Rg, S, T | deciduous and mixed forest | |
| | | | | | | | | |
| CREEPERS | | | | | | | | |
| Brown Creeper<br>*(Certhia americana)* | B, R | R | | U | T | I, Rg, S, T | deciduous and mixed woodlands | |
| | | | | | | | | |
| WRENS | | | | | | | | |
| Cactus Wren<br>*(Campylorhynchus brunneicapillus)* | B, R | R | U | U | T | I, Rg, S, T | arid desert thickets and cacti | |
| Rock Wren<br>*(Salpinctes obsoletus)* | B, R | R | | U | T | I, Rg, S, T | rock-strewn slopes, canyons, cliffs, and dams, in arid country | |
| Canyon Wren<br>*(Catherpes mexicanus)* | B, R | R | U | U | | I, Rg, S, T | rocky canyons and cliffs; old stone buildings | |
| Carolina Wren<br>*(Thryothorus ludovicianus)* | B, R | R | U | U | T | I, Rg, S, T | woodland thickets, ravines, and rocky slopes covered with brush | |
| Bewick's Wren<br>*(Thryomanes bewickii)* | B, R | R | U | U | T | I, Rg, S, T | thickets, brush piles, and hedgerows in farming country; also open woodland and scrubby areas, often near streams | |
| House Wren<br>*(Troglodytes aedon)* | B, R | R | U | | T | I, Rg, S, T | residential areas, city parks, farmlands, and woodland edges | |
| Winter Wren<br>*(Troglodytes troglodytes)* | B, R | R | | U | T | I, Rg, S, T | dense tangles and thickets in coniferous and mixed forests | |
| Sedge Wren<br>*(Cistothorus platensis)* | | | | | T | I, Rg, S, T | grassy freshwater marshes and sedges; also brackish marshes and wet meadows in winter | |
| Marsh Wren<br>*(Cistothorus palustris)* | B, R | R | | | T | I, Rg, S, T | freshwater and brackish marshes with cattails, reeds, bulrushes, or sedges | |
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| KINGLETS | | | | | | | | |
| Golden-crowned Kinglet<br>*(Regulus satrapa)* | B, R | R | | U | T | I, Rg, S, T | dense, old conifer stands; also in deciduous forests and thickets in winter | |

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| Ruby-crowned Kinglet<br>*(Regulus calendula)* | B, R | R | U | U | T | I, Rg, S, T | coniferous forests in summer; also deciduous forests and thickets in winter | |
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| GNATCATCHERS | | | | | | | | |
| Blue-gray Gnatcatcher<br>*(Polioptila caerulea)* | B, R | R | U | U | T | I, Rg, S, T | open, moist woodlands and brushy streamside thickets | |
| Black-tailed Gnatcatcher<br>*(Polioptila melanura)* | | | U | | | | desert and arid country; dry washes in the low desert | |
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| THRUSHES, AND ALLIES | | | | | | | | |
| Eastern Bluebird<br>*(Sialia sialis)* | B, R | R | U | U | T | I, Rg, S, T | open farmland with scattered trees | |
| Western Bluebird<br>*(Sialia mexicana)* | | | | | | I, Rg, S, T | open woodlands and pastures where old trees provide nest sites | |
| Mountain Bluebird<br>*(Sialis currucoides)* | B, R | | | | | I, Rg, S, T | breeds in high mountain meadows with scattered trees and bushes; in winter descends to lower elevations; where it occurs on plains and grasslands | |
| Townsend's Solitaire<br>*(Myadestes townsendi)* | B, R | R | U | | | I, Rg, S, T | open coniferous forests, edges, or burns with single standing trees in the mountains | |
| Gray-cheeked Thrush<br>*(Catharus minimus)* | | | | | T | I, Rg, S, T | nests in coniferous forests, especially in dense stands of stunted spruce and balsam; widespread in migration | |
| Swainson's Thrush<br>*(Catharus ustulatus)* | B, R | | | | T | I, Rg, S, T | coniferous forests and willow thickets | |
| Hermit Thrush<br>*(Catharus guttatus)* | B, R | R | U | U | T | I, Rg, S, T | coniferous and mixed forests; deciduous woodlands and thickets in winter | |
| Wood Thrush<br>*(Hylocichla mustelina)* | | | | | | I, Rg, S, T | moist, deciduous woodlands with a thick understory; also well-planted parks and gardens | |
| American Robin<br>*(Turdus migratorius)* | B, R | R | U | U | T | I, Rg, S, T | towns, gardens, open woodland, and agricultural land | |

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| THRASHERS, AND ALLIES | | | | | | | | |
| Gray Catbird *(Dumetella carolinensis)* | B, R | | U | | T | I, Rg, S, T | thickets and brush, residential areas and gardens | |
| Northern Mockingbird *(Mimus polyglottos)* | B, R | R | U | U | T | I, Rg, S, T | residential areas, city parks, farmlands, open country with thickets, and desert brush | |
| Sage Thrasher *(Oreoscoptes montanus)* | | | | U | T | I, Rg, S, T | dry sagebrush plains and arid areas as in rocky canyons; winters in dense thickets and lowland scrub | |
| Brown Thrasher *(Toxostoma rufum)* | | | | | T | I, Rg, S, T | thickets, fields with scrub, and woodland borders | |
| Long-billed Thrasher *(Toxostoma longirostre)* | B, R | | U | | | I, Rg, S, T | dense tangles and thickets in both open country and wooded areas and in both moist and dry regions | |
| Curve-billed Thrasher *(Toxostoma curvirostre)* | B, R | | U | U | T | I, Rg, S, T | arid desert brushland and cactus | |
| Crissal Thrasher *(Toxostoma crissale)* | | | | | | I, Rg, S, T | dense underbrush near desert streams; edge of canyon chaparral in the hot, low desert | |
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| STARLINGS | | | | | | | | |
| European Starling *(Sturnus vulgaris)* | B, R | | U | U | T | I, Rg, S, T | cities, suburban areas, farmlands, and ranches | I |
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| PIPITS | | | | | | | | |
| American Pipit *(Anthus rubescens)* | B, R | | | U | T | I, Rg, S, T | Arctic and alpine tundra; during migration and winter, beaches, barren fields, agricultural land, and golf courses | |
| Sprague's Pipit *(Anthus spragueii)* | B, R | | | | T | I, Rg, S, T | short-grass plains and plowed fields | |
| | | | | | | | | |
| WAXWINGS | | | | | | | | |
| Cedar Waxwing *(Bombycilla cedrorum)* | B, R | R | U | U | T | I, Rg, S, T | open woodlands, orchards, and residential areas | |
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| SILKY-FLYCATCHERS | | | | | | | | |

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| Phainopepla<br>*(Phainopepla nitens)* | | | | | | I, Rg, S, T | desert scrub, but does not have strong preference for desert; it favors hot country with single, tall trees, preferably with mistletoe or other berries available when flying insects are scarce | |
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| WOOD-WARBLERS | | | | | | | | |
| Blue-winged Warbler<br>*(Vermivora pinus)* | B, R | | | | | I, Rg, S, T | abandoned fields and pastures grown up to saplings; forest clearings and edges with clumps of catbrier, blackberry, and various bushes and young trees | |
| Golden-winged Warbler<br>*(Vermivora chrysoptera)* | B, R | | | | | | abandoned fields and pastures grown up to saplings but usually in moister situations | |
| Tennessee Warbler<br>*(Vermivora peregrina)* | B, R | R | | | | I, Rg, S, T | open mixed woodlands in the breeding season; in trees and bushes during migration | |
| Orange-crowned Warbler<br>*(Vermivora celata)* | B, R | R | | U | T | I, Rg, S, T | thickets and brushy woodlands | |
| Nashville Warbler<br>*(Vermivora ruficapilla)* | B, R | R | U | U | T | I, Rg, S, T | woodland edges; thickets in open mixed forest or brushy borders of swamps | |
| Northern Parula<br>*(Parula americana)* | B, R | | U | U | T | I, Rg, S, T | breeds in wet chiefly coniferous woods, swamps, and along lakes and ponds; more widespread on migration | |
| Yellow Warbler<br>*(Dendroica petechia)* | B, R | R | | U | T | I, Rg, S, T | moist thickets, especially along streams and in swampy areas; gardens | |
| Chestnut-sided Warbler<br>*(Dendroica pensylvanica)* | B, R | | | | | | young, open second-growth woodland and scrub | |
| Magnolia Warbler<br>*(Dendroica magnolia)* | | | U | | | | breeds in open stands of young spruce and fir; in migration is found almost any place where shrubbery or trees occur | |
| Yellow-rumped Warbler<br>*(Dendroica coronata)* | B, R | R | U | U | T | I, Rg, S, T | coniferous and mixed forests; widespread during migration and winter | |

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| Townsend's Warbler *(Dendroica townsendi)* | B, R | | | | | | coniferous forests; in old stands of Douglas firs, where it forages in the upper canopy | |
| Black-throated Green Warbler *(Dendroica virens)* | B, R | | U | | | I, Rg, S, T | open stands of hemlock or pine; in migration in a variety of habitats | |
| Golden-cheeked Warbler *(Dendroica chrysoparia)* | B, R | R | U | U | | | rocky hillsides clothed with juniper | SE, FE |
| Blackburnian Warbler *(Dendroica fusca)* | B, R | | | | | | most numerous in mixed forests of hemlock, spruce, and various hardwoods, usually ranging high in the trees | |
| Yellow-throated Warbler *(Dendroica dominica)* | B, R | R | U | U | | | forests of pine, cypress, sycamore, and oak, in both swampy places and dry uplands | |
| Pine Warbler *(Dendroica pinus)* | | | | | | I, Rg, S, T | pine forests | |
| Palm Warbler *(Dendroica palmarum)* | | | | | | I, Rg, S, T | in summer, bogs in the North; during migration, open places, especially weedy fields and borders of marshes | |
| Blackpoll Warbler *(Dendroica striata)* | B, R | | | | | | breeds in coniferous forests; during migration is found chiefly in tall trees | |
| Black-and-white Warbler *(Mniotilta varia)* | B, R | R | U | U | T | I, Rg, S, T | primary and secondary forest, chiefly deciduous; in migration in parks, gardens, and lawn areas with trees and shrubs | |
| American Redstart *(Setophaga ruticilla)* | B, R | | | | T | I, Rg, S, T | second-growth woodlands; thickets with saplings | |
| Prothonotary Warbler *(Protonotaria citrea)* | B, R | | U | | | I, Rg, S, T | wooded swamps, flooded bottomland forest, and streams with dead trees | |
| Worm-eating Warbler *(Helmitheros vermivorus)* | B, R | | | | | I, Rg, S, T | chiefly dry wooded hillsides | |
| Ovenbird *(Seiurus aurocapillus)* | | | | | | I, Rg, S, T | mature, dry forest with little undergrowth | |
| Northern Waterthrush *(Seiurus noveboracensis)* | B, R | | | | T | I, Rg, S, T | cool bogs, wooded swamps, and lake shores in the breeding season; almost any wooded habitat in migration | |

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| Louisiana Waterthrush<br>*(Seiurus motacilla)* | B, R | | U | | | I, Rg, S, T | prefers swift-moving brooks on hillsides and, where the Northern Waterthrush is absent, occurs in river swamps and along sluggish streams | |
| Kentucky Warbler<br>*(Oporornis formosus)* | B, R | | | | | I, Rg, S, T | low, moist, rich woodland with luxuriant undergrowth; often in ravines | |
| Mourning Warbler<br>*(Oporornis philadelphia)* | B, R | | | | T | I, Rg, S, T | dense thickets of blackberries and briars in forest clearings; also in wet woods with thick undergrowth | |
| MacGillivray's Warbler<br>*(Oporonis tolmiei)* | B, R | | U | | T | I, Rg, S, T | coniferous forest edges, burns, brushy cuts, or second-growth alder thickets and streamside growth | |
| Common Yellowthroat<br>*(Geothlypis trichas)* | B, R | | U | U | T | I, Rg, S, T | moist thickets and grassy marshes | |
| Wilson's Warbler<br>*(Wilsonia pusilla)* | B, R | R | U | U | T | I, Rg, S, T | moist thickets in woodland and along streams; alder and willow thickets and bogs | |
| Canada Warbler<br>*(Wilsonia canadensis)* | B, R | | | | | | cool, moist woodland that is nearly mature and has much undergrowth | |
| Rufous-capped Warbler<br>*(Basileuterus rufifrons)* | B, R | | | | | | U. S. sightings have primarily come from canyon bottoms bordered by brushy thorn scrub or oak slopes | |
| Yellow-breasted Chat<br>*(Icteria virens)* | B, R | R | U | U | T | I, Rg, S, T | dense thickets and brush, often with thorns; streamside tangles and dry brushy hillsides | |
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| TANAGERS | | | | | | | | |
| Summer Tanager<br>*(Piranga rubra )* | B, R | R | U | U | T | I, Rg, S, T | open woodlands and shade trees | |
| Western Tanager<br>*(Piranga ludoviciana)* | B, R | | | | | I, Rg, S, T | coniferous or mixed pine-oak forests | |
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| SPARROWS, BUNTINGS, AND ALLIES | | | | | | | | |

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| Olive Sparrow *(Arremonops rufivirgatus)* | | | U | | | | brushy areas, woodland borders and clearings, and overgrown fields | |
| Green-tailed Towhee *(Pipilo chlorurus)* | B, R | R | | | T | I, Rg, S, T | sagebrush, mountain chaparral, pinon-juniper stands and thickets bordering alpine meadows | |
| Eastern Towhee *(Pipilo erythrophthalmus)* | | | | | T | I, Rg, S, T | thickets and brushy woodland edges | |
| Spotted Towhee *(Pipilo maculatus)* | B, R | R | U | U | T | I, Rg, S, T | thickets and brushy woodland edges | |
| Canyon Towhee *(Pipilo fuscus)* | B, R | R | U | U | T | I, Rg, S, T | brushy and rocky hills in arid country | |
| Cassin's Sparrow *(Aimophila cassinii)* | B, R | | U | | T | I, Rg, S, T | sparsely vegetated country; barren rocky areas with scattered cacti and yuccas, and short grass; it uses such plants, as well as fence posts and wires, as song perches | |
| Rufous-crowned Sparrow *(Aimophila ruficeps)* | B, R | R | U | U | T | I, Rg, S, T | open oak woodlands; treeless dry uplands with grassy vegetation and bushes, often near rocky outcrops | |
| American Tree Sparrow *(Spizella arborea)* | | | | | T | I, Rg, S, T | arctic willow and birch thickets, fields, weedy woodland edges, and roadside thickets in winter | |
| Chipping Sparrow *(Spizella passerina)* | B, R | R | U | U | T | I, Rg, S, T | grassy woodland edges, gardens, city parks, brushy pastures, and lawns | |
| Clay-colored Sparrow *(Spizella pallida)* | B, R | R | U | | T | I, Rg, S, T | brushy grasslands and prairies | |
| Brewer's Sparrow *(Spizella breweri)* | | | U | | T | I, Rg, S, T | sagebrush and alpine meadows | |
| Field Sparrow *(Spizella pusilla)* | B, R | R | U | U | T | I, Rg, S, T | abandoned fields and pastures grown up to weeds, scattered bushes, and small saplings | |
| Vesper Sparrow *(Pooecetes gramineus)* | B, R | R | U | U | T | I, Rg, S, T | fields, pastures, and roadsides in farming country | |
| Lark Sparrow *(Chondestes grammacus)* | B, R | R | U | U | T | I, Rg, S, T | grasslands with scattered bushes and trees; open country generally in winter | |

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| Black-throated Sparrow<br>*(Amphispiza bilineata)* | B, R | R | U | | T | I, Rg, S, T | desert with cactus, mesquite, and creosote bush, and also sagebrush; often found where it is rocky | |
| Lark Bunting<br>*(Calamospiza melanocorys)* | B, R | R | | U | T | I, Rg, S, T | open plains and fields | |
| Savannah Sparrow<br>*(Passerculus sandwichensis)* | B, R | | U | U | T | I, Rg, S, T | fields, prairies, salt marshes, and grassy dunes | |
| Baird's Sparrow<br>*(Ammodramus bairdii)* | | | | | T | I, Rg, S, T | dry upland prairies | |
| Grasshopper Sparrow<br>*(Ammodramus savannarum)* | B, R | | U | | T | I, Rg, S, T | open grassy and weedy meadows, pastures, and plains | |
| Henslow's Sparrow<br>*(Ammodramus henslowii)* | | | | | | | local in moist or dry grassland with scattered weeds and small shrubs | |
| Le Conte's Sparrow<br>*(Ammodramus leconteii)* | | | | | T | I, Rg, S, T | moist grassland and boggy meadows; also dry fields in winter | |
| Fox Sparrow<br>*(Passerella iliaca)* | | | | | T | I, Rg, S, T | coniferous forest undergrowth in summer; dense woodland thickets, weedy pastures, and brushy roadsides in winter | |
| Song Sparrow<br>*(Melospiza melodia)* | B, R | R | | U | T | I, Rg, S, T | thickets, pastures, undergrowth in gardens, and city parks | |
| Lincoln's Sparrow<br>*(Melospiza lincolnii)* | B, R | R | U | U | T | I, Rg, S, T | brushy bogs, willow, or alder thickets; winters in woodland thickets and brushy pastures | |
| Swamp Sparrow<br>*(Melospiza georgiana)* | B, R | R | | | T | I, Rg, S, T | freshwater marshes and open wooded swamps; in migration with other sparrows in weedy fields, parks, and brush piles | |
| White-throated Sparrow<br>*(Zonotrichia albicollis)* | B, R | R | U | | T | I, Rg, S, T | brushy undergrowth in coniferous woodlands; winters in brush woodland, pastures, and suburban areas | |
| Harris's Sparrow<br>*(Zonotrichia querula)* | | R | | | T | I, Rg, S, T | breeds in mossy bogs and scrub forests, migrates through the prairie regions, and winters in dense river-bottom thickets, woodland borders, clearings, and brush piles | |

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| White-crowned Sparrow *(Zonotrichia leucophrys)* | B, R | R | U | U | T | I, Rg, S, T | nests in dense brush, especially where near open grassland; winters in open woods and gardens | |
| Dark-eyed Junco *(Junco hyemalis)* | B, R | R | | | T | I, Rg, S, T | coniferous or mixed forests; winters in fields, gardens, city parks, and roadside thickets | |
| McCown's Longspur *(Calcarius mccownii)* | | | | | | I, Rg, S, T | arid plains | |
| *Chestnut-collared Longspur* *(Calcarius ornatus)* | B, R | | | | | I, Rg, S, T | dry elevated prairies and short-grass plains | |
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| GROSBEAKS, AND ALLIES | | | | | | | | |
| Northern Cardinal *(Cardinalis cardinalis)* | B, R | R | U | U | T | I, Rg, S, T | woodland edges, thickets, brushy swamps, and gardens | |
| Pyrrhuloxia *(Cardinalis sinuatus)* | B, R | R | U | U | T | I, Rg, S, T | desert brush, especially along stream beds | |
| Rose-breasted Grosbeak *(Pheucticus ludovicianus)* | | R | | | | I, Rg, S, T | moist woodland adjacent to open fields with tall shrubs; also old and overgrown orchards | |
| Black-headed Grosbeak *(Pheucticus melanocephalus)* | B, R | | | | T | I, Rg, S, T | open, deciduous woodland near water, such as river bottoms, lakeshores, and swampy places with a mixture of trees and shrubs | |
| Blue Grosbeak *(Guiraca caerulea)* | B, R | R | U | U | T | I, Rg, S, T | brushy, moist pastures and roadside thickets | |
| Lazuli Bunting *(Passerina amoena)* | B, R | | U | | T | I, Rg, S, T | dry, brushy ravines and slopes; cleared areas and weedy pastures | |
| Indigo Bunting *(Passerina cyanea)* | B, R | | U | | T | I, Rg, S, T | brushy slopes, abandoned farmland, old pastures and fields grown up to scrub, woodland clearings, and forest edge adjacent to fields | |
| Varied Bunting *(Passerina versicolor)* | B, R | | | | | I, Rg, S, T | dense desert brush, especially along stream beds | |
| Painted Bunting *(Passerina ciris)* | B, R | R | U | U | T | I, Rg, S, T | brushy tangles, hedgerows, briar patches, woodland edges, and swampy thickets | |

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| Dickcissel<br>*(spiza americana)* | B, R | | U | U | | I, Rg, S, T | open country in grain or hay fields and in weed patches | |
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| BLACKBIRDS AND ORIOLES | | | | | | | | |
| Bobolink<br>*(Dolichonyx oryzivorus)* | | | | | | I, Rg, S, T | prairies and meadows; marshes during migration | |
| Red-winged Blackbird<br>*(Agelaius phoeniceus)* | B, R | R | U | U | T | I, Rg, S, T | marshes, swamps, and wet and dry meadows; pastures | |
| Eastern Meadowlark<br>*(Sturnella magna)* | B, R | R | U | U | T | I, Rg, S, T | meadows, pastures, and prairies; in migration, in open country generally | |
| Western Meadowlark<br>*(Sturnella neglecta)* | B, R | R | U | U | T | I, Rg, S, T | meadows, plains, and prairies | |
| Yellow-headed Blackbird<br>*(Xanthocephalus xanthocephalus)* | B, R | R | U | | T | I, Rg, S, T | freshwater marshes | |
| Rusty Blackbird<br>*(Euphagus carolinus)* | | | | | | I, Rg, S, T | wooded swamps and damp woods with pools during migration; boreal bogs in the breeding season | |
| Brewer's Blackbird<br>*(Euphagus cyanocephalus)* | B, R | | U | | T | I, Rg, S, T | prairies, fields, and farm yards | |
| Common Grackle<br>*(Quiscalus quiscula)* | B, R | | U | | T | I, Rg, S, T | lawns, parks, fields, open woodland | |
| Great-tailed Grackle<br>*(Quiscalus mexicanus)* | | R | U | U | T | I, Rg, S, T | farmlands with scattered trees and thickets | |
| Bronzed Cowbird<br>*(Molothrus aeneus)* | B, R | R | U | U | | I, Rg, S, T | pastures, roadside thickets, ranches, open country generally; also parks and orchards | |
| Brown-headed Cowbird<br>*(Molothrus ater)* | B, R | R | U | U | T | I, Rg, S, T | agricultural land, fields, woodland edges, and suburban areas | |
| Orchard Oriole<br>*(Icterus spurius)* | B, R | R | U | U | T | I, Rg, S, T | orchards, shade trees in parks and gardens, and scattered trees along lakes and streams | |
| Hooded Oriole<br>*(Icterus cucullatus)* | B, R | R | U | U | | | originally streamside growth, but has adapted to tree plantations, city parks, and suburbs with palm or eucalyptus trees and shrubbery | |

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|---|---|---|---|---|---|---|---|---|
| Baltimore Oriole<br>*(Icterus galbula)* | B, R | R | | U | T | I, Rg, S, T | deciduous woodland and shade trees; before its decline, the American elm was a favorite nesting site for the Eastern bird | |
| Bullock's Oriole<br>*(Icterus bullockii)* | B, R | | U | | T | I, Rg, S, T | deciduous woodland and shade trees | |
| Scott's Oriole<br>*(Icterus parisorum)* | B, R | R | U | U | | I, Rg, S, T | breeds in the pinon-juniper woodlands of semidesert areas; in yucca trees or palms in deserts; or in sycamores or cottonwoods in canyons | |
| | | | | | | | | |
| FINCHES AND ALLIES | | | | | | | | |
| Purple Finch<br>*(Carpodacus purpureus)* | B, R | R | | U | | I, Rg, S, T | mixed and coniferous woodlands; ornamental conifers in gardens | |
| Cassin's Finch<br>*(Carpodacus cassinii)* | | R | | | | | open coniferous stands at high elevations | |
| House Finch<br>*(Carpodacus mexicanus)* | B, R | R | U | U | T | I, Rg, S, T | cities and residential areas in the East; also in desert brush in Texas and the Far West | |
| Red Crossbill<br>*(Loxia curvirostra)* | B, R | | | | | I, Rg, S, T | coniferous forests; visits ornamental evergreens in winter | |
| Pine Siskin<br>*(Carduelis pinus)* | B, R | R | U | U | T | I, Rg, S, T | coniferous and mixed woodlands, alder thickets, and brushy pastures | |
| Lesser Goldfinch<br>*(Carduelis psaltria)* | B, R | R | U | U | T | I, Rg, S, T | oak savannas, woodlands, suburban gardens | |
| American Goldfinch<br>*(Carduelis tristis)* | B, R | R | U | U | T | I, Rg, S, T | brushy thickets, weedy grasslands, and nearby trees | |
| | | | | | | | | |
| OLD WORLD SPARROWS | | | | | | | | |
| House Sparrow<br>*(Passer domesticus)* | B, R | R | U | U | T | I, Rg, S, T | cities, towns, and agricultural areas | I |

[1] B=Bandera, I=Irion, R=Real, Rg=Reagan, S=Schleicher, T=Tom Green, Up=Upton, U=Uvalde

[2]FE=federally endangered, FT=federally threatened, I=introduced, G=game, PDL=proposed de-listing, PT=proposed threatened, SE=state endangered, ST=State Threatened,

**Appendix E2. List of amphibians and reptiles in Edwards and Twin Buttes watersheds according to current distribution maps.**

| Species | Watershed[1] | County(ies)[2] | Habitat | Comments[3] |
|---|---|---|---|---|
| **Frogs and Toads** | | | | |
| Blanchard's Cricket Frog<br>*(Acris crepitans blanchardi)* | E<br>TB | **B**, **R**, **U**,<br>**I**, Rg, **S**, **T**, Up | sunny ponds of shallow water with good growth of vegetation in the water or on shore; slow-moving streams with sunny banks | |
| Eastern Green Toad<br>*(Bufo debilis delibis)* | E<br>TB | **B**, R, **U**,<br>I, **Rg**, **S**, **T**, **Up** | shelter of rocks in semiarid regions; also found in prairies | |
| Red-spotted Toad<br>*(Bufo punctatus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | desert and rocky regions and prairie grasslands, usually near source of permanent water or dampness, natural or man-made | |
| Texas Toad<br>*(Bufo speciosus)* | E<br>TB | B, R, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | prairie grasslands and open woodlands; adapted for dry conditions | |
| Gulf Coast Toad<br>*(Bufo valliceps valliceps)* | E | **B**, **R**, **U**, | various humid locations, from roadsideditches to the barrier beaches of the Gulf of Mexico | |
| Southwestern Woodhouse's Toad<br>*(Bufo woodhousii australis)* | TB | I, **Rg**, Up | sandy areas near marshes, irrigation ditches, backyards, and temporary rain pools | |
| Woodhouse's Toad<br>*(Bufo woodhousii woodhousii)* | E<br>TB | **B**, R, U,<br>I, S, **T** | sandy areas near marshes, irrigation ditches, backyards, and temporary rain pools | |
| Eastern Barking Frog<br>*(Eleutherodactylus augusti latitans)* | E | **B**, **R**, **U** | damp limestone caves and crevices, especially where rain is frequent | |
| Eastern Narrowmouth Toad<br>*(Gastrophryne carolinensis)* | E | B, R | near water, especially along the edge of ponds or ditches and under moist debris and decaying vegetative matter | |
| Great Plains Narrowmouth Toad<br>*(Gastrophryne olivacea)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **S**, **T** | montane woodlands, grasslands, and desert from sea level to 4000'; moist or damp areas from marshes to leaf litter and rodent burrows | |
| Cope's Gray Tree Frog / Gray Tree Frog<br>*(Hyla chrysoscelis/versicolor)* | E | **B**, **R**, **U** | trees of shrubs growing in or near permanent water | |
| Green Tree Frog<br>*(Hyla cinerea)* | E | B, **R**, U | vegetation near permanent water; during the day frequently found asleep on underside of large leaves or in other moist, | |

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| | | | shady places | |
| Spotted Chorus Frog<br>*(Pseudacris clarki)* | E<br>TB | **R**, **U**,<br>**Rg**, **S**, **T** | shortgrass prairie | |
| Strecker's Chorus Frog<br>*(Pseudacris streckeri)* | E | B, R, **U** | moist areas, including wooded and open fields, swamps, and streams | |
| Rio Grande Leopard Frog<br>*(Rana berlandieri)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | any water or moist conditions, natural or artificial | |
| Plains Leopard Frog<br>*(Rana blairi)* | TB | I, **T** | prairies and other grassy, moist areas, along margins of ponds, streams, marshes | |
| Bullfrog<br>*(Rana catesbeiana)* | E<br>TB | **B**, **R**, **U**,<br>**T** | aquatic;prefers ponds, lakes, and slow-moving streams large enough to avoid crowding and with sufficient vegetation to provide easy cover | |
| Couch's Spadefoot<br>*(Scaphiopus couchi)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | tolerant of dry terrain; likes shortgrass praiire as well as mesquite savannah and creosote bush desert | |
| Plains Spadefoot<br>*(Spea bombifrons)* | TB | I, Rg, **S**, T, Up | shortgrass prairie where soil is loose and dry, rainfall low; likes sandy and gravelly soils | |
| New Mexico Spadefoot<br>*(Spea multiplicata)* | TB | I, **Rg**, **S**, **T**, **Up** | tolerates wide range of conditions from semiarid to arid; prefers shortgrass plains and shady, gravelly areas such as alkali flats, washes, and river floodplains | |
| Cliff Chirping Frog<br>*(Syrrhophus marnocki)* | E<br>TB | **B**, **R**, **U**,<br>**S**, **T**, **Up** | crevices and caves of limestone hills | |
| **Lizards** | | | | |
| Green Anole<br>*(Anolis carolinensis)* | E<br>TB | **B**, R, **U**,<br>I, S, **T** | arboreal; encountered on vertical surfaces like fence posts and walls; but favors tree boles, shrubs, vines, tall grasses, palm fronds | |
| Texas Spotted Whiptail<br>*(Cnemidophorus gularis gularis)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | semiarid prairie grasslands, open brushy areas; also arid washes and canyons, frequently in vicinity of streams | |
| Trans-pecos Striped Whiptail<br>*(Cnemidophorus inornatus heptogrammus)* | TB | **I**, **Rg**, S, T,**Up** | arid and semiarid grasslands with some low brush; flatlands, gentle slopes | |
| Six-lined Racerunner<br>*(Cnemidophorus sexlineatus sexlineatus)* | E | **B**, R, **U** | dry sunny areas; grasslands, open woodlands, usually on well-drained soils | |
| Prairie-lined Racerunner<br>*(Cnemidophorus sexlineatus viridis)* | TB | I, **Rg**, T, Up | dry sunny areas; grasslands, open woodlands, usually on well-drained soils | |

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| Colorado Checkered Whiptail<br>*(Cnemidophorus tesselatus)* | TB | I, **Rg**, **Up** | rocky locations on sand or gravel supporting grass or sparse brush | |
| Western Marbled Whiptail<br>*(Cnemidophorus tigris marmoratus)* | TB | Rg, **Up** | arid and semiarid desert to open woodlands; where vegetation is sparse enough to make running easy | |
| Texas Banded Gecko<br>*(Coleonyx brevis)* | E<br>TB | B, R, **U**,<br>I, **Rg**, **Up** | rock outcrops and canyon beds in desert areas; found beneath shelving rocks, vegetative debris, and discarded boards | |
| Texas Earless Lizard<br>*(Cophosaurus texanus texanus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T** | stretches of broken rock, limestone cliffs, dry sandy streambeds, rocky washes | |
| Eastern Collared Lizard<br>*(Crotaphytus collaris collaris)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | hardwood forests to arid areas with large rocks for basking; more frequent in hilly regions, especially among limestone ledges that provide crevices for good cover | |
| Reticulate Collared Lizard<br>*(Crotaphytus reticulatus)* | E | **U** | semiarid brushland, escarpments, isolated rock piles, pack rat burrows | ST |
| Many-lined Skink; undescribed subspecies<br>*(Eumeces multivirgatus ssp.)* | TB | **I**, **Rg**, S, T, Up | mountainous wooded areas to 8200' | |
| Great Plains Skink<br>*(Eumeces obsoletus)* | E<br>TB | **B**, **R**, **U**,<br>I, **Rg**, S, **T**, Up | open rocky grasslands of the Great Plains; near permanent or semipermanent water in otherwise drier areas | |
| Short-lined Skink<br>*(Eumeces tetragrammus brevilineatus)* | E<br>TB | **B**, **R**, U,<br>**I**, **Rg**, **S**, **T**, Up | arid and semiarid country; rocky ravines, grassy zones, scrub, forest, woodland, sea level to 6500' | |
| Texas Alligator Lizard<br>*(Gerrhonotus infernalis)* | E | **B**, **R**, U | rocky slopes with some scrub vegetation | |
| Mediterranean Gecko<br>*(Hemidactylus turcicus turcicus)* | E<br>TB | **B**, **U**,<br>**T** | under palm leaves and in crevices of tree bark and rocky outcrops; most common in occupied buildings | I |
| Plateau Earless Lizard<br>*(Holbrookia lacerata lacerata)* | E<br>TB | B, **R**, U,<br>**I**, **Rg**, **S**, **T**, Up | arid areas with sparse vegetation; seasonally dry prairie brushland | |
| Northern Earless Lizard<br>*(Holbrookia maculata maculata)* | TB | Rg, Up | sandy soil areas in grassy prairie, cultivated fields, dry streambeds, desert grasslands | |
| Western Slender Glass Lizard<br>*(Ophisaurus attenuatus)* | E | B, R | dry grassland and dry open woodland | |
| Texas Horned Lizard<br>*(Phrynosoma cornutum)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | from sea level to 6000' in dry areas, most open country with loose soil supporting grass, mesquite, cactus | ST |
| Roundtail Horned Lizard<br>*(Phrynosoma modestum)* | TB | **I**, **Rg**, S, **T**, **Up** | sandy, gravelly washes and other semiarid regions of scrub vegetation | |

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| Texas Spiny Lizard<br>*(Sceloporus olivaceus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, Rg, **S**, **T**,**Up** | primarily arboreal; in mesquite, live oak. And other trees; also on man-made structures that provide shelter | |
| Eastern Tree Lizard<br>*(Sceloporus ornatus ornatus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | trees, rocks, fence posts, and buildings in arid regions; often near streams, and dry wshes | |
| Crevice Spiny Lizard<br>*(Sceloporus poinsetti poinsetti)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, S, **T**, **Up** | limestone and other exposed rocky outcrops in arid and semiarid areas | |
| Southern Prairie Lizard<br>*(Sceloporus undulatus consobrinus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | generally sunny locations; favors rotting logs, open woodlands, open grassy dunes, prairie | |
| Rose-bellied Lizard<br>*(Sceloporus variabilis marmoratus)* | E | **B**, **U** | arid regions, from sea level to 7500'; frequents mesquite branches, cacti, and, less often, rocks | |
| Ground Skink<br>*(Scincella lateralis)* | E<br>TB | **B**, **R**, **U**,<br>I, Rg, S, **T** | humid forests, hardwood hammocks, and forested grasslands, generally where leaf litter is abundant | |
| Desert Side-blotched Lizard<br>*(Uta stansburiana stenjnegeri)* | TB | I, **Rg**, S, T, **Up** | arid and semiarid regions with coarse, gravelly soil and low-growing vegetation | |
| **Salamanders** | | | | |
| Barred Tiger Salamander<br>*(Ambystoma tigrinum mavortium)* | E<br>TB | B, R, U,<br>I, **Rg**, S, **T**, Up | varied; arid sagebrush plains, pine barrens, mountain forests, and damp meadows where ground is easily burrowed; also in mammal and invertebrate burrows; sea level to 11000' | |
| Texas Salamander<br>*(Eurycea neotenes)* | E | **B**, **R**, **U** | small cave streams, springs, seeps, and headwaters of creeks | |
| Western Slimy Salamander<br>*(Plethodon albagula)* | E | **B**, **R**, **U** | shaded ravine slopes, shale banks, wooded floodplains, cave entrances; near sea level to 5500' | |
| **Snakes** | | | | |
| Broad-banded Copperhead<br>*(Agkistrodon contortrix laticinctus)* | E<br>TB | **B**, **R**, **U**,<br>I, Rg, S, **T** | wooded hillsides with rock outcrops above streams or ponds; edges of swamps and periodically flooded areas in coastal plain; near canyon springs and dense cane stands along Rio Grande; sea level to 5000' | |
| Trans-pecos Copperhead<br>*(Agkistrodon contortrix pictigaster)* | TB | **Up** | wooded hillsides with rock outcrops above streams or ponds; edges of swamps and periodically flooded areas in coastal plain; near canyon springs and dense cane stands along Rio Grande; sea level to 5000' | |

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| Trans-pecos Copperhead X Broad-banded Copperhead<br>*(Agkistrodon contortrix pictigaster X A. c. laticinctus)* | TB | I, **Rg** | wooded hillsides with rock outcrops above streams or ponds; edges of swamps and periodically flooded areas in coastal plain; near canyon springs and dense cane stands along Rio Grande; sea level to 5000' | |
| Western Cottonmouth<br>*(Agkistrodon piscivorus leucostoma)* | E<br>TB | **B**, R, **U**,<br>**I**, Rg, S, **T** | lowland swamps, lakes, rivers, bayheads, sloughs, irrigation ditches, canals, rice fields, to small clear rocky mountain streams; sea level to ca. 1500' | |
| Texas Glossy Snake<br>*(Arizona elegans arenicola)* | E | **U** | dry, open sandy areas, coastal chaparral, creosote-mesquite desert, sagebrush flats, and oak-hickory woodland; below sea level to 5500' | |
| Kansas Glossy Snake<br>*(Arizona elegans elegans)* | TB | I, Rg, **T**, **Up** | dry, open sandy areas, coastal chaparral, creosote-mesquite desert, sagebrush flats, and oak-hickory woodland; below sea level to 5500' | |
| Trans-Pecos Rat Snake<br>*(Bogertophis subocularis subocularis)* | E | B, R, **U** | Chihuahuan Desert; agave-creosote bush-ocotillo-dominated slopes to rocky areas characterized by persimmon-shinoak or cedar; ca. 1500-4500' | |
| Eastern Yellow-bellied Racer<br>*(Coluber constrictor flaviventris)* | E<br>TB | B, **R**, U<br>**T** | abandoned fields, grassland, sparse brushy areas along prairie land, open woodland, mountain meadows, rocky wooded hillsides, grassy-bordered streams, and pine flatwoods; sea level to ca. 7000' | |
| Western Diamondback Rattlesnake<br>*(Crotalus atrox)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | arid and semiarid areas from plains to mountains; brushy desert, rocky canyons, bluffs along rivers, sparsely vegetated foothills; sea level to 7000' | |
| Mottled Rock Rattlesnake<br>*(Crotalus lepidus lepidus)* | E | **B**, **R**, **U** | chiefly rocky mountainous areas; talus slopes, gorges, rimrock, limestone outcrops, rocky streambeds; 1500-9600' | |
| Black-tailed Rattlesnake<br>*(Crotalus molossus molossus)* | E<br>TB | **B**, **R**, U<br>I, Rg, S, T, **Up** | most common in rocky mountainous areas; among rimrock and limestone outcrops, wooded stony canyons, chaparral, rocky streambeds; near sea level to ca. 9000' | |
| Prairie Rattlesnake<br>*(Crotalus viridis viridis)* | TB | **I**, **Rg**, **S**, **T**, **Up** | Great Plains grassland to brush-covered sand dunes on Pacific coast, and to timberline in th Rockies and the coniferous forests of the Northwest; rocky outcrops, | |

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| | | | talus slopes, stony canyons, and prairie dog towns sea level to 11000' | |
| Prairie Ring-necked Snake<br>*(Diadophis punctatus arnyi)* | E | **B**, **R**, U | moist situations in varied habitat; forests, grassland, rocky wooded hillsides, chaparral, into upland desert along streams; sea level to ca. 7000' | |
| Regal Ring-necked Snake<br>*(Diadophis punctatus regalis)* | TB | **I**, **Rg**, S, **T**, Up | moist situations in varied habitat; forests, grassland, rocky wooded hillsides, chaparral, into upland desert along streams; sea level to ca. 7000' | |
| Texas Indigo Snake<br>*(Drymarchon corais erebennus)* | E | B, R, **U** | in Texas: dry grassland and thickets near ponds and rivers | ST ? |
| Baird's Rat Snake<br>*(Elaphe bairdi)* | E<br>TB | **B**, **R**, **U**<br>S | hardwood forest, wooded canyons, swamps, rocky timbered upland, farmland, old fields, barnyards; from wet to arid situations; sea level to 4400' | |
| Great Plains Rat Snake<br>*(Elaphe guttata emoryi)* | TB | **I**, Rg, **S**, **T**, Up | wooded groves, rocky hillsides, meadowland; along watercourses, around springs, woodlots, barnyards, and abandoned houses; sea level to ca. 6000' | |
| Great Plains Rat Snake X Southwestern Rat Snake<br>*(Elaphe guttata emoryi X E. g. meahllmorum)* | E | **B**, **R**, **U** | wooded groves, rocky hillsides, meadowland; along watercourses, around springs, woodlots, barnyards, and abandoned houses; sea level to ca. 6000' | |
| Texas Rat Snake<br>*(Elaphe obsoleta lindheimeri)* | E<br>TB | **B**, **R**, U<br>**I**, Rg, S, **T** | hardwood forest, wooded canyons, swamps, rocky timbered upland, farmland, old fields, barnyards; from wet to arid situations; sea level to 4400' | |
| Western Hook-nosed Snake<br>*(Gyalopion canum)* | TB | **I**, **Rg**, **T** | arid regions dominated by creosote bush, mesquite, and shadescale, and juniper-grassland or pinon-juniper associations | |
| Dusky Hog-nosed Snake<br>*(Heterodon nasicus gloydi)* | E<br>TB | B, R, U,<br>**I**, **Rg**, S, **T**, **Up** | sand and gravelly-soiled prairie, scrubland, river floodplains; sea level to 8000' | |
| Eastern Hog-nosed Snake<br>*(Heterodon platirhinos)* | E | **B**, **R**, U | prefers open sandy-soiled areas; thinly wooded upland hillsides, cultivated fields, woodland meadows; sea level to 2500' | |
| Texas Night Snake<br>*(Hypsiglena torquata jani)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, Up | semiarid and arid sandy or rocky situations from plains and desert flats, to heavy brush chaparral and blue oak-Digger pine | |

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| | | | woodland; sea level to 7000' | |
| Gray-banded King Snake<br>*(Lampropeltis alterna)* | TB | Rg, **Up** | arid mesquite-creosote bush desert flats, barren rocky hillsides, canyons, limestone ledges, ranging into semimoist mountainous situations; 1200-7500' | |
| Desert King Snake<br>*(Lampropeltis getula splendida)* | E<br>TB | B, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, Up | diverse; New jersey pine barrens to Florida Everglades; dry rocky wooded hillsides to river swamps and coastal marshes, and prairie, desert, and chaparral; sea level to 6900' | |
| Mexican Milk Snake<br>*(Lampropeltis triangulum annulata)* | E | **B**, R, U | diverse situations: semiarid to damp coastal bottomland to Rocky Mountains and tropical hardwood forests; pine forests, open deciduous woodland, meadows, rocky hillsides, prairie, high plains, sand dunes, farmland, and suburban areas; sea level to ca. 8000' | |
| Central Plains Milk Snake<br>*(Lampropeltis triangulum gentilis)* | TB | **I**, **Rg**, S, **T**, Up | diverse situations: semiarid to damp coastal bottomland to Rocky Mountains and tropical hardwood forests; pine forests, open deciduous woodland, meadows, rocky hillsides, prairie, high plains, sand dunes, farmland, and suburban areas; sea level to ca. 8000' | |
| New Mexico Blind Snake<br>*(Leptotyphlops dulcis dissectus)* | TB | **Up** | semiarid deserts, prairies, hillsides, mountain slopes with sandy or loamy soil suitable for burrowing; sea level to 5000' | |
| Plains Blind Snake<br>*(Leptotyphlops dulcis dulcis)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, S, **T**, Up | semiarid deserts, prairies, hillsides, mountain slopes with sandy or loamy soil suitable for burrowing; sea level to 5000' | |
| Western Coachwhip<br>*(Masticophis flagellum testaceus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | dry, relatively open situations; pine and palmetto flatwoods, rocky hillsides, grassland prairies, desert scrub, thorn forest, and chaparral; sea level to ca. 7000' | |
| Schott's Whip Snake<br>*(Masticophis schotti schotti)* | E | B, R, **U** | from grassland and arid brushy flatland to rugged mountainous terrain dominated by pinon-juniper and open pine-oak woodlands; sea level to 9400' | |

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| Central Texas Whip Snake<br>*(Masticophis taeniatus girardi)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, S, T, Up | from grassland and arid brushy flatland to rugged mountainous terrain dominated by pinon-juniper and open pine-oak woodlands; sea level to 9400' | |
| Texas Coral Snake<br>*(Micrurus fulvius tenere)* | E<br>TB | **B**, **R**, **U**,<br>S, T | moist, densely vegetated hammocks near ponds or streams in hardwood forests; pine flatwoods; rocky hillsides and canyons | |
| Blotched Water Snake<br>*(Nerodia erythrogaster transversa)* | E<br>TB | **B**, **R**, **U**,<br>**I**, Rg, S, **T** | river swamps and the forested edges of streams, ponds, lakes, and bayous | |
| Concho Water Snake<br>*(Nerodia harteri paucimaculata)* | TB | I, **T** | swift rocky streams and rivers | ST, FT |
| Diamondback Water Snake<br>*(Nerodia rhombifer rhombifer)* | E<br>TB | **B**, **R**, **U**,<br>**I**, Rg, **S**, **T**, Up | margins of lakes, rivers, streams, swamps, marshes, canals, ditches, and ponds | |
| Rough Green Snake<br>*(Opheodrys aestivus)* | E<br>TB | **B**, **R**, **U**,<br>I, Rg, S, **T** | vines, bushes, and trees near water; sea level to 5000' | |
| Bull Snake<br>*(Pituophis catenifer sayi)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, Up | dry, sandy pine-oak woodlands and pine flatwoods, cultivated fields, prairies, open brushland, rocky desert, chaparral; sea level to 9000' | |
| Graham's Crayfish Snake<br>*(Regina grahami)* | TB | **T** | sluggish streams, ponds, lakes, and ditches where crayfish are abundant | |
| *Texas Long-nosed Snake*<br>*(Rhinocheilus lecontei tessellatus)* | E<br>TB | B, R, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | dry open prairie, desert brushland, coastal chaparral to tropical habitat in Mexico; sea level to 5400' | |
| Texas Patch-nosed Snake<br>*(Salvadora grahamiae lineata)* | E<br>TB | **B**, **R**, **U**,<br>I, Rg, **S**, **T**, Up | western form prefers open woodland and forested mountainous slopes above 4000'; eastern subspecies, prairie and brushland to rocky canyons, creek beds, and rugged hillsides; sea level to 6500' | |
| Desert Massasauga<br>*(Sistrurus catenatus edwardsi)* | TB | **I**, Rg, S, **T**, Up | sphagnum bogs, swamps, marshland, and flood plains to dry woodland in the East; grassy wetland, rocky hillsides, sagebrush prairie, into desert grassland in the West | |
| Western Massasauga<br>*(Sistrurus catenatus tergeminus)* | E | B, R, U | sphagnum bogs, swamps, marshland, and flood plains to dry woodland in the East; grassy wetland, rocky hillsides, sagebrush prairie, into desert grassland in the West | |
| Ground Snake<br>*(Sonora semiannulata semiannulata)* | E<br>TB | **B**, **R**, U<br>**I**, **Rg**, **S**, **T**, **Up** | dry open areas with loose sandy soil; rocky wooded or prairie hillsides, mesquite thickets along river beds, sand hummocks, vacant lots, brushy desert; sea level to 6000' | |

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|---|---|---|---|---|
| Ground Snake X South Texas Ground Snake *(Sonora semiannulata semiannulata X S. s. taylori)* | E | **U** | dry open areas with loose sandy soil; rocky wooded or prairie hillsides, mesquite thickets along river beds, sand hummocks, vacant lots, brushy desert; sea level to 6000' | |
| Texas Brown Snake *(Storeria dekayi texana)* | E<br>TB | **B**, R, **U**,<br>S, **T** | moist upland woodland to lowland freshwater and saltwater marshes; margins of swamps, bogs, and ponds; vacant lots, gardens, golf courses | |
| Flatheaded Snake *(Tantilla gracilis)* | E<br>TB | **B**, **R**, **U**,<br>**I**, Rg, **S**, **T** | rocky prairie and wooded hillsides; sea level to 2000' | |
| Southwestern Black-headed Snake *(Tantilla hobartsmithi)* | E<br>TB | **B**, R, **U**,<br>I, **Rg**, S, T, **Up** | a burrowing snake usually found on the surface only where moisture has condensed under flat stones | |
| Plains Black-headed Snake *(Tantilla nigriceps nigriceps)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | rocky and grassy prairie; hillsides where soil is moist | |
| Eastern Black-necked Garter Snake *(Thamnophis cyrtopsis ocellatus)* | E<br>TB | **B**, **R**, **U**,<br>I, R, **S**, T | mesquite-dominated desert flats to pine-fir forests; prefers canyon and mountain streams and spring seepages; sea level to 8750' | |
| Checkered Garter Snake *(Thamnophis marcianus marcianus)* | E<br>TB | **B**, R, **U**,<br>**I**, **Rg**, **S**, **T**, Up | arid and semiarid grassland near streams, springs, ponds, and irrigation sites; sea level to ca. 5000' | |
| *Arid Land Ribbon Snake* *(Thamnophis proximus diabolicus)* | TB | Up | weedy margins of lakes, ponds, cattle tanks, marshes, ditches, streams, rivers; sea level to 8000' | |
| Red-striped Ribbon Snake *(Thamnophis proximus rubrilineatus)* | E<br>TB | **B**, **R**, **U**,<br>**I**, S, **T** | weedy margins of lakes, ponds, cattle tanks, marshes, ditches, streams, rivers; sea level to 8000' | |
| Red-striped Ribbon Snake X Arid Land Ribbon Snake *(Thamnophis proximus rubrilineatus X T. p. diabolicus)* | TB | **I**, Rg, S | weedy margins of lakes, ponds, cattle tanks, marshes, ditches, streams, rivers; sea level to 8000' | |
| *Texas Garter Snake* *(Thamnophis sirtalis annectens)* | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | near water--wet meadows, marshes, prairie swales, irrigation and drainage ditches, damp woodland, farms, parks; sea level to 8000' | |
| Texas Lined Snake *(Tropidoclonion lineatum texanum)* | E<br>TB | B, R, U,<br>**I**, Rg, **S**, **T** | open prairie hillsides, edges of woodland, and vacant suburban lots; sea level to ca. 5300' | |
| Rough Earth Snake *(Virginia striatula)* | E | B, R, **U** | dry coastal plain, woodland, exposed rocky wooded hillsides, and heavily timbered | |

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|---|---|---|---|---|
| | | | uplands and valleys | |
| Western Earth Snake<br>*(Virginia valeriae elegans)* | E | B, R, U | | |
| **Turtles** | | | | |
| Common Snapping Turtle<br>*(Chelydra serpentina serpentina)* | E<br>TB | **B**, **R**, U<br>**I**, Rg, S, **T**, Up | freshwater; likes soft mud bottoms and abundant vegetation; also enters brackish waters | |
| Texas Tortoise<br>*(Gopherus berlandieri)* | E | B, R, **U** | scrub woodlands with sandy soils; also chaparral and mesquite | ST |
| Cagle's Map Turtle<br>*(Graptemys caglei)* | E | B | streams and rivers with numerous stumps and logjams and an abundance of molluscs | ST, FC |
| Texas Map Turtle<br>*(Graptemys versa)* | E<br>TB | B, R,<br>**I**, **S**, **T** | Colorado River system, Texas | |
| Yellow Mud Turtle<br>*(Kinosternon flavescens flavescens)* | E<br>TB | **B**, **R**, **U**,<br>**T**, **Up** | prefers quiet or slow-moving bodies of freshwater<br>with mud or sandy bottoms | |
| Mississippi Mud Turtle<br>*(Kinosternon subrubrum hippocrepis)* | E | B, R | fresh or brackish water; prefers shallow, soft-bottomed, slow-moving water with abundant vegetation; often occupies muskrat lodges | |
| Stinkpot<br>*(Sternotherus odoratus)* | E<br>TB | **B**, R, **U**<br>I, S, T | freshwater; prefers quiet or slow-moving shallow, muddy-bottomed waters | |
| Texas River Cooter<br>*(Pseudemys texana)* | E<br>TB | **B**, **U**,<br>**I**, **T** | streams and rivers with moderate currents; large lakes, spring runs, and occasionally brackish tidal marshes | |
| Three-toed Box Turtle<br>*(Terrapene carolina triunguis)* | E | B | moist forested areas, but also wet meadows, pastures, and floodplains | |
| Ornate Box Turtle<br>*(Terrapene ornata ornata)* | E<br>TB | **B**, **R**, U<br>**I**, **Rg**, S, **T**, Up | primarily open prairies; also grazed pasturelands, open woodlands, and waterways in arid, sandy-soiled terrain | |
| Guadalupe Spiny Soft-shelled Turtle<br>*(Trionyx spiniferus guadalupensis)* | E<br>TB | **B**, **R**, U<br>I, S, **T** | likes small marshy creeks and farm ponda as well as large, fast-flowing rivers and lakes | |
| Western Spiny Soft-shelled Turtle<br>*(Trionyx spiniferus hartwegi)* | TB | I, Rg, Up | likes small marshy creeks and farm ponda as well as large, fast-flowing rivers and lakes | |
| Red-eared Slider<br>*(Trachemys scripta elegans)* | E<br>TB | **B**, **R**, **U**,<br>**I**, **T** | sluggish rivers, shallow streams, swamps, ponds, and lakes with soft bottoms and dense vegetation | |

[1]E=Edward's (Bandera, Real, and Uvalde counties), TB=Twin Buttes (Irion, Reagan, Schleicher, Tom Green, and Upton counties).

[2]B=Bandera, I=Irion, R=Real, Rg=Reagan, S=Schleicher, T=Tom Green, Up=Upton, U=Uvalde. Bold font=counties with "dots" on a county map. Normal font=counties without dots, but within distribution boundaries (when boundaries are designated).

[3]FE=federally endangered, FT=federally threatened, I=introduced, G=game, PDL=proposed de-listing, PT=proposed threatened, SE=state endangered, ST=State Threatened.

**Appendix E3. List of mammals in Edwards and Twin Buttes watersheds according to current distribution maps.**

| Family | Species | Watershed[1] | County(ies)[2] | Habitat | Comments[3] |
|---|---|---|---|---|---|
| **Didelphimorpha** | | | | | |
| Didelphidae (opossums) | Virginia Opossum (*Didelphis virginiana*) | E<br>TB | B, R, U,<br>I, Rg, S, **T**, **Up** | primarily inhabitants of deciduous woodlands but are often found in prairies, marshes, and farmlands. In the western part of their native range they generally keep to the woody vegetation along streams and rivers, a habit which permits them to penetrate the otherwise treeless grasslands and deserts of west Texas | |
| **Insectivora** | | | | | |
| Soricidae (shrews) | Least Shrew (*Cryptotis parva)* | E | B | an inhabitant of grasslands where it utilizes the surface runways of cotton rats (Sigmodon) and other grassland rodents. It seldom occurs in forests but occasional individuals have been found under logs and leaf litter in moist, forested areas | |
| Soricidae (shrews) | Desert Shrew (*Notiosorex crawfordi*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | found in the more arid, western and southern parts of the state but do not appear to be restricted to any particular habitat. Specimens have been taken in cattail marshes, in beehives, under piles of cornstalks, among yuccas, in wood rat nests, and beneath piles of brush and refuse | |
| Talpidae (moles) | Eastern Mole (*Scalopus aquaticus*) | E | B | they occur largely in moist (not wet), sandy soils; deep, dry sands and heavy clays are avoided | |
| **Chiroptera** | | | | | |
| Mormoopidae (mormoopid bats) | Ghost-faced Bat (*Mormoops megalophylla*) | E | B, R, **U** | a colonial, cave-dwelling bat whose distribution is closely correlated with the distribution of caves, crevices, and abandoned mine tunnels which serve as daytime roosts; probably forages relatively high above the ground in areas unobstructed by tall vegetation | |
| Vespertilionidae (vespertilionid bats) | Cave Myotis (*Myotis velifer*) | E<br>TB | B, **R**, **U**,<br>I, Rg, S, T, Up | cave dwelling bat; they may also roost in rock crevices, old buildings, carports, under bridges, and even in abandoned cliff swallow nests | |
| Vespertilionidae (vespertilionid bats) | Silver-haired Bat (*Lasionycteris noctivagans*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | denizens of forested areas and seldom are observed in xeric areas except in migration; cavities in trees and spaces under loose bark are favorite daytime retreats but these bats may also use buildings; typically forages in or near coniferous and/or mixed deciduous forests adjacent to ponds or other sources of water | |

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| Vespertilionidae<br>(vespertilionid bats) | Western Pipistrelle<br>(*Pipistrellus hesperus*) | E<br>TB | B, R, **U**,<br>I, Rg, S, T, **Up** | associated chiefly with rocky situations along watercourses. Its daytime retreat is in the cracks and crevices of canyon walls or cliffs, under loose rocks, or in caves | |
| Vespertilionidae<br>(vespertilionid bats) | Eastern Pipistrelle<br>(*Pipistrellus subflavus*) | E<br>TB | **B**, **R**, **U**,<br>S | retreats in caves, crevices in cliffs, buildings, and other man-made structures offering concealment; flutter and flit along watercourses or over pastures and woodlands; appear to favor watercourses as foraging grounds | |
| Vespertilionidae<br>(vespertilionid bats) | Eastern Red Bat<br>(Lasiurus borealis) | E<br>TB | **B**, R, **U**,<br>I, Rg, S, T, Up | forest dwelling, solitary; roost in the open in trees; roosting sites are common in tree foliage or Spanish moss where the bats are concealed as they resemble dead leaves; generally forage near the forest canopy at or above treetop level | |
| Vespertilionidae<br>(vespertilionid bats) | Hoary Bat<br>(*Lasiurus cinereus*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | more or less solitary and frequents wooded areas where it roosts in the open by hanging from a branch or twig | |
| Vespertilionidae<br>(vespertilionid bats) | Evening Bat<br>(*Nycticeius humeralis*) | E | **B**, **R**, **U** | frequent forested areas and watercourses, and utilize hollow trees as roosting sites and nurseries; they use the attics of houses and other man-made structures as roosts when natural sites are not available | |
| Vespertilionidae<br>(vespertilionid bats) | Townsend's Big-eared Bat<br>(*Plecotus townsendii*) | E<br>TB | R,<br>I, Rg, S, T, Up | correlated largely with rocky situations where caves or abandoned mine tunnels are available; may occasionally inhabit old buildings | |
| Vespertilionidae<br>(vespertilionid bats) | Pallid Bat<br>(*Antrozous pallidus*) | E<br>TB | B, R, **U**,<br>I, Rg, S, T, **Up** | inhabit rocky, outcrop areas where they commonly roost in rock crevices, caves, and mine tunnels but they also roost in the attics of houses, under the eaves of barns, behind signs, in hollow trees, and in abandoned adobe buildings; to some extent, terrestrial foragers | |
| Molossidae<br>(free-tailed bats) | Brazilian Free-tailed Bat<br>(*Tadarida brasiliensis*) | E<br>TB | **B**, **R**, **U**,<br>**I**, Rg, **S**, **T**, Up | utilize caves, mine tunnels, old wells, hollow trees, human habitations, bridges, and other buildings | |
| Molossidae<br>(free-tailed bats) | Big Free-tailed Bat<br>(*Nyctinomops macrotis*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | seasonal inhabitants of rugged, rocky country in both lowland and highland habitats | |
| **Xenarthra** | | | | | |
| Dasypodidae<br>(armadillos) | Nine-banded Armadillo<br>(*Dasypus novemcinctus*) | E<br>TB | **B**, **R**, **U**,<br>I, Rg, S, T, Up | In the rocky terrain of the Edwards Plateau, the animals tend to concentrate in the alluvial stream bottoms and den in the cracks and crevices of the numerous limestone outcroppings in that area | |
| **Lagomorpha** | | | | | |
| Leporidae<br>(hares and rabbits) | Desert Cottontail<br>(*Sylvilagus audubonii*) | E<br>TB | B, **R**, U,<br>I, Rg, S, **T**, Up | adapted to a variety of habitats, varying from grassland to creosote brush and cactus deserts; wherever it may be, it frequents brushy areas or, where the vegetation is short, the underground burrows of prairie dogs, skunks, and so forth | |

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| Leporidae (hares and rabbits) | Eastern Cottontail (*Sylvilagus flordanus*) | E TB | **B**, R, **U**, **I**, **Rg**, S, **T**, Up | a denizen of brushland and marginal areas and seldom ventures far from brushy cover; in central Texas, it commonly frequents brush-dotted pastures, the brushy edges of cultivated fields, and well-drained streamsides; occasionally, it inhabits poorly drained bottom lands with the swamp rabbit; in many places it is common along country roads, especially where the sides are grown up to dense vegetation and adjoining areas are heavily grazed or farmed | |
| Leporidae (hares and rabbits) | Black-tailed Jackrabbit (*Lepus californicus*) | E TB | B, R, **U**, I, Rg, S, **T**, **Up** | denizen of the hot, dry, desert scrubland; it occupies a latitudinal range from sea level to well over 2,500 m on the southwest slopes of some of the desert mountains but seldom inhabits coniferous forests (pinyon pine and juniper areas excepted), although occasionally it may stray into them; because of a preference for sparsely vegetated areas, this species often concentrates in pastures overgrazed by livestock, further depleting the vegetation | |
| **Rodentia** | | | | | |
| Sciuridae (squirrels and allies) | Texas Antelope Squirrel (*Ammospermophilus interpres*) | TB | I, **Rg**, S, Up | live chiefly around the edges of the lower valleys and in the low hills. They seem live chiefly around the edges of the lower valleys and in the low hills. They seem to prefer hard-surfaced, gravelly washes or rocky hill slopes and are less common or entirely absent on level, sandy terrain entirely absent on level, sandy terrain | |
| Sciuridae (squirrels and allies) | Mexican Ground Squirrel (*Spermophilus mexicanus*) | E TB | B, R, **U**, I, Rg, S, **T**, Up | inhabit brushy or grassy areas; in southern Texas, they are frequently associated with mesquite and cactus flats; in Kerr County, they are most common in pastures and along the highways; in Trans-Pecos Texas, they are frequently found in areas dominated by creosote-bush (Larrea) | |
| Sciuridae (squirrels and allies) | Spotted Ground Squirrel (*Spermophilus spilosoma*) | TB | I, Rg, S, T, Up | prefer dry, sandy areas, but they are also found in grassy parks, open pine forests, scattered brush, and occasionally on rocky mesas | |
| Sciuridae (squirrels and allies) | Rock Squirrel (*Spermophilus variegatus*) | E TB | **B**, **R**, **U**, I, **Rg**, **S**, T, Up | nearly always found in rocky areas — cliffs, canyon walls, talus slopes, boulder piles, fills along highways, and so forth — where they seek refuge and have their dens | |
| Sciuridae (squirrels and allies) | Black-tailed Prairie Dog (*Cynomys ludovicianus*) | E TB | B, I, Rg, **S**, **T**, **Up** | typically inhabit short-grass prairies; they usually avoid areas of heavy brush and tall grass, possibly because visibility is considerably reduced. In Trans-Pecos Texas, favored habitat sites are alluvial fans at the mouths of draws, "hard pan" flats where brush is sparse or absent, and the edges of shallow valleys | |

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| Sciuridae<br>(squirrels and allies) | Eastern Fox Squirrel<br>(*Sciurus niger*) | E<br>TB | **B**, R, **U**,<br>I, S, **T** | Along the western parts of their range, fox squirrels are restricted more or less to river valleys which support pecans, walnuts, oaks, and other "required" trees | G |
| Geomyidae<br>(pocket gophers) | Botta's Pocket Gopher<br>(*Thomomys bottae*) | E<br>TB | B, R, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | occur in soils ranging from loose sands and silts to tight clays and in vegetative zones grading from dry deserts to montane meadows | |
| Geomyidae<br>(pocket gophers) | Attwater's Pocket Gopher<br>(*Geomys attwateri*) | E | B | typically inhabits sandy soils where the topsoil is 10 cm or more in depth; clayey soils are usually avoided | |
| Geomyidae<br>(pocket gophers) | Plains Pocket Gopher<br>(*Geomys bursarius*) | TB | I, **T** | typically inhabits sandy soils where the topsoil is 10 cm or more in depth; clayey soils are usually avoided | |
| Geomyidae<br>(pocket gophers) | Llano Pocket Gopher<br>(*Geomys texensis*) | E | B, **U** | typically inhabits sandy soils where the topsoil is 10 cm or more in depth; clayey soils are usually avoided | |
| Geomyidae<br>(pocket gophers) | Yellow-faced Pocket Gopher<br>(*Cratogeomys castanops*) | TB | **I**, **Rg**, S, T, **Up** | partial to deep, mellow soils that are relatively free from rocks | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Merriam's Pocket Mouse<br>(*Perognathus merriami*) | E<br>TB | **B**, **R**, U,<br>I, Rg, S, **T**, Up | most common on sandy soils where vegetation is sparse or at least short | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Hispid Pocket Mouse<br>(*Chaetodipus hispidus*) | E<br>TB | B, R, **U**,<br>I, **Rg**, S, **T**, Up | prefer areas of sand or other friable soil covered with scattered to moderate stands of herbaceous vegetation; the margins of brush fields and the rank growth in fence rows offer suitable cover | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Nelson's Pocket Mouse<br>( *Chaetodipus nelsoni*) | TB | Rg, **Up** | a rock-loving species | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Desert Pocket Mouse<br>(*Chaetodipus penicillatus*) | TB | Up | general occurs on sandy or soft alluvial soils along stream bottoms, desert washes, and valleys | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Merriam's Kangaroo Rat<br>(*Dipodomys merriami*) | TB | I, **Rg**, Up | can succeed equally well on sandy soils, clays, gravels, and even among rocks | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Ord's Kangaroo Rat<br>(*Dipodomys ordii*) | TB | I, Rg, S, T, **Up** | dwellers of wastelands where shifting sands constitute a conspicuous part of the landscape; they are one of the few pioneer mammals that move into shifting dunes and establish themselves with pioneer plants | |
| Heteromyidae<br>(pocket mice and kangaroo rats) | Banner-tailed Kangaroo Rat<br>(*Dipodomys spectabilis*) | TB | Rg, Up | limited in distribution to sparsely brush-covered slopes and low hills at elevations usually between 1,200 and 1,500 m | |
| Castoridae<br>(beavers) | American Beaver<br>(*Castor canadensis*) | E | B, R, U | essentially aquatic and require water in the form of a pond, stream, lake, or river for their well-being | |
| Muridae<br>(mice and rats) | Fulvous Harvest Mouse<br>(*Reithrodontomys fulvescens*) | E | B, R, U | occur chiefly in grassy or weedy areas dotted with shrubs, or in creek bottoms with their tangles of grasses, vines, and bushes | |

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| Muridae (mice and rats) | Plains Harvest Mouse (*Reithrodontomys montanus*) | E TB | B, R, U, I, S, **T**, Up | prefer climax, or nearly climax, well-drained grassland | |
| Muridae (mice and rats) | Texas Mouse (*Permyscus attwateri*) | E TB | **B**, R, **U**, I, Rg, S, **T**, Up | inhabits the cliffs and rocky outcrops; seem to prefer rocky areas where the dominant vegetation is juniper; a habitat generalist and may be found not only in areas of rock ledges and leaf litter but also more open, grassy areas with only scattered rock cover | |
| Muridae (mice and rats) | White-footed Mouse (*Peromyscus leucopus*) | E TB | B, R, **U**, **I**, Rg, S, T, Up | woodland dwellers; along the western border of their range they are restricted almost entirely to creek and river bottoms; they are adept at climbing and often den in hollow trees out of danger from overflow waters; in areas not subject to inundation, they live in dens under logs, in stumps, brush piles, burrows, or buildings | |
| Muridae (mice and rats) | Deer Mouse (*Peromyscus maniculatus*) | E TB | B, R, **U**, I, Rg, **S**, **T**, **Up** | usually inhabit grasslands or areas of open brush, especially where weeds and grasses offer concealment and a source of food; weed-choked fence rows and washes offer almost ideal habitat | |
| Muridae (mice and rats) | White-ankled Mouse *(Peromyscus pectoralis)* | E TB | **B**, **R**, **U**, I, Rg, S, **T**, **Up** | rock-dwelling species; they are associated with rocks in oak-juniper woodlands | |
| Muridae (mice and rats) | Northern Pygmy Mouse (*Baiomys taylori*) | E TB | **B**, R, **U**, I, Rg, **S**, T, Up | have a preference for grassy areas, and they are commonly found in old fields, pastures, and along railroad and highway rights-of-way; if other types of ground cover such as rocks, cactus, and fallen logs are available, the pygmy mouse may be found in areas where grass is relatively sparse | |
| Muridae (mice and rats) | Mearns' Grasshopper Mouse (*Onychomys arenicola*) | TB | Rg, Up | chiefly inhabits the low, arid, sandy or gravelly desert areas where vegetation in the form of creosote bush, mesquite, yucca, lechuguilla, condalia, and so forth is sparse and scattered | |
| Muridae (mice and rats) | Northern Grasshopper Mouse (*Onychomys leucogaster*) | TB | I, Rg, S, **T**, Up | occur chiefly in association with sandy or powdery soils in grasslands or open brushlands | |
| Muridae (mice and rats) | Hispid Cotton Rat (*Sigmodon hispidus*) | E TB | B, R, **U**, I, Rg, S, **T**, **Up** | inhabits tall-grass areas where such grasses as bluestem (Andropogon), cordgrass (Spartina), or sedges (Carex) offer both freedom of movement under a protective canopy and an adequate food supply; in western Texas, where grassy ground cover is not available, the rats live in dens at the bases of small, low clumps of mesquite in otherwise nearly barren terrain; preferred sites are old fields, natural prairie, unmolested rights-of-way for roads and railroads, and other places not subject to flooding and where the vegetation grows rank and tall | |

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| Muridae (mice and rats) | White-throated Woodrat (*Neotoma albigula*) | E TB | B, R, **U**, I, Rg, S, T, Up | characteristic of the brush lands of the southwestern deserts; the availability of such desert shrub vegetation as prickly pear, cholla cactus, mesquite, sotol, lechuguilla, and creosote bush which afford shelter for their houses, seems to affect their abundance more than the nature of the terrain; occasionally, their houses are built in the open or in sparse vegetation; in rocky situations the associated cracks and crevices afford the usual den site | |
| Muridae (mice and rats) | Eastern Woodrat (*Neotoma floridana*) | E | B, R | wide range encompassing habitats ranging from swamplands, forested uplands, to the arid plains; in central Texas, they frequently live in rocky canyon walls | |
| Muridae (mice and rats) | Southern Plains Woodrat (*Neotoma micropus*) | E TB | B, R, **U**, I, Rg, S, **T**, Up | characteristic of the brushlands in the semi-arid region between the timberlands and the arid deserts to the west; usually found associated with cactus or some of the thorny desert shrubs | |
| Muridae (mice and rats) | Norway Rat (*Rattus norvegicus*) | ? | ? | chiefly where vegetation is tall and rank and affords adequate protection | I |
| Muridae (mice and rats) | Roof Rat (*Rattus rattus*) | ? | ? | largely commensals and live in close association with man | I |
| Muridae (mice and rats) | House Mouse (*Mus musculus*) | ? | ? | may be found in fields, along watercourses, and in other places where vegetation is dense enough to afford concealment | I |
| Muridae (mice and rats) | Woodland Vole (*Microtus pinetorum*) | E | B | ccur largely in woodland areas where ground cover in the form of leaf litter and lodged grasses offers suitable protection | |
| Erethizontidae (New World porcupines) | Porcupine (*Erethizon dorsatum*) | E TB | B, R, U, I, Rg, S, T, Up | largely an inhabitant of forested areas in the West and prefers rocky areas, ridges, and slopes. It is less common in flats, valleys, and gulches | |
| Myocastoridae (myocastorids) | Nutria (*Myocastor coypus*) | E TB | **B**, **R**, **U**, I, Rg, **S**, T | prefer a semiaquatic existence in swamps, marshes, and along the shores of rivers and lakes | I |
| **Carnivora** | | | | | |
| Canidae (canids) | Coyote (*Canis latrans*) | E TB | B, R, **U**, **I**, **Rg**, S, **T**, **Up** | from sea level to well over 3,000 m and habitats ranging from desert scrub through grassland into the timbered sections of the West | |
| Canidae (canids) | Swift or Kit Fox (*Vulpes velox*) | TB | **I**, **Rg**, S, T, **Up** | generally live in the open desert or grasslands where they often have dens and hunt mesa country along the borders of valleys, sparsely vegetated habitats on sloping plains, hilltops, and other well-drained areas. Also, they have adapted to pasture, plowed fields, and fencerows | |
| Canidae (canids) | Red Fox (*Vulpes vulpes*) | E TB | B, **I**, **Rg**, S, **T**, **Up** | mixed woodland uplands interspersed with farms and pastures; the den is usually an underground burrow, a crevice in a rocky outcrop, or a cavity under boulders | I |

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|---|---|---|---|---|---|
| Canidae<br>(canids) | Common Gray Fox<br>(*Urocyon cineroargenteus*) | E<br>TB | B, R, U,<br>I, Rg, S, **T**, Up | essentially an inhabitant of wooded areas, particularly mixed hardwood forests. It is common throughout the wooded sections east of the shortgrass plains and in the pinyon-juniper community above the low lying deserts | |
| Procyonidae<br>(procyonids) | Ringtail<br>(*Bassariscus astutus*) | E<br>TB | B, R, **U**,<br>I, Rg, S, **T**, Up | live in a variety of habitats within their range, but they have a decided preference for rocky areas such as rock piles, stone fences, canyon walls, and talus slopes; they occur less commonly in woodland areas where they live in hollow trees and logs, and they are also known to live in buildings | |
| Procyonidae<br>(procyonids) | Common Raccoon<br>(*Procyon lotor*) | E<br>TB | B, R, U,<br>**I**, Rg, S, **T**, **Up** | primarily inhabitants of broadleaf woodlands, although they are rather common in the mixed-pine forests of southeastern Texas; they seldom occur far from water, which seems to have more influence on their distribution than does any particular type of vegetation | |
| Procyonidae<br>(procyonids) | White-nosed Coati<br>(*Nasua narica*) | E | B, R, **U** | spend considerable time on the ground, but they climb trees; they also occur in some of the rocky canyons that enter the mountains from the lowlands | ST |
| Mustelidae<br>(mustelids) | Long-tailed Weasel<br>(*Mustela frenata*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | occupy a variety of habitats in Texas. In general, they occupy a range nearly coextensive with the ranges of pocket gophers and ground squirrels on which they prey in large measure | |
| Mustelidae<br>(mustelids) | Mink<br>(*Mustela vison*) | E | B | closely associated with the waterways and lakes of North America, but the smaller streams are preferred to the large, broad rivers; they are most common along streams partly choked by windfalls and other debris which create numerous water holes and at the same time offer concealment | |
| Mustelidae<br>(mustelids) | American Badger<br>(*Taxidea taxus*) | E<br>TB | B, R, **U**,<br>I, **Rg**, **S**, **T**, **Up** | occupy a variety of habitats; most common in the prairie and desert sections of the West, but limited numbers venture into the mountains; in general, they occupy the entire range inhabited by ground squirrels and prairie dogs general, they occupy the entire range inhabited by ground squirrels and prairie dogs | |
| Mustelidae<br>(mustelids) | Western Spotted Skunk<br>(*Spilogale gracilis*) | E<br>TB | B, R, **U**,<br>I, Rg, S, T, Up | variety of habitats and often occurs in close association with man; most records of capture indicate that it is most often associated with rocky bluffs, cliffs, and brush-bordered canyon streams or stream beds. In the Edwards Plateau, rock fences seem to be especially attractive | |

| | | | | | |
|---|---|---|---|---|---|
| Mustelidae<br>(mustelids) | Eastern Spotted Skunk<br>(*Spilogale putorius*) | E | B | occur largely in wooded areas and tall-grass prairies, preferring rocky canyons and outcrops when such sites are available; they are less common in the short-grass plains; in areas where common, they have a tendency to live around farmyards and often den under or in buildings | |
| Mustelidae<br>(mustelids) | Striped Skunk<br>(*Mephitis mephitis*) | E<br>TB | B, R, U,<br>**I**, **Rg**, S, **T**, Up | inhabitants of wooded or brushy areas and their associated farmlands; rocky defiles and outcrops are favored refuge sites, but when these are absent the skunks seek out the burrows of armadillos, foxes, and other animals; in central Texas, favored refuge sites are under large boulders | |
| Mustelidae<br>(mustelids) | Common Hog-nosed Skunk<br>(*Conepatus mesoleucus*) | E<br>TB | B, R, **U**,<br>I, Rg, S, **T**, Up | inhabit mainly the foothills and partly timbered or brushy sections of their general range; the largest populations occur in rocky, sparsely timbered areas | |
| Felidae<br>(cats) | Mountain Lion<br>(*Felis concolor*) | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | chief range preferences are rocky, precipitous canyons, escarpments, rimrocks or, in the absence of these, dense brush | |
| Felidae<br>(cats) | Ocelot<br>(*Felis pardalis*) | E | **B**, R, U | dense, almost impenetrable chaparral thickets | SE, FE |
| Felidae<br>(cats) | Bobcat<br>(*Lynx rufus*) | E<br>TB | **B**, **R**, **U**,<br>**I**, **Rg**, **S**, **T**, **Up** | have a decided preference for rocky canyons or outcrops when such are available; in rockless areas they resort to thickets for protection and den sites; they are associated more commonly with pinyon pines, junipers, oak, or chaparral in Texas but they also occur in small numbers in open pine forests | |
| **Artiodactyla** | | | | | |
| Suidae<br>(pigs) | Feral Pig<br>(*Sus Scrofa*) | ? | ? | diverse forests with some openings; the presence of a good litter layer to support soil invertebrates and/or the presence of ground vegetation affording green forage, roots, and tubers is desirable | I |
| Dicotylidae<br>(peccaries) | Collared Peccary<br>(*Tayassu tajacu*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | occupy the brushy semidesert where prickly pear is a conspicuous part of the flora; they are commonly found in dense thickets of prickly pear, chaparral, scrub oak, or guajillo; also in rocky canyons where caverns and hollows afford protection and in barren wastelands | G |
| Cervidae<br>(cervids) | Axis Deer<br>(*Cervus axis*) | ? | ? | inhabitants of secondary forest lands broken here and there by glades, with an understory of grasses, forbs, and tender shoots which supply adequate drinking water and shade | I |

| | | | | | |
|---|---|---|---|---|---|
| Cervidae (cervids) | Fallow Deer (*Cervus dama*) | ? | ? | do much of their feeding in open, grassy areas but require tree cover and undergrowth for shelter and winter food; deciduous or mixed woodlands on gently rolling terrain are best, but conifer forests may be suitable in some places; the Edwards Plateau region, with its mosaic of oak mottes, juniper brushland, and grassy areas is well-suited | I |
| Cervidae (cervids) | Sika Deer (*Cervus nippon*) | ? | ? | characteristic of broad-leaved and mixed forests where snowfall does not exceed 10-20 cm and snow-free sites are also available; large forest tracts with dense understory and occasional clearings are ideal; the patchwork of brush cover and open grassland found in the Edwards Plateau and South Texas regions are well-suited | I |
| Cervidae (cervids) | Mule Deer (*Odocoileus hemionus*) | TB | Rg, Up | prefer the more arid, open situations in which sagebrush, juniper, pinyon pine, yellow pine, bitter brush, mountain mahogany, and such plants predominate; in western Texas, rocky hillsides covered with lechuguilla, sotol, juniper, and pinyon pine provide the essentials | G |
| Cervidae (cervids) | White-tailed Deer (*Odocoileus verginianus*) | E<br>TB | B, R, U,<br>I, Rg, S, T, Up | occur almost entirely in the hardwood areas within their general range | G |
| Antilocapridae (pronghorn) | Pronghorn (*Antilocapra americana*) | TB | I, Rg, Up | inhabits areas where both its sight and its running will be unimpaired by woodland vegetation; water in the immediate vicinity is not a requisite because the pronghorn is so adapted physiologically that it can go for long periods without drinking | G |
| Bovidae (bovids) | Barbary Sheep (*Ammotragus lervia*) | ? | ? | adapted to a dry, rough, barren, and waterless habitat | I |

[1]E=Edward's (Bandera, Real, and Uvalde counties), TB=Twin Buttes (Irion, Reagan, Schleicher, Tom Green, and Upton counties). ?=distribution not listed.

[2] B=Bandera, I=Irion, R=Real, Rg=Reagan, S=Schleicher, T=Tom Green, Up=Upton, U=Uvalde. Counties indicated with normal font are within the general range (distribution based
on known county records). Counties indicated in bold font have a verified occurrence. ?=distribution not listed.

[3]FE=federally endangered, FT=federally threatened, I=introduced, G=game, PDL=proposed de-listing, PT=proposed threatened, SE=state endangered, ST=State Threatened,

## Appendix F: Aquatic Community Sampling Field Data

[This appendix contains original data too large to be delivered using PDF format]

## Appendix G: Fish Species and Abundance Sample Number

[This appendix contains original data too large to be delivered using PDF format]

## Appendix H: Aquatic Macro Invertebrata Taxa

[This appendix contains original data too large to be delivered using PDF format]

## Appendix I: Values for IBI scores and proportional landcover by categories for sub-basins under scenario IV.

| Sub-basin Number | Calculated IBI Score (Complete Model) | Calculated IBI Score (Two Factor Model) | Min IBI Score | Mean IBI Score | Cedar | Mesquite | Mixed | Oak | Pasture | Urban | Cropland |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010301 | 67 | 63 | 60 | 76 | 0.1313 | 0.0162 | 0.1986 | 0.1195 | 0.0052 | 0.0000 | 0.0030 |
| 2010401 | 62 | 60 | 60 | 60 | 0.1668 | 0.0152 | 0.2056 | 0.1254 | 0.0068 | 0.0000 | 0.0013 |
| 2010501 | 71 | 68 | 53 | 68 | 0.0863 | 0.0175 | 0.1807 | 0.0998 | 0.0048 | 0.0000 | 0.0028 |
| 2010601 | 68 | 64 | 53 | 64 | 0.1237 | 0.0161 | 0.1954 | 0.1186 | 0.0062 | 0.0000 | 0.0045 |
| 2020201 | 70 | 68 | 66 | 66 | 0.0767 | 0.0184 | 0.1617 | 0.0936 | 0.0069 | 0.0000 | 0.0063 |
| 2020303 | 71 | 68 | 72 | 79 | 0.0743 | 0.0226 | 0.1654 | 0.0941 | 0.0091 | 0.0000 | 0.0104 |
| 6010101 | 71 | 71 | 77 | 77 | 0.0494 | 0.0160 | 0.1739 | 0.0678 | 0.0031 | 0.0000 | 0.0000 |
| 6010301 | 64 | 65 | 34 | 63 | 0.1127 | 0.0153 | 0.2049 | 0.0840 | 0.0065 | 0.0000 | 0.0000 |
| 6010501 | 63 | 63 | 37 | 61 | 0.1459 | 0.0082 | 0.2558 | 0.1038 | 0.0094 | 0.0000 | 0.0000 |
| 6010503 | 71 | 65 | 39 | 61 | 0.1164 | 0.0089 | 0.2248 | 0.1156 | 0.0089 | 0.0000 | 0.0000 |
| 6010801 | 76 | 69 | 70 | 75 | 0.0763 | 0.0138 | 0.2259 | 0.1063 | 0.0077 | 0.0000 | 0.0030 |
| 6060101 | 61 | 60 | 40 | 65 | 0.1739 | 0.0118 | 0.2224 | 0.1232 | 0.0081 | 0.0000 | 0.0000 |
| 6060201 | 60 | 59 | 52 | 62 | 0.1789 | 0.0097 | 0.2420 | 0.1170 | 0.0138 | 0.0000 | 0.0000 |
| 6060301 | 65 | 69 | 51 | 61 | 0.0775 | 0.0130 | 0.1840 | 0.0899 | 0.0085 | 0.0000 | 0.0276 |
| 6060501 | 59 | 72 | 56 | 59 | 0.0387 | 0.0230 | 0.1621 | 0.0695 | 0.0052 | 0.0000 | 0.0610 |
| 7060105 | 56 | 60 | 37 | 59 | 0.1722 | 0.0107 | 0.1856 | 0.1061 | 0.0060 | 0.0000 | 0.0000 |
| MC 25 | 47 | 54 | 12 | 40 | 0.1483 | 0.1218 | 0.0139 | 0.0089 | 0.0075 | 0.0047 | 0.0152 |
| MC 27 | 45 | 53 | 39 | 60 | 0.1510 | 0.1335 | 0.0157 | 0.0134 | 0.0075 | 0.0021 | 0.0110 |
| SC 16 | 64 | 55 | 52 | 71 | 0.0967 | 0.1772 | 0.0199 | 0.0298 | 0.0382 | 0.0011 | 0.0315 |
| SD 13 | 54 | 51 | 32 | 43 | 0.1358 | 0.1720 | 0.0212 | 0.0312 | 0.0041 | 0.0000 | 0.0019 |
| SD 15 | 50 | 57 | 0 | 44 | 0.1276 | 0.1029 | 0.0151 | 0.0230 | 0.0420 | 0.0000 | 0.0279 |
| SD 21 | 66 | 58 | 56 | 66 | 0.1179 | 0.0989 | 0.0200 | 0.0129 | 0.0141 | 0.0173 | 0.0433 |

## Appendix I. Values for IBI scores and proportional landcover by categories for sub-basins under scenario V.

| Sub-basin Number | Calculated IBI Score (Complete Model) | Calculated IBI Score (Two Factor Model) | Min IBI Score | Mean IBI Score | Cedar | Mesquite | Mixed | Oak | Pasture | Urban | Cropland |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010301 | 76 | 62 | 60 | 76 | 0.1408 | 0.0233 | 0.2529 | 0.1622 | 0.0052 | 0.0000 | 0.0030 |
| 2010401 | 69 | 59 | 60 | 60 | 0.1741 | 0.0205 | 0.2445 | 0.1580 | 0.0068 | 0.0000 | 0.0013 |
| 2010501 | 81 | 66 | 53 | 68 | 0.0993 | 0.0281 | 0.2668 | 0.1434 | 0.0048 | 0.0000 | 0.0028 |
| 2010601 | 78 | 63 | 53 | 64 | 0.1341 | 0.0237 | 0.2518 | 0.1671 | 0.0062 | 0.0000 | 0.0045 |
| 2020201 | 81 | 65 | 66 | 66 | 0.0977 | 0.0330 | 0.2534 | 0.1427 | 0.0069 | 0.0000 | 0.0063 |
| 2020303 | 81 | 65 | 72 | 79 | 0.0932 | 0.0379 | 0.2475 | 0.1430 | 0.0091 | 0.0000 | 0.0104 |
| 6010101 | 82 | 68 | 77 | 77 | 0.0672 | 0.0306 | 0.3126 | 0.1096 | 0.0031 | 0.0000 | 0.0000 |
| 6010301 | 75 | 64 | 34 | 63 | 0.1196 | 0.0210 | 0.2856 | 0.1263 | 0.0065 | 0.0000 | 0.0000 |
| 6010501 | 70 | 62 | 37 | 61 | 0.1503 | 0.0128 | 0.2924 | 0.1335 | 0.0094 | 0.0000 | 0.0000 |
| 6010503 | 79 | 64 | 39 | 61 | 0.1237 | 0.0148 | 0.2775 | 0.1528 | 0.0089 | 0.0000 | 0.0000 |
| 6010801 | 85 | 67 | 70 | 75 | 0.0858 | 0.0227 | 0.2960 | 0.1454 | 0.0077 | 0.0000 | 0.0030 |
| 6060101 | 67 | 59 | 40 | 65 | 0.1793 | 0.0158 | 0.2561 | 0.1512 | 0.0081 | 0.0000 | 0.0000 |
| 6060201 | 68 | 59 | 52 | 62 | 0.1821 | 0.0125 | 0.2674 | 0.1484 | 0.0138 | 0.0000 | 0.0000 |
| 6060301 | 73 | 66 | 51 | 61 | 0.0917 | 0.0258 | 0.2766 | 0.1229 | 0.0085 | 0.0000 | 0.0276 |
| 6060501 | 69 | 68 | 56 | 59 | 0.0565 | 0.0486 | 0.2613 | 0.1075 | 0.0052 | 0.0000 | 0.0610 |
| 7060105 | 67 | 59 | 37 | 59 | 0.1806 | 0.0191 | 0.2334 | 0.1566 | 0.0060 | 0.0000 | 0.0000 |
| MC 25 | 16 | 36 | 12 | 40 | 0.3211 | 0.1391 | 0.0514 | 0.0097 | 0.0075 | 0.0047 | 0.0152 |
| MC 27 | 17 | 36 | 39 | 60 | 0.3099 | 0.1511 | 0.0523 | 0.0134 | 0.0075 | 0.0021 | 0.0110 |
| SC 16 | 43 | 39 | 52 | 71 | 0.2282 | 0.2190 | 0.0480 | 0.0307 | 0.0382 | 0.0011 | 0.0315 |
| SD 13 | 28 | 36 | 32 | 43 | 0.2835 | 0.1942 | 0.0516 | 0.0320 | 0.0041 | 0.0000 | 0.0019 |
| SD 15 | 19 | 39 | 0 | 44 | 0.3045 | 0.1225 | 0.0506 | 0.0237 | 0.0420 | 0.0000 | 0.0279 |
| SD 21 | 41 | 41 | 56 | 66 | 0.2704 | 0.1355 | 0.0618 | 0.0129 | 0.0141 | 0.0173 | 0.0433 |