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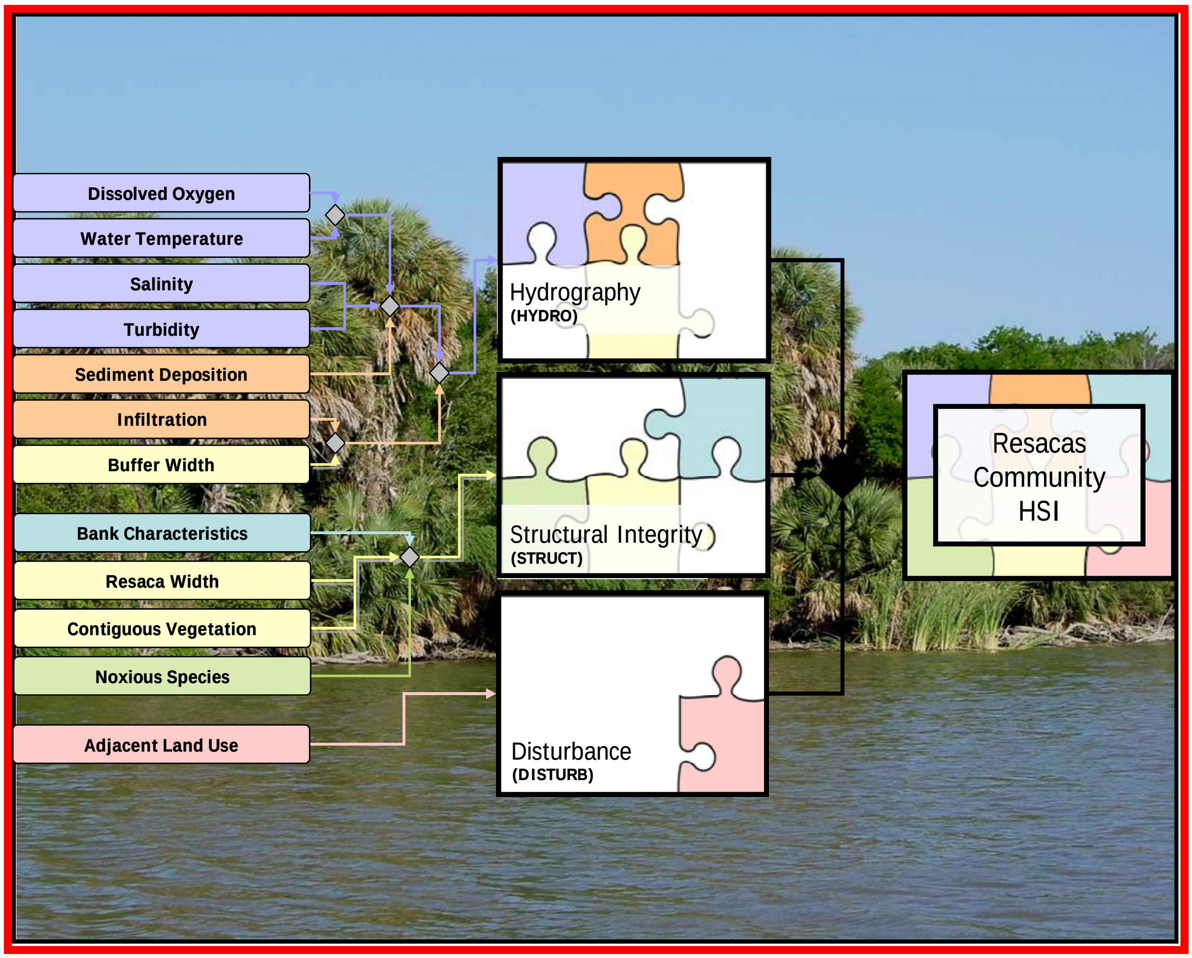
System-Wide Water Resources Program

A Community-based Ecosystem Response Model for the Resacas (Oxbow Lakes) of the Lower Rio Grande

Model Documentation

Kelly A. Burks-Copes and Antisa C. Webb

December 2012



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Kelly A. Burks-Copes and Antisa C. Webb

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 31980-6199

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Abstract

Over the last century, the Lower Rio Grande running through Brownsville, Texas has experienced significant anthropogenic pressures that, when combined with severe droughts of the last decade, have produced a highly degraded ecosystem that today is poised on the brink of collapse. In 1999, the U.S. Army Corps of Engineers (USACE) (Galveston District) was authorized to study the feasibility of providing improvements to the resacas (Spanish for oxbow lakes) near Brownsville, Texas in the interest of flood control, watershed management, environmental restoration and protection, and water quality. The District has been preparing an Environmental Assessment (EA) to evaluate the environmental benefits to ecosystem restoration efforts in the area. A multi-agency, multi-disciplinary evaluation team was convened to formulate alternatives that would improve, restore, and expand sustainable terrestrial and aquatic habitats in and around the existing Brownsville resacas ecosystems. Between 2004 and 2009, this team designed, calibrated, and applied a community-based index model for the Brownsville resaca ecosystems using field and spatial data gathered from 111 reference sample sites scattered across the watershed. This unique community was modeled by combining 13 individual variables into numerous predictive community functional components capable of capturing the changes to ecosystem integrity in response to changes in land and water management activities. This document provides the scientific basis upon which the model was developed, and describes the 6-year process the team undertook to complete this effort. Application of this model to the City of Brownsville Resacas Ecosystem Restoration project is discussed in a second report (Burks-Copes and Webb, in preparation).

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Preface

This report documents a newly developed community-based Habitat Suitability Index (HSI) model [using standard Habitat Evaluation Procedures (HEP) protocols] for resaca (oxbow lake) communities within the South Laguna Madre watershed of Cameron County, Brownsville, Texas.

The work described herein was conducted at the request of the U.S. Army Engineer District, Galveston, Texas. This report was prepared by Kelly A. Burks-Copes and Antisa C. Webb, U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, Mississippi. At the time of this report, Burks-Copes and Webb were ecologists in the Ecological Resources Branch, EL.

Many people contributed to the overall success of the production of the model documentation. The authors wish to thank the following people for their hard work and persistence during the intensive months over which the project was assessed: Jennifer Emerson (Bowhead Information Technology Services), Andrea Catanzaro, Seth Jones, and Steve Ireland (USACE, Galveston District). We also thank Dr. Andy Casper and Marie Perkins (ERDC-EL) for their comprehensive review of the report.

This report was prepared under the general supervision of Antisa C. Webb, Chief, Ecological Resources Branch, EL, and Dr. Edmond Russo, Chief, Ecosystem Evaluation and Engineering Division, EL. At the time of publication of this report, Dr. Beth Fleming was Director of EL.

COL Kevin J. Wilson was Commander of ERDC, and Dr. Jeffery P. Holland was Director of ERDC.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
square miles	2.589998 E+06	square meters

1 Introduction

The desiccated landscape of the Southwest brings to mind tumbleweeds blowing along dusty grounds, ancient petroglyphs carved in dark caves and canyon walls, cattle skulls blanching under the merciless sun, and sidewinders slithering between the cacti. But running through these harsh and arid region are ribbons of lush green narrow corridors where rivers and streams, some ephemeral, some continually flowing, have slaked the parched desert to give rise to rare yet significant riparian ecosystems rich with life (Figure 1).

Figure 1. The arid Southwest often appears to be a desolate landscape, yet the presence of water offers an opportunity for fish and wildlife to find a niche (photo from www.wanapiteicanoe.com/trips.asp?ID=39 MAY 2008).

While occupying a mere fraction of the land area, these wetlands support both the largest concentrations of animal and plant life, and the majority of species diversity in the desert Southwest (Johnson and Jones 1977, Johnson et al. 1985, Knopf et al.1988, Ohmart et al. 1988, Dahl 1990, Johnson 1991, Minckley and Brown 1994, Noss et al. 1995, American Bird Conservancy 2008) (Figure 2).

Figure 2. Wetlands immediately associated with rivers in the arid Southwest offer lush habitat for fish and wildlife species (picture taken at the Resaca de La Guerra near Brownsville, Texas in Cameron County).

Perhaps some of the more notable riparian ecosystems can be found along the Rio Grande. Arising in the San Juan Mountains of southwest Colorado, the river flows southwest through the middle of New Mexico and into Texas along the Texas-Mexico border emptying finally into the Gulf of Mexico. The Rio Grande offers some of the more ecologically complex, highly resilient, and culturally significant resources in the semi-arid western United States (Figure 3).

Study background

Over the last century, Texas has lost thousands of acres of historic wetlands, while human activities, including landscape alteration for agricultural, industrial, or urban uses, significantly threaten remaining wetland habitats [Texas Parks and Wildlife Department (TPWD) 2002]. The most important human-caused components of environmental change in Texas wetlands over the last 30 years have been forest and shrubland clearing, water diversion and flood control, human population increases, habitat fragmentation, and water quality degradation. In addition to human effects,

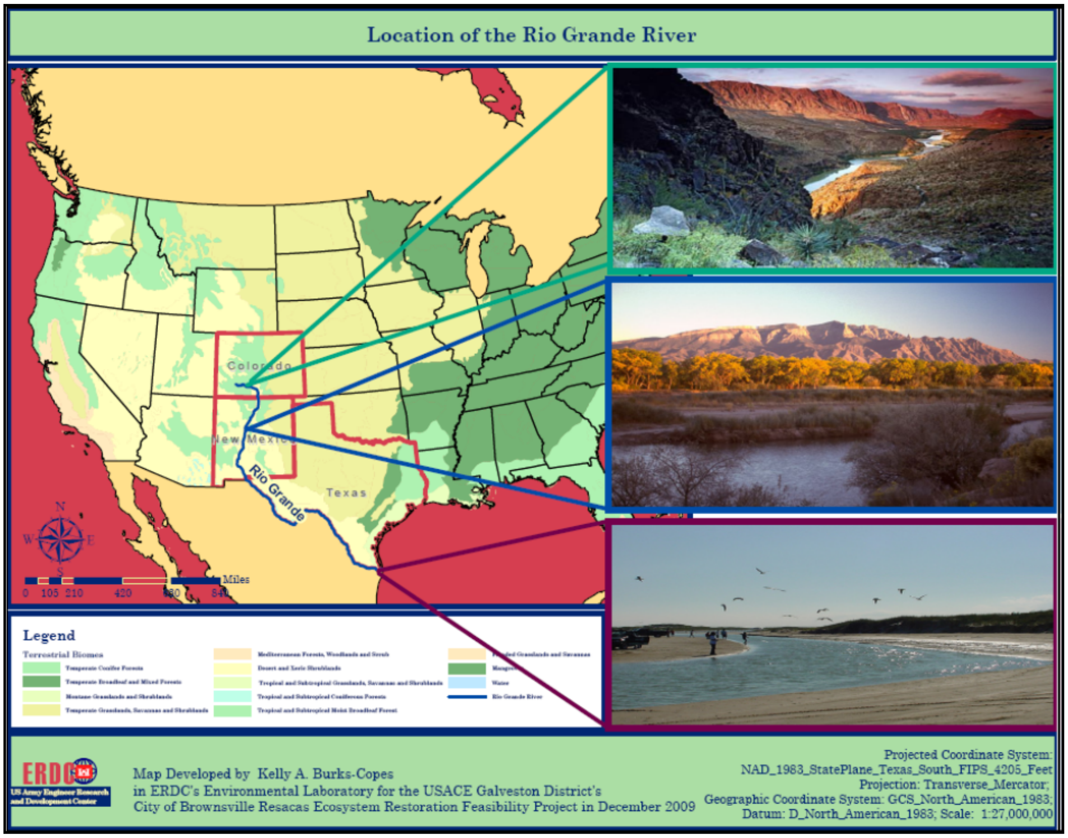


Figure 3. Location of the Rio Grande in the arid Southwest. Images capture the changing characteristics of the river as it flows from Colorado (top), through New Mexico (middle), and down into Texas (bottom) on its way to the Gulf of Mexico.

parts of the Rio Grande watershed have been in a severe drought since 1993, exacerbating water quantity and quality problems (Mac et al. 1998). Some of the more serious concerns facing the Lower Rio Grande Valley in general, and the Brownsville resaca (Spanish for oxbow lakes) ecosystems specifically, are listed below. Although concerns are presented in stand-alone sections, the activities described therein are inherently inter-related, and their effects on the resaca ecosystems are cumulative and synergistic.

Vegetative clearing

Over-harvesting of timber and clearing of lands for agricultural production threaten the shrubland and wooded wetlands, as is evidenced in the state's bottomland hardwoods, pine flatwoods, and swamp community declines in the last 100 years. In some areas of Cameron County, mixed native grasses, introduced grasses, and forbs can be found on previously disturbed sites. These grassland sites or mixed herbaceous communities established themselves as dominant vegetation in areas where native woody vegetation was removed (U.S. Army Corps of Engineers (USACE) 1998). One sobering reality is that an estimated 99% of the riparian vegetation along the U.S. side of the Rio Grande has been removed [U.S. Fish and Wildlife Service (USFWS) 1997].

Alteration of hydrologic regimes

Extensive water development projects along the Rio Grande have disrupted the natural flow and flooding regime of the Rio Grande (USACE 2003b). Numerous projects were constructed to provide flood protection and deliver water to agricultural and urban areas. The controlled flow of the river further encouraged the clearing of native vegetation (mentioned above) for croplands in the floodplain. Reservoir construction has submerged wetland areas upon filling, or destroyed wetlands by diverting or capturing their source of water. Changes in hydrologic flow and control (mentioned above) have in turn altered the riparian communities and wetlands present along the river (USACE 2003b). The natural riparian communities that once existed along the river have been partially replaced by drier upland species due to reduced number, duration, and magnitude of flooding events. Regulating flows and flooding events influences the vegetation as the availability of water and the characteristics of the soils change. For example, woody species such as cedar elm (*Ulmus crassifolia*) and Montezuma bald cypress (*Taxodium mucronatum*) are replaced by xeric (extremely dry) species such as mesquite (*Prosopis glandulosa*) when the frequency of flooding declines (Judd 1985; Jahrsdoerfer and Leslie 1988). Loss of the flood cycle has also been implicated in recent increases in nonindigenous species - native species are adapted to the periodic disruptions, which probably kept the nonindigenous species in check (Edwards and Contreras-Balderas 1991). Thus, changes in the vegetation composition of the region can be directly attributed to the flood and water control projects.

Changing land use practices and urban encroachment

The Texas Lower Rio Grande Valley is one of the nation's most important agricultural regions, producing fruit, vegetables, sugarcane, grain, cotton, and beef. Numerous changes to the natural communities within the valley are a continuing result of human encroachment. Extensive agriculture has fragmented and reduced the areal extent of native riparian ecosystems. Hidalgo and Cameron Counties are experiencing tremendous population growths that far exceed the state or national growth rates. Population growth and fragmentation, or the division of single ownership properties into two or more parcels, have had profound effects on the landscape. For example, Texas A&M's Fragmented Lands report found that the conversion of rural land to urban uses in Texas exceeded 2.6 million acres from 1982 to 1997 (Wilkins et al. 1998). While average ownership size seems to be closely related to the distribution of the state's population, the most recent fragmentation trends seem to be influenced more by ecological region. More people are buying land for its beauty and recreation value, including proximity to trees, water, rolling hills, and wildlife (Figure 4).

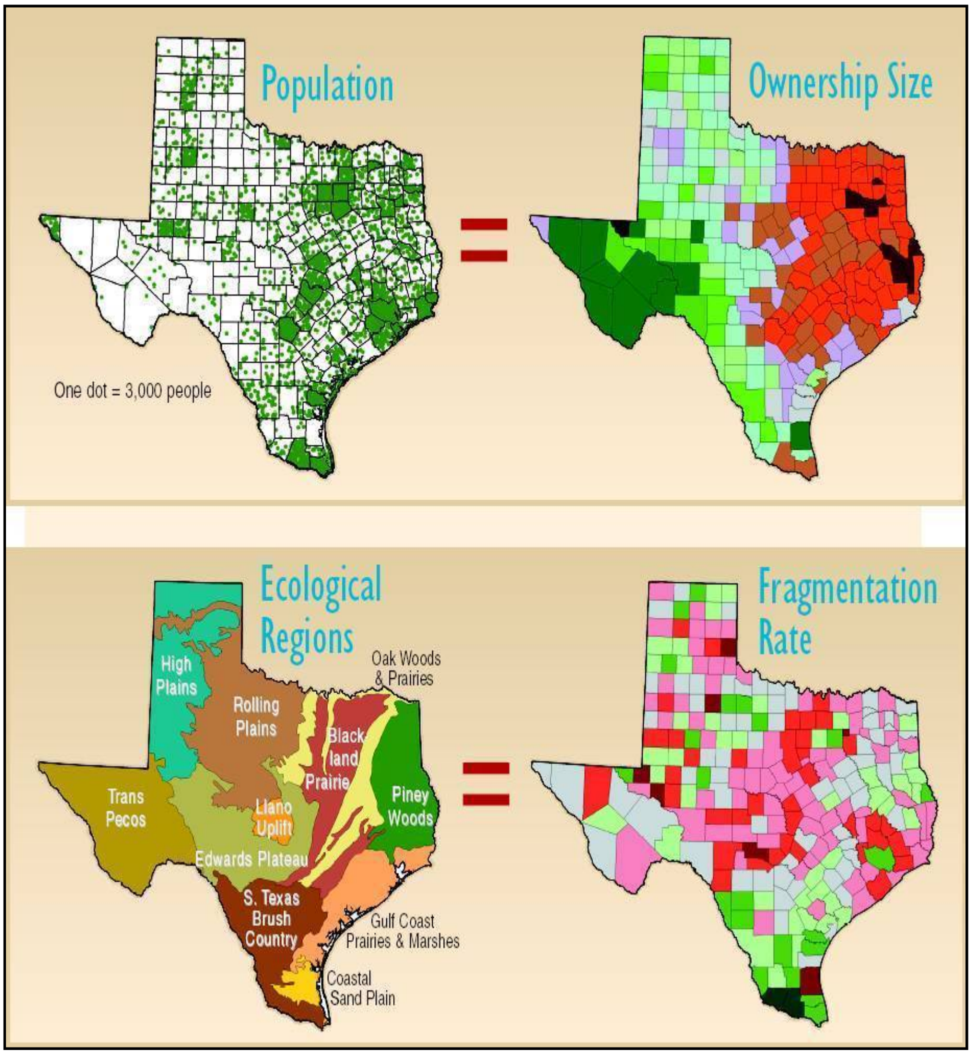


Figure 4. Population trends and their effects on fragmentation in Texas – darker areas are experiencing the highest levels of fragmentation across the state (Wilkins et al. 1998).

Such changes will increase pressures on natural resources throughout the state, especially near growing metropolitan areas. As the population expands, additional commercial, private, and public development is required to support these increases. Land conversions have changed natural habitats over the last 100 years, and now threaten the viability of critical riparian habitats such as the Brownsville resacas, thus threatening the sustainability of wildlife populations in these remnant communities.

Non-native invasions

Non-native plant and animal species introduced into the state have displaced native species, threatened habitat integrity, and have profoundly altered the landscape (TPWD 2002). As more persons populate the project area, more exotic species are brought to the area, some of which have the potential to escape into the wild communities and compete with native species. For example, Chinese tallow and Brazilian pepper-tree (exotic species planted by humans for ornamentation) have invaded woodlands and coastal prairies and, left unchecked, will change these diverse habitats into monocultures (Figure 5).

Figure 5. Chinese tallow (*Sapium sebiferum* L.) is a common and aggressive invasive species threatening the diversity of the resaca setting.[1]

Introduced grass species can create monocultures devoid of quality wildlife forage. For some ground-dwelling birds like quail, these dense turf-type grasses cannot be traversed, which fragments their habitats. Imported red fire ants in Texas have profound, but as yet not fully understood, adverse impacts on many wildlife species.

[1] Photo by James R. Allison found on the Georgia Department of Natural Resources website: http://www.invasivespecies.gov/profiles/chtallow.shtml

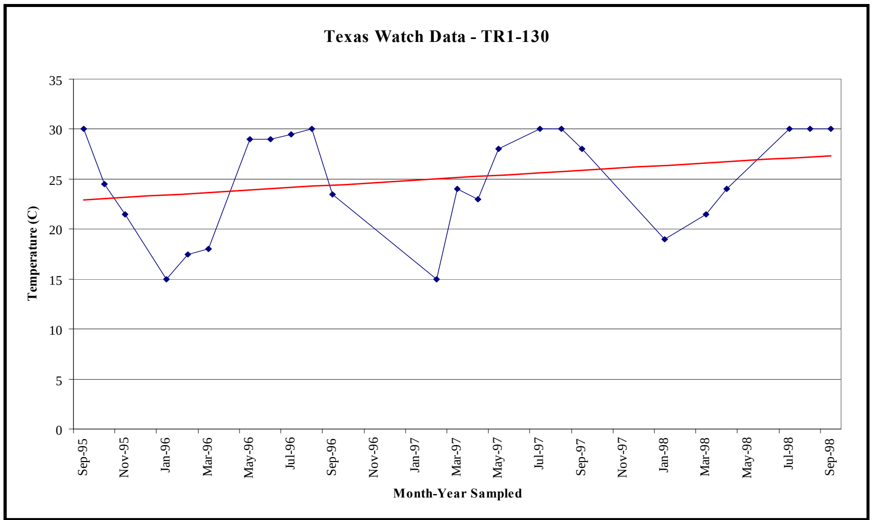
Water quality degradation

The value of the resacas is dependent upon their water quality and permanency. In most cases, water quality degradation within resaca ecosystems is a direct result of agricultural runoff and sewage releases during flood events (Ramirez 1986). Expanding human development and increased water consumption have been detrimental to these freshwater ecosystems and the plant and animal species they sustain. Decreased levels of dissolved oxygen, shallowing pools due to sedimentation (Figure 6), increasing temperatures (Figure 7), and increased salinity have all led to vast declines in water quality within the resacas.

Increasing demand for water

By 2050, almost 900 cities in Texas (representing 38% of the projected population) will need either to reduce water demand (through conservation and/or drought management) or develop additional sources of water beyond those currently available to meet their needs during droughts (Texas Water Development Board 2002). The water sources of the state (or cities or region) are currently unable to meet water demands during drought conditions by 2.4 million acre-feet per year (AFY) - and this is projected to increase to 7.5 million AFY by 2050. This includes water users who cannot rely on current sources because contracts expire during the planning period.

Figure 6. Sedimentation has become a significant problem for the Brownsville resaca ecosystems (October 2004 photo).



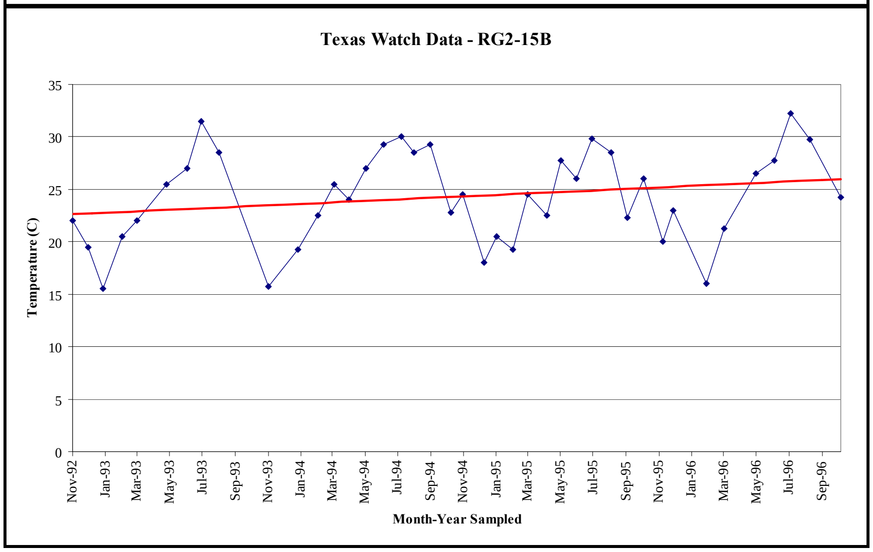


Figure 7. Temperatures have shown steady increases in the Town Resaca and Resaca de La Guerra pools over the past several years.[1]

Were a drought of record to occur today, 20% of irrigation demand could not be met by existing sources. Seven percent of municipal demand would not be met by existing sources if a drought were to occur now. However, if a drought were to occur in 2050, almost half (43%) of the municipal demand could not be satisfied by current sources. Similar percentages of water-dependent manufacturing and steam-electric power generation demands could not be met in 2050. While the exact consequences are impossible to specify, failure to meet these demands would have an unacceptable impact on the people and economy of Texas. The best response to this situation is a

[1] Data taken from the Texas Watch data set in March 2005 from the website: http://www.texaswatch.geo.swt.edu/Dataviewer.htm and personal communications with Kevin Bailey.

thoughtful, feasible, long-term plan for water supply acquisition and demand reduction.

Average per capita water use in Brownsville alone is 144 gal per person per day, while total daily use for the city is typically around 23 million gal.[1] The city's population growth is estimated at 2.5% annually, and the city has grown by 24.9% since 1984. Given its location, water conservation at a city-wide and individual level is needed to maintain and extend the water supply. The authority responsible for treating, supplying, and conserving the city's water is the Brownsville Public Utilities Board (BPUB). BPUB operates two water treatment plants, and can treat up to 40 million gal daily (this number increases to an excess of 47.5 million gal if the Southmost Regional Water Authority Project is included), but the water may not always be available. Brownsville presently has 29,285 AFY of water rights.

Feasibility project background

In response to these regional crises, the U.S. Army Corps of Engineers (Galveston District) was asked to address the feasibility of improving the resacas (oxbow lakes) in the vicinity of Brownsville, Texas in the interest of flood control, watershed management, environmental restoration and protection, and water quality (Figure 8).

In 2001, the Galveston District completed a Reconnaissance Report for the study area addressing these concerns and recommending a cost-shared feasibility study with the BPUB as the lead cost-sharing sponsor (USACE 2001). At present, the District is conducting a feasibility study of ecosystem restoration measures for Brownsville resacas (authorized under a Resolution of the Committee on Transportation and Infrastructure of the U.S. House of Representatives dated 10 November 1999). The District is preparing an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the environmental benefits to ecosystem restoration efforts in the Brownsville area (Texas).[2] The City of Brownsville Resacas Ecosystem Restoration Feasibility Study (Cameron County, Texas) is being conducted as a joint effort between the District and BPUB. The goal of the study is to identify and recommend an effective, affordable, and environmentally sensitive restoration project

[1] Personal Communication. March 30, 2005. E. Campirano, Brownsville Public Utilities Board, Brownsville, TX.

[2] For convenience, symbols and abbreviations are listed in the notation (Appendix A).

Figure 8. The Lower Rio Grande is diverted through a series of resacas (oxbow lakes) in the heart of Brownsville, Texas on its way south to the Gulf of Mexico.

for the Brownsville resacas system, and in turn, conduct the necessary engineering, economic, and environmental studies in a timely manner to establish a viable project that is acceptable to the public, local sponsors, and USACE. The study objectives include:

1. Restore fish and wildlife habitat within the resacas, given the urban environment context (i.e., the City of Brownsville, TX);
2. Enhance the city's ability to store and transport freshwater during drought or low-water events;
3. Improve water quality in the resacas within the city; and
4. Increase flood control and stormwater storage within the City of Brownsville.

The effort to date has involved, and will continue to involve, public communications and cooperation. Concurrently, the USFWS (Corpus Christi, Texas) has been asked to prepare a Fish and Wildlife Coordination Act Report (CAR) under the National Transfer Fund agreement.

Purpose of the model

Planning, management, and policy decisions require information on the status, condition, and trends of these complex ecosystems and their components at various scales (e.g. local, regional, watershed, and system levels) to make reasonable and informed decisions about the planning, management, and conservation of sensitive or valued resources. One well-accepted solution has been to develop index models that assess ecosystems at varying scales. By definition, index models are comprehensive, multi-scale, grounded in natural history, relevant and helpful, able to integrate terrestrial and aquatic environments, flexible and measurable (Andreasen et al. 2002). Determining the value of diverse biological resources in this study required a method that captured the complex biotic patterns of the landscape, rather than merely focusing on a single species habitat or suitability requirements within the study area. In effect, the Ecosystem Assessment Team (E-Team) made the decision to assess ecosystem benefits using a community-based (functional) model rather than employing a series of species- or guild-based models.

Ecosystem functions are defined here as a series of processes that take place within an ecosystem. These include the storage of water, transformation of nutrients, growth of living matter, and diversity of plants, and they have value for the community itself, for surrounding ecosystems, and for people. Functions can be grouped broadly as habitat, hydrology, water quality, and spatial integrity, although these distinctions are somewhat arbitrary and simplistic. For example, the value of a wetland for recreation (hunting, fishing, bird watching) is a product of all the processes that work together to create and maintain the ecosystem. Not all communities perform all functions nor do they perform all functions equally well. The location and size of a community may determine what functions it will perform. For example, the geographic location may determine its habitat functions, and the location of a community within a watershed may determine its hydrologic or water-quality functional capacity. Many factors determine how well a community will perform these functions: climatic conditions, quantity and quality of water entering the system, and disturbances or alteration within the community or the surrounding landscape. Disturbances may be the result of natural conditions, such as an extended drought, or human activities, such as land clearing, dredging, or the introduction of invasive species.

A community habitat suitability index model was developed that would allow its users to broadly capture existing (baseline) conditions of the communities, and compare changes that would occur to the resources present given different project scenarios or alternatives under the standard USACE planning paradigm (USACE 2000). The model was used to facilitate plan formulation based upon project benefits. The purpose of the model was not to exhaustively capture the full range of all chemical, physical, and biological characteristics of ecological resources within the project area, but to provide tools for assessing and comparing effects between potential plans in order to select plans with the least environmental impact or highest environmental benefit. Planning decisions for the feasibility study were subsequently made based on the results of the model applied within the well-received and respected Habitat Evaluation Procedures (HEP) (refer to the USFWS Ecological Services Manuals, USFWS 1980a, 1980b, 1980c) framework.[1]

Contribution to the planning effort

The HEP methodology helps to characterize the baseline conditions (in a quantitative manner) of the numerous ecological resources throughout the watershed. The method assisted the study team in the projection of change to fundamental ecosystem processes[2] (without which, ecosystem restoration itself could not happen), under proposed alternative scenarios. The study team designed the HEP assessments to evaluate the future changes in both quantity (acres) and quality (community habitat suitability and/or functional capacity) of aquatic, wetland, and terrestrial ecosystems simultaneously. Outputs were calculated in terms of annualized changes anticipated over the life of the project (i.e., period of analysis).

Transdisciplinary approach

A transdisciplinary approach was necessary to develop the model herein– one that involved both academic researchers from different unrelated disciplines as well as non-academics, such as land managers and stakeholders (Tress et al. 2005, Fry et al. 2007). This approach implies that practical experience garnered from professionals is as desirable as theoretical knowledge derived from academia. It is important to recognize

[1] A complete list of acronyms and a glossary have been provided in *Appendix A* and *Appendix B* of this report.

[2] There are four fundamental ecosystem processes – water cycling, mineral cycling, solar energy flow, and community dynamics (succession).

that this approach required the combination of interdisciplinary collaboration in an interactive, participatory forum. Thus, a transdisciplinary E-Team was convened early in the process.[1] Scientists from the U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL) facilitated the efforts. Representatives from the District, BPUB, Texas General Land Office (TGLO), Texas A&M University (TAMU), University of Texas Pan-American (UTPA), U.S. Fish and Wildlife Service (USFWS), Texas Parks and Wildlife Department (TPWD), and local consulting firms actively participated in the assessment process.

Planning at the landscape scale

It is important to note that the model herein was developed with an emphasis on evaluating landscape-level functionality. Ecology addresses the understanding of fundamental processes and the consequences of managing spatially and temporally homogeneous and heterogeneous geomorphic and living systems (Risser et al. 1983, page 7). One can develop models at the level of the individual, the population, the community, the ecosystem, or the landscape (referred to collectively as ecological sub-disciplines). Models of **individuals** are concerned mostly with physiology, reproduction, development or behavior, while studies of **populations** usually focus on the habitat and resource needs of individual species, their group behaviors, population growth, and what limits their abundance or causes extinction. Models of **communities** examine how populations of many species interact with one another, such as predators and their prey, or competitors that share common needs or resources. Models of **ecosystems** examine how the system operates as a whole rather than focusing on a particular species, emphasizing the functional aspects of the system (i.e., energy and material flows through trophic levels, decomposition, and nutrient cycling). Models of **landscapes** focus on the interaction between spatial configuration and ecological processes, examining the causes and consequences of spatial heterogeneity on a range of scales (Turner et al. 2001, and various authors therein). Although many definitions exist, the most comprehensive description of landscape ecology can be found in Risser et al. (1983), page 7:

> *Landscape ecology considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchanges across heterogeneous landscapes, influences of spatial*

[1] A list of E-Team participants can be found in *Appendix D*.

> *heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity.*

It is this focus on the "spatial" aspects of ecological interactions and broad spatial and temporal scales that distinguishes landscape-level ecological models from models generated by the other sub-disciplines. As such, landscape-level models emphasize the effects of spatial configuration and the mosaic on predation, dispersal, population dynamics, nutrient distribution, and disturbance. However, one other aspect of landscape ecology distinguishes it from the others – these models incorporate human influences (and their response to landscape change) into their constructs (Risser et al. (1983) and numerous others).

So how does this approach contribute to the USACE planning effort? USACE does much more than plan. It serves as a protector and steward of natural resources. USACE planners must therefore anticipate surprises. They must deal with crises and capitalize on change. As the USACE alters natural resources with improvements or withdrawals, they must maximize and optimize decisions based on project-specific planning objectives. Planners must determine the best place (and the undesirable places) to implement change that is consistent with these planning objectives. As such, a key challenge is to keep an eye on the "big picture."

The intent of landscape-scale index modeling is to characterize this "big picture." When comparing and contrasting these sub-disciplines, it is particularly useful to couch their distinctions in terms of application. If one were intent on using one of the sub-disciplines to characterize ecological integrity[1], and thus focus planning efforts on the recovery and conservation of ecological integrity, then Figure 9 offers some guidance on model development.

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[1] The authors subscribe to the Society for Ecological Restoration (SERI) (2004) definition of ecological integrity of an ecosystem (ecosystem integrity) here, which has been defined as "the state or condition of an ecosystem that displays the biodiversity characteristics of the reference, such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning." The authors expand upon this definition by including Dale and Beyeler's (2001) descriptions, which refer to "system wholeness, including the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes."

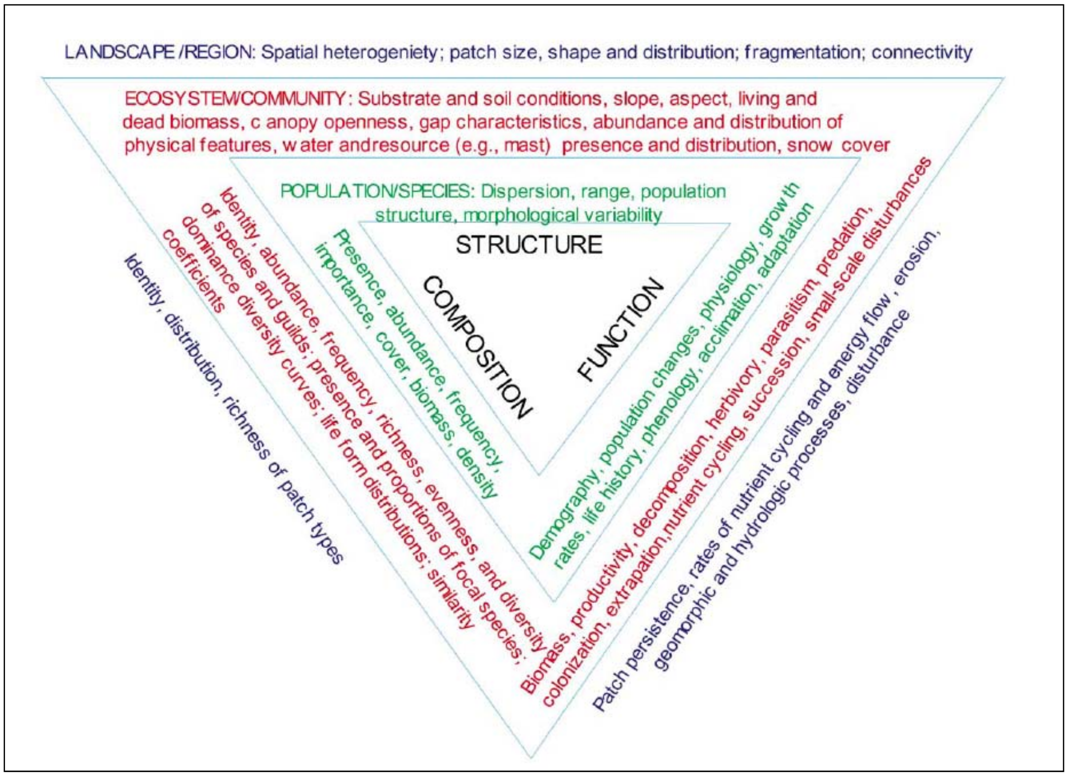

Figure 9. This diagram gives model developers direction in the selection and quantification of planning activities through the use of indicators of system composition, structure, and function (Dale and Beyeler (2001), adapted from Franklin (1988) and Noss (1990)).

These indicators (e.g., patch size, biomass, richness, etc.) can quantify the magnitude of stress, the degree of exposure to the stresses, and/or the degree of ecological response to the exposure. They are therefore intended to provide a simple and efficient method to examine the ecological composition, structure, and function of complex ecological systems to both assess baseline conditions and monitor trends in change over time (Dale and Beyeler 2001, page 4). Variables such as patch distribution, spatial heterogeneity, and disturbance all help to characterize the landscape effects of proposed planning alternatives on the system. Combining this information with data gathered at the species/population, community, and ecosystem levels offers a “unifying framework” for systematic recovery of ecological integrity.

With regards to planning and policy, the considerations fall largely upon the “scale” of the issues, and the tradeoff decisions regarding available resources. Where population/species or even community ecology sub-disciplines focus down at the patch level, landscape ecology hierarchically addresses issues of restoration and conservation at the broad scales of basins, watersheds, regions, and sometimes national perspectives. This perspective forces planners and policy-makers alike to shift their decision-making paradigms, looking beyond the traditional "individual site" conservation strategies to take note of configurations and processes occurring at much larger scales.

In order to capture the range of cumulative effects occurring at multiple scales across the entire watershed, the model developers chose to produce a community-based ecosystem response model enhanced with landscape-level sensitivities. Such a model must address planning activities formulated at the "alternative" level rather than at the feature, action, or treatment level (Figure 10).[1]

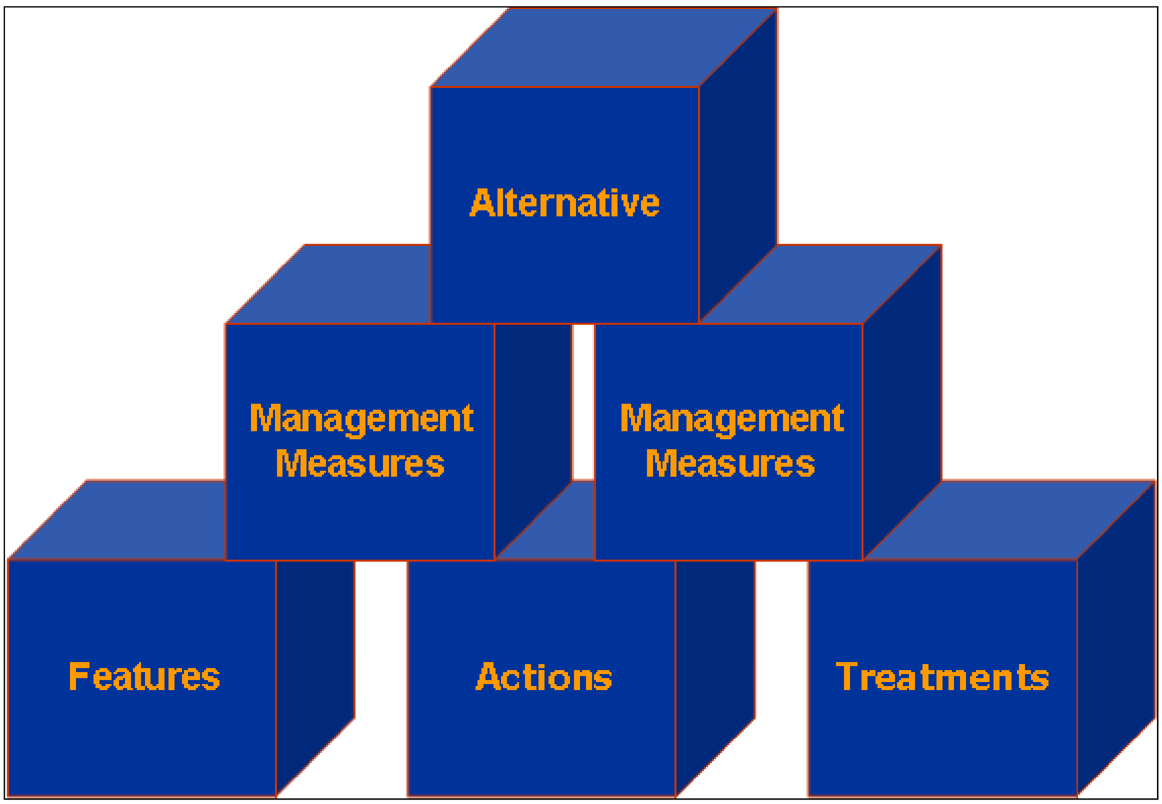

Figure 10. By definition, the community model was designed to assess alternatives, not individual features, actions, or treatments. The components of an alternative that may or may not be separable actions that can be taken to affect environmental variables and produce environmental outputs are often referred to as "management measures" in USACE planning studies. As such, management measures are typically made up of one or more features, activities, or treatments at a site.

It is the collective and/or cascading effects of the combination of management measures (comprised of features, actions, and/or treatments) that together generate watershed-responsive alternatives. The remainder of this

[1] For working definitions of these terms, please refer to *Appendix B, "Glossary"* in this report.

document focuses on the community-based Habitat Suitability Index (HSI) model developed by the E-Team to assess proposed planning alternatives applied at the landscape level.

Model objectives and independent measures of function (performance measures)

Given the model purpose described above, the following modeling objectives have been adopted:

1. Develop a quantifiable, community-based index model that can characterize the baseline conditions at the landscape level within the modeling domain on a scale of 0-1 with results that appear reasonable to the expert team.[1]
2. Develop a model with outputs that can distinguish the differences between high- and low-quality reference sites within the model's domain.[2]
3. Develop a model that can be easily used to compare proposed project plans.

According to ESM 103 (USFWS 1980c), model outputs must be directly linked to "performance measures" or independent measures of function. In modeling vernacular, this process is referred to as "validation." By definition, "validation" refers to independent data collections that could be compared to the model outcomes to determine whether the model is capturing the essence of the ecosystem's functionality. Two independent measures of function are proposed to meet the performance measure requirements of ESM 103:

1. A quantification of biodiversity (both ***species richness*** and/or ***diversity per acre***) could be used to validate the model's outcomes. It is important to note that a full validation of the model using a biodiversity assessment would require that a majority of the faunal groups present be surveyed (mammals, birds, fish, reptiles, amphibians, plants, and possibly even insects) as the model is capturing "community" rather than individual species requirements. Such an analysis would need to be conducted over a series of years to account for annual variations in

[1] Verbiage here was taken directly from ESM 103, page 3-3 (first bullet).

[2] Verbiage directly reflects ESM 103, page 3-3 (third bullet) and corresponds with the authors' definition of verification which is the comparison of the model output to data from well-known, published test cases to confirm that the algorithms and computer code accurately represent system dynamics.

climate, and would need to be conducted at the subdivision level to accurately characterize the landscape-level focus of the community modeled.[1]

2. Alternatively, since the diversity and structure (biotic integrity) of the system's vertebrate communities are assumed to vary consistently in response to complexity of vegetation structure, the presence of specific vegetative compositional elements (i.e., spatial heterogeneity and compositional diversity - i.e., biocomplexity) could serve as an indicator of interactive niche diversification and animal community diversity (Carey (2003) and references therein), thereby serving as an independent measure of function. Even when high levels of diversity are not critical for maintaining the resaca's ecosystem processes under constant or benign environmental conditions, it is nevertheless important to maintain a heterogeneous assemblage or "mosaic" of internally uniform elements or patches, such as blocks of forest, agricultural fields, and housing subdivisions. This "insurance hypothesis" (Yachi and Loreau 1999) and related hypotheses presented in Loreau et al. (2001) suggest that biocomplexity would provide the system an "insurance" or buffer, against environmental fluctuations - various species would respond to these fluctuations and diverse, yet stable communities would survive. A GIS analysis of landscape pattern complexity or niche diversity (number and variety of patches) would generate a ***degree of patch heterogeneity or mosaic juxtaposition per acre*** that could provide a landscape-level validation of the model's outcomes.

Planning model certification

As an aside, the USACE Planning Models Improvement Program (PMIP) was established to review, improve, and validate analytical tools and models for USACE Civil Works business programs. In May of 2005, the PMIP developed Engineer Circular (EC) 1105-2-407, "Planning Models Improvement Program: Model Certification" (USACE 2005). This EC requires the use of certified models for all planning activities. It tasks the Planning Centers of Expertise to evaluate the technical soundness of all

[1] Subdivisions, by definition in this study, are smaller planning units or subsets of the individual resacas within the study area (namely Resaca de La Guerra, Town Resaca, and Resaca del Rancho Viejo). For planning purposes, each resaca was divided into three "subdivisions" based on a specific series of operation criteria including the degree of human disturbance, land use, resaca morphology (resaca width, bank characteristics, flow patterns, and water depth) as well as current flow control/pumping stations to delineate unique resaca conditions across the watershed. More information regarding the individual subdivisions can be found later in this report (see Figure 38 and accompanying text).

planning models based on theory and computational correctness. EC 1105-2-407 defines planning models as,

> *. . any models and analytical tools that planners use to define water resources management problems and opportunities, to formulate potential alternatives to address the problems and take advantage of the opportunities, to evaluate potential effects of alternatives and to support decision-making.*

Clearly, the community-based HSI model presented here must be either certified or approved for one-time use - the Galveston District has initiated this activity. Information necessary to address the model's review has been outlined in Table 2 of EC 1105-2-407 (pages 9-11). To assist the reviewers in this process, the authors have developed an appendix to crosswalk the EC checklist requirements and this report (Appendix C).

For purposes of model certification, it is important to note that the model must be either formally certified or approved for one-time use. However, the methodology under which it is applied (i.e., HEP) does not require certification, as it is considered part of the application process. HEP in particular has been specifically addressed in the EC:

> *The Habitat Evaluation Procedures (HEP) is an established approach to assessment of natural resources, developed by the US Fish and Wildlife Service in conjunction with other agencies. The HEP approach has been well documented and is approved for use in Corps projects as an assessment framework that combines resource quality and quantity over time, and is appropriate throughout the United States (refer to Attachment 3, page 22, of the EC).*

The authors used the newly developed **Habitat Evaluation and Assessment Tools (HEAT)** (Burks-Copes et al., in preparation (a)) to automate the calculation of habitat units for the study. This software is not a "shortcut" to HEP modeling, or a model in and of itself, but rather a series of computer-based programming modules that accept the input of mathematical details and data comprising the index models, and through their applications in the HEP processes, calculate the outputs in response to parameterized alternative conditions. The **HEAT** software contains two separate programming modules – one used for HEP applications referred to as the **EXpert Habitat Evaluation Procedures (EXHEP)** module, and a second used in HGM applications referred to as the **EXpert Hydrogeomorphic Approach to Wetland Assessments (EXHGM)** modules. Both the **EXHEP and EXHGM** module were employed to calculate outputs for the study. The developers of the **HEAT** tool (including both the **EXHEP** and **EXHGM** modules themselves) are pursuing certification through a separate initiative, and hope to complete the certification process in the next year, barring unforeseen financial and institutional problems.

Report objectives

This document describes the development of a community-based HSI model for a single community habitat type (resacas) located within the South Laguna Madre watershed, in the Brownsville, Texas area (Cameron County). The objectives of this report are to:

1. Characterize the watershed within the study area;
2. Characterize the habitat community used in the HEP evaluation and its applicable cover types;
3. Present the relationships of habitat maintenance components for the community model;
4. Define and justify the selection of assessment variables and their associated curve calibrations used to characterize the components of the community model; and
5. Provide critical information to reviewers to facilitate the certification (or one-time approval for use) of the index model.

Report structure

This report is organized in the following manner: *Chapter 1* provides the background, objectives and organization of the document. *Chapter 2* provides a brief overview of HEP, and the method in which the model will be applied, including the procedures recommended for its development and application of the HSI model. *Chapter 3* discusses the evolution of the community model in terms of conceptual development, offers critical insight into the characterization of the community, provides details regarding the key functional components in the model (and their mathematical representations), and then concludes with a summary of construction and testing over the last two years. *Chapter 4* offers insight into the model calibration approach as it applies to the model described herein, and describes the assessment variables used to characterize the community including definitions, rationale for selection, and specific sampling guidelines. *Chapter 5* provides a brief summary and conclusions.

Several appendices are attached to this document. *Appendix A* is a list of acronyms used throughout this document. *Appendix B* is a glossary of commonly used terms regarding the HSI model and the HEP evaluation. *Appendix C* offers a crosswalk between the standard requirements and information necessary to certify the model and this report. *Appendix D* contains a point of contact for the formal minutes documenting the decisions made during the initial model development workshops and offers a complete list of E-Team participants. *Appendix E* provides individual suitability index curves for the variables used in the community model. *Appendix F* offers a test of the model's veracity by applying the tool to a series of five hypothetical alternative designs on one of the nine resaca subdivisions in the Brownsville, Texas area. *Appendix G* documents the review comments and actions taken to address these issues as the planning study proceeded through final review.

2 HEP Overview

The HEP process

The HEP methodology is an environmental accounting process developed to appraise habitat suitability for fish and wildlife species in the face of potential change (USFWS 1980a, 1980b, 1980c). Designed to predict the response of habitat variables in a quantifiable fashion, HEP is an objective, reliable, and well-documented process used nationwide to generate environmental outputs for all levels of proposed projects and monitoring operations in the natural resources arena. When applied correctly, HEP provides an impartial look at environmental effects, and delivers measurable products to the user for comparative analysis.

In HEP, a Suitability Index (SI) is a mathematical relationship that reflects a species' or community's sensitivity to a change in a limiting factor (i.e., variable) within the habitat type. These suitability relationships are depicted using scatter plots and bar charts (i.e., suitability curves). The SI value (Y-axis) ranges from 0.0 to 1.0, where an SI = 0.0 represents a variable that is extremely limiting, and an SI = 1.0 represents a variable in abundance (not limiting) for the species or community. In HEP, an HSI model is a quantitative estimate of habitat. HSI models combine the SIs of measurable variables into a formula depicting the limiting characteristics of the site for the species/community on a scale of 0.0 (unsuitable) to 1.0 (optimal).

Statement of limitations

The HEP methodology can provide a rational, supportable, focused, and traceable evaluation of habitat functionality. However, the user must understand the basic HEP tenets as defined in supporting literature (USFWS 1980a, 1980b, 1980c) prior to attempting application of the methodology. Outcomes derived under HEP are dependent on the user's ability to predict future conditions and the reliability of resource data used. The user should understand that HEP is not a carrying-capacity model and cannot comprehensively predict future species and species population sizes. Furthermore, HEP is not designed to make comparisons across evaluation elements (e.g. compare prairie habitat to forest habitat). The user should not expect HEP to provide the only predictive environmental response to project development scenarios, and should understand the limitations of the methodology's response to predictive evaluations prior to its application.[1]

HSI models in HEP

Users can select several indicator species to evaluate overall site fitness. In the HEP process, species are often selected on the basis of their ecological, recreational, spiritual, or economic value. In other instances, species are chosen for their representative value (i.e., one species can "represent" a group or guild of species that have similar habitat requirements). Most of these species can, in turn, be described using single or multiple habitat models and a single HSI mathematical formula. In some studies, several cover types are included in an HSI model to accurately reflect the complex interdependencies critical to the species' or community's existence. Regardless of the number of cover types incorporated within an HSI model, any HSI model based on the existence of a single life requisite requirement (e.g. food, water, cover, or reproduction) uses a single formula to describe that relationship.

Some species are insufficiently examined using the simplistic approach. In these instances, a more detailed model can emphasize critical life requisites, increase limiting factor sensitivity, and improve the predictive power of the analysis. Multiple habitats and formulas are often necessary to calculate the habitat suitability of these more comprehensive HSI models. The second type of HSI model is used to capture the juxtaposition of habitats, essential dependencies, and performance requirements such as reproduction, roosting needs, escape cover demands, or winter cover that describe the sensitivity of a species or community. Multiple formula models require more extensive processing to evaluate habitat conditions.

Habitat units in HEP

HSI models can be tailored to a particular situation or application and adapted to meet the level of effort desired by the user. Thus, a single model (or a series of inter-related models) can be adapted to reflect a site's response to a particular design at any scale (e.g., species, community, ecosystem, regional, or global dimensions). Several agencies and organizations have adapted the basic HEP methodology for their specific needs in this

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[1] Additional support for the HEP methodology has been provided in *Table C1, 2 Technical Quality, a. Theory*.

manner (Inglis et al. 2006, Gillenwater et al. 2006, and Ahmadi-Nedushan et al. 2006). HEP combines both the habitat quality (HSI) and quantity of a site (measured in acres) to generate a measure of change referred to as Habitat Units (HUs). Once the HSI and habitat quantities have been determined, the HU values can be mathematically derived with the following equation: HU = HSI x Area (acres). Under the HEP methodology, one HU is equivalent to 1 acre of optimal habitat for a given species or community.

Capturing changes over time in HEP applications

In studies spanning several years, Target Years (TYs) must be identified early in the process. Target Years are units of time measurements used in HEP that allow users to anticipate and direct significant changes (in area or quality) within the project (or site). As a rule, the baseline TY is always TY = 0, where the baseline year is defined as a point in time before proposed changes would be implemented. As a second rule, there must always be a TY = 1 and a TY = X_2. TY_1 is the first year that land- and water-use conditions are expected to deviate from baseline conditions. TYX_2 designates the ending target year. A new target year must be assigned for each year the user intends to develop or evaluate change within the site or project. The habitat conditions (quality and quantity) described for each TY are the expected conditions at the end of that year. It is important to maintain the same target years in both the environmental and economic analyses, and between the baseline and future analyses. In studies focused on the long-term effects, HUs generated for indicator species are estimated for several TYs to reflect the life of the project (period of analysis). In such analyses, future habitat conditions can be estimated for both the without-project (e.g., No Action Plan) and with-project conditions. Projected long-term effects of the project are reported in terms of Average Annual Habitat Units (AAHUs) values. Based on the AAHU outcomes, alternative designs can be formulated and trade-off analyses can be simulated to promote environmental optimization.

Developing index models for HEP

Based on the USFWS's Ecological Service Manual (ESM) series on HEP (USFWS 1980a, 1980b, 1980c), 12 steps are involved in the application of HEP when assessing an environmental project:

1. Build a multi-disciplinary E-Team,
2. Define the project,

3. Map the site's cover types (CTs),
4. Select, modify, and/or create index model(s),
5. Conduct field sampling,
6. Perform data management and statistical analyses,
7. Calculate baseline conditions,
8. Set goals and objectives, and define project life and TYs,
9. Generate without-project (WOP) conditions and calculate outputs,
10. Generate with-project (WP) conditions and calculate outputs,
11. Perform tradeoffs, and
12. Report the results of the analyses.

However, this document only addresses the development of the model used in the HEP process for this study. For further detail on each of the 12 steps, refer to the Burks-Copes and Webb (in preparation) habitat assessment report for the current study.

Steps in model development

Landscape-level community assessment was identified as a priority for the District's upcoming feasibility study. However, few HSI community models were published and available for application. ERDC-EL proposed a strategy to the District to develop a community model for the current study. The strategy entailed five steps:

1. Compile all available information that could be used to characterize the communities of concern.
2. Convene an expert panel in a workshop setting to examine this material and generate a list of significant resources and common characteristics (land cover classes, topography, hydrology, physical processes) of the system that could be combined in a meaningful manner to "model" the communities. In the workshop, it was important to outline study goals and objectives and then identify the desired model endpoints (e.g., outputs of the model). It was also critical for the participants to identify the limiting factors present in the project area relative to the model endpoints and habitat requirements. The outcome of the workshop was a series of mathematical formulas that were identified as functional components (e.g., Hydrology, Vegetative Structure, Diversity, Connectivity, Disturbance, etc.), which were comprised of variables that were:

    a. Biologically, ecologically, or functionally meaningful for the subject,

b. Easily measured or estimated,
c. Amenable to the assignment of scores for past and future conditions,
d. Related to an action that could be taken or a change expected to occur,
e. Influenced by planning and management actions, and
f. Independent from other variables in each model.

3. Develop both a field and a spatial data collection protocol (using Geographic Information Systems (GIS)) and, in turn, use these strategies to collect all necessary data and apply these data to the model in both the "reference" setting and on the proposed project area.
4. Present the model results to an E-Team and revise/recalibrate the model based on their experiences, any additional and relevant regional data, and application directives.
5. Submit the model to both internal ERDC/District/E-Team review and then request review from the initial expert panel that participated in the original workshop. Solicit review from independent regional experts who were not included in the model development and application process.

Model review process

The process described in *Appendix C* is currently being implemented to assure that quality control is an integral part of model development and document production. In essence, a laboratory-directed model review process is underway, one that involves both direct-line supervisors of the model authors, and peer reviews by researchers and planning personnel outside of the model development team. It is important to note that the District will be responsible for incorporating the ERDC-EL documents into their integrated feasibility study reports and documents. In addition, an external peer review will be conducted to determine whether the model can be certified or approved for one-time use. The information in *Appendix C* will also address the comments obtained as a result of the external peer review and will ultimately provide a list of actions taken by the authors to address these concerns.

3 Community-based HSI Modeling

As described earlier in *Chapter 2* of this report, community-based index models quantify the effects of change in a given ecosystem setting and can be used to account for losses and mitigation or restoration gains under the HEP assessment paradigm. This chapter describes the relevant ecological communities found in the study area, and describes the process by which the E-Team developed and tested the resultant community-based index model. A general description of the variables and their relationships to one another are provided for the model. The goal of this chapter is to describe the E-Team's effort to capture the character of the ecosystem using a traditional index model-based approach.

Model development workshops

A series of six workshops were held over the course of six years (2004-2009) to develop the model and characterize baseline conditions of the study area prior to plan formulation and alternative assessment. Several federal, state, and local agencies, as well as local and regional experts from the stakeholders' organizations, and private consultants, participated in the model workshops.[1] In the first workshop, the E-Team was briefed on the project scope and opportunities by the District planners. Land and water management activities (e.g., hydrologic alterations, urban development, and agricultural production) were identified as the system's key anthropogenic drivers. The stressors (i.e., physical, chemical, and biological changes to system structure and function) were identified and grouped into five categories: 1) hydrologic alteration, 2) geomorphic and topographic alteration, 3) climate change, 4) urban encroachment and agricultural use, and 5) exotic species introductions. Each stressor altered ecosystem integrity within a water, soils, habitat, and/or landscape context.

Coupling conceptual modeling and index modeling

Conceptual models are proving to be an innovative approach to organize, communicate, and facilitate analysis of natural resources at the landscape scale (Harwell et al. 1999, Turner et al. 2001, Henderson and O'Neil 2004,

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[1] A list of E-Team participants can be found in *Appendix D*. Formal E-Team meeting minutes documenting model development may be obtained for review by contacting Ms. Andrea Catanzaro, Galveston District (refer to contact information in *Appendix D*).

Davis et al. 2005, Ogden et al. 2005, Watzin et al. 2005, Alvarez-Rogel et al. 2006). By definition, a conceptual model is a representation of relationships among natural forces, factors, and human activities believed to impact, influence, or lead to an interim or final ecological condition (Harwell et al. 1999, Henderson and O'Neil 2004). In most instances these models are presented as qualitative or descriptive narratives and illustrated by influence diagrams that depict the causal relationships among natural forces and human activities that produce changes in systems (Harwell et al. 1999, Turner et al. 2001, Ogden et al. 2005, Alvarez-Rogel et al. 2006). No doubt, conceptual models provide a forum in which individuals of multiple disciplines representing various agencies and outside interests can efficiently and effectively characterize the system and predict its response to potential alternatives in a descriptive manner. In theory and practice, conceptual models have proved an invaluable tool to focus stakeholders on developing ecosystem restoration goals given recognized drivers and stressors. These, in turn, are translated into essential ecosystem characteristics that can be established as targets for modeling activities.

For purposes of this effort, a systematic framework was developed that coupled the traditional USACE planning process with an index modeling approach derived from a sound conceptual understanding of ecological principles and ecological risk assessment that characterized ecosystem integrity across spatial and temporal scales, organizational hierarchy, and ecosystem types, yet adapted to the project's specific environmental goals. Ideally, the development of conceptual models involves a close linkage with community-index modeling, and produces quantitative assessment of systematic ecological responses to planning scenarios (Figure 11).

Under this modeling paradigm, conceptual modeling led to the choice of an appropriate scale for conducting the analysis and to the selection of ecologically meaningful explanatory variables for the subsequent environmental (index) modeling efforts. The model was then calibrated using reference-based conditions and modified when the application dictated a necessary change.

As a first step in the model development process, ERDC-EL generated a conceptual model to illustrate the relationships between system-wide drivers and stressors, highlighting the ecosystem responses across the entire watershed (Figure 12).

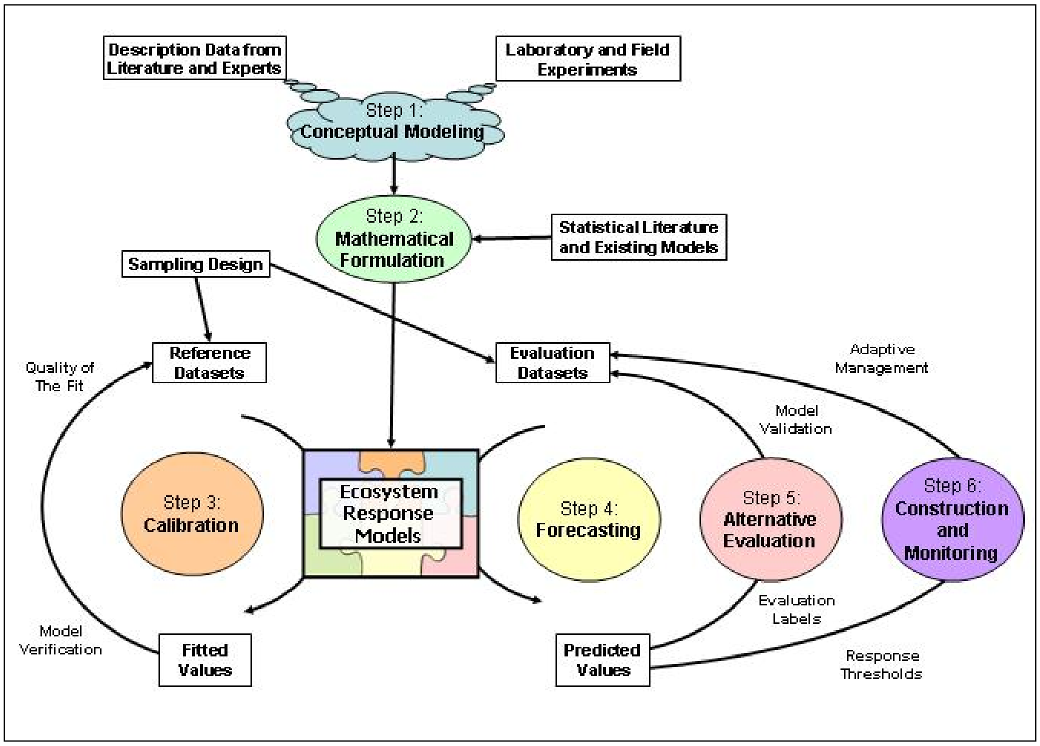

Figure 11. Overview of the successive steps (1-6) of the community-based index model building and application process for ecosystem restoration, where two data sets (one for calibration and one for alternative evaluations) are used (adapted from Guisan and Zimmerman 2000).[1]

Conceptually speaking, the "Significant Ecosystem Components" (water, soils, habitat, and landscape) were characterized by variables responsive to project design. These variables (hydroperiod, vegetative cover, disturbance, etc.) were grouped in a meaningful manner to quantify the functionality of the community in the face of change based on expert opinion and scientific literature. For example, hydrologic alterations to the system have caused changes not only in hydrologic regime, but have altered ecosystem function and structure across the basin. Urban encroachment has exacerbated these problems by reducing infiltration, increasing stormwater runoff, and increasing disturbance regimes system-wide. These changes have ultimately led to opportunities for exotic species invasions, reducing spatial complexity on a landscape scale. The direct and indirect effects of these alterations are as obvious as they are numerous – reduced hydrologic pulsing, reduced sediment transport, fragmentation, and loss of biodiversity. The effort to combine the variables in mathematical algorithms can then be viewed as

[1] It is important to note here that the models used to evaluate alternatives should also be used in the future to monitor the restored ecosystem and generate response thresholds to trigger adaptive management under the indicated feedback mechanism. As such, the District can use these models to adaptively manage the system over the long term.

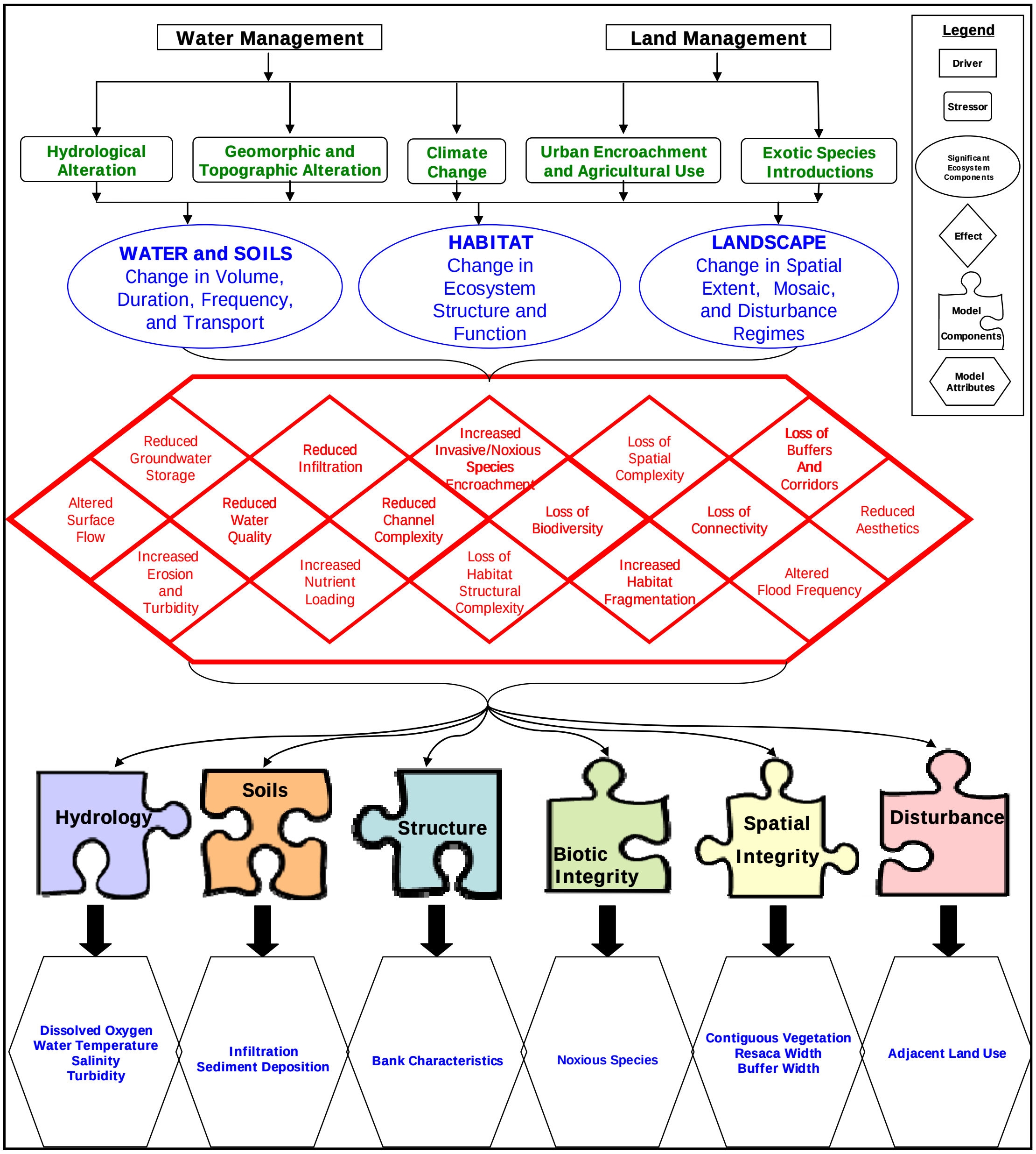

Figure 12. A conceptual model for the South Laguna Madre Watershed – bold information reflects specific effects and variables used to build the index model for this project.

community index modeling under the HEP paradigm. For purposes of organization, the community-based index model was constructed from combinations of components – an analogy used was one of puzzle building. The individual model components were represented as “pieces” of the ecosystem puzzle, that when combined captured the essence of the system’s functionality (Figure 13).

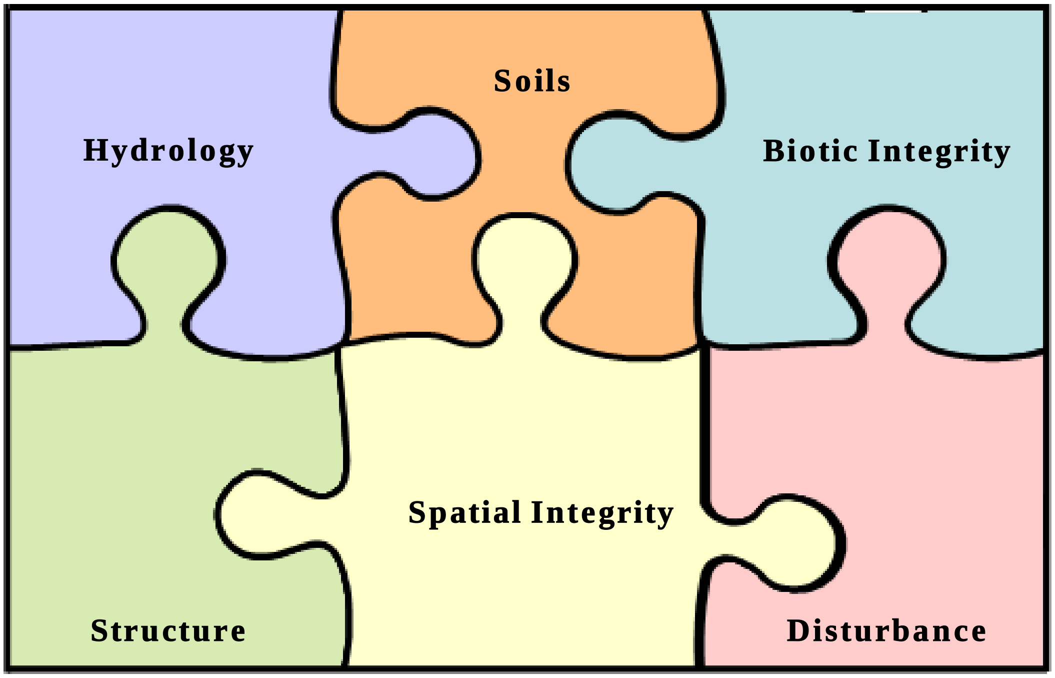

Figure 13. Within the conceptual modeling building framework, the various model components (color-coded for organization purposes) are pieced together to capture the essence of community functionality using the ecosystem puzzle analogy.

Vegetation communities in the area ranged from riparian forests, shrublands, savannahs, meadows, and open marshes, to the river itself. Out of this effort, a single draft model arose for the watershed's resacas (oxbow lakes). Subsequent refinement of this model led to the identification of contributing ecosystem components, and a description of associated variables (with suggested sampling protocols) that can be used to measure ecosystem response. The accuracy and utility of the proposed model was "tested" (e.g., verified) with specific field and planning exercises on the District's ongoing ecosystem restoration feasibility study. The application required ERDC-EL to modify the model several times over the course of the study to accommodate broader planning specifications. A general description of the system's reference domain and the unique ecosystems therein follows.

Characterization of the Lower Rio Grande resacas

General description

Prior to the construction of the international Amistad and Falcon reservoirs, the Lower Rio Grande River Basin was subject to periodic flooding. Between 1900 and 1939, the Rio Grande overflowed its banks some 23 times (Ramirez 1986). Historically, the river would meander and change course.

This movement cut new river channels throughout the landscape that would refill during cyclic flooding events. Today, these cast-off channels/oxbow lakes are known locally as “resacas.” Oxbow lakes formed by the Rio Grande meanderings are commonly referred to as “bancos.” The term “resaca” is used to describe channels that have considerable linear extent (USACE 2003b). Often, the two terms are confused, and the term “resaca” has been used to describe either situation. There are actually two explanations for the origin of the word "resaca.” The less likely holds that it is a contraction of Spanish “rio seco” (dry river). The other is that the word stems from the Spanish “resacar” (to retake), since the primary geological function of a resaca seems to be diversion and dissipation of floodwater from the river (Texas State Historical Association 2003).

Reference domain

It is important to note that the model developed here is applicable to a specific domain – that of the lacustrine/riparian fringe habitat associated with the Lower Rio Grande resacas found within the South Laguna Madre Watershed, inside Cameron County, and specifically within the city limits of Brownsville, Texas (Figure 14).

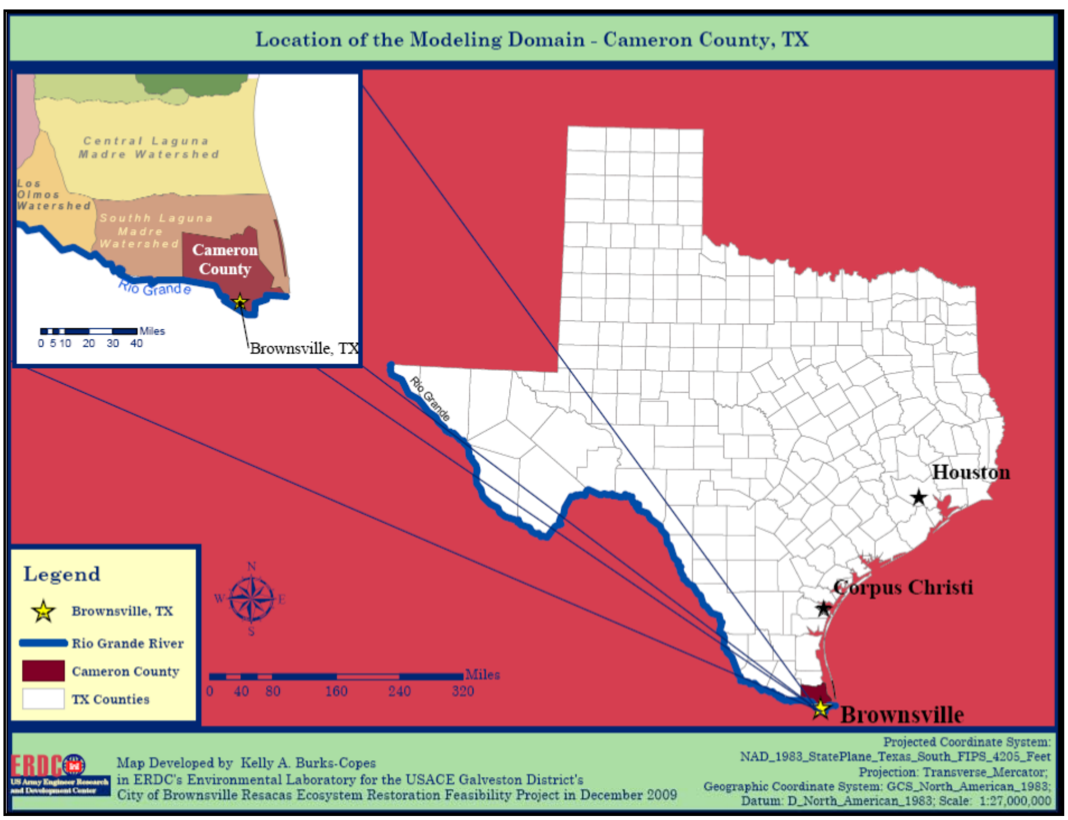

Figure 14. Location of Cameron County in southeastern Texas.

Cameron County itself is located 140 miles south of Corpus Christi in the Rio Grande Plains region of South Texas. The county's largest city and county seat is Brownsville, which serves as the terminus of U.S. Highways 77, 83, and 281 and the Missouri Pacific and Southern Pacific railroads (Figure 15).

Figure 15. Map of Brownsville, TX – site of the proposed study area.[1] The reference domain for this model centers on the resaca systems in the Lower Rio Grande Valley of southeastern Texas.

For purposes of this modeling effort, the resacas were identified specifically as (Figure 16):

1. **Resaca del Rancho Viejo** (to the north of Brownsville and identified in blue on the map below),
2. **Resaca de la Guerra** (located centrally on the map and highlighted in green), and
3. **Town Resaca** (in the center of Brownsville and drawn in yellow).

Climatic characterization

Cameron County's climate is subtropical and sub-humid, with hot summers and mild winters. Temperatures range from an average low of 50° to 69°F in January and from an average high of 75° to 94°F in July (Texas State Historical Association 2003). Rainfall varies dramatically from one end of the Texas Coast to the other (Figure 17).

[1] Map copied from the Brownsville Convention and Visitors Bureau website (2005).

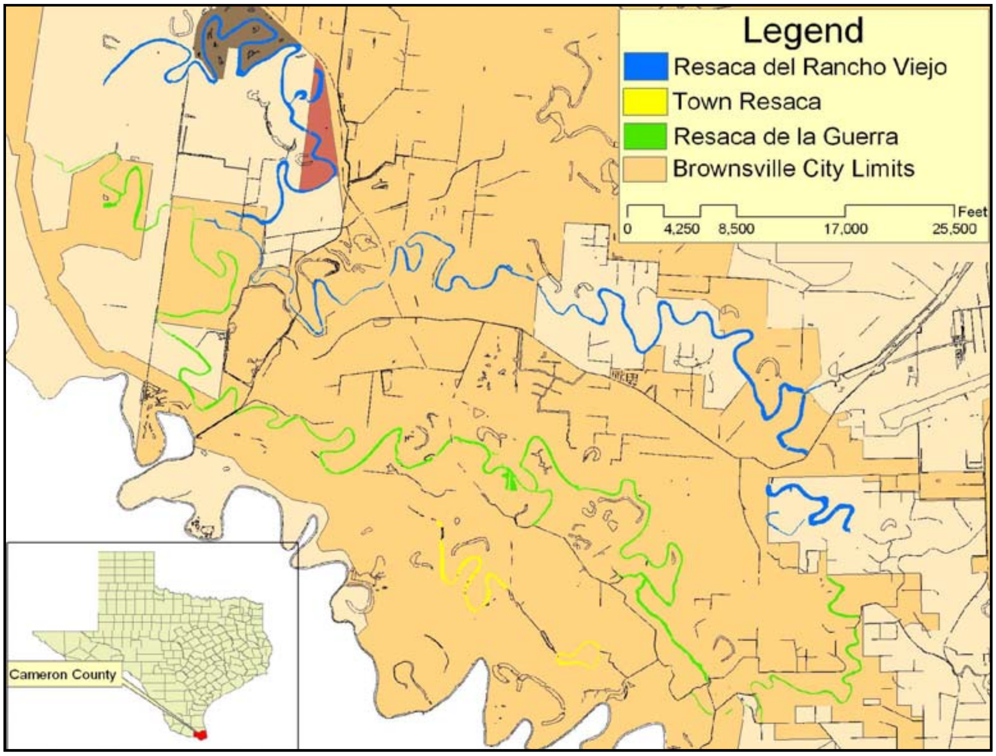

Figure 16. Location of the resacas assessed with the model in the current study.

Average annual rainfall drops from 55 in. at Port Arthur in Jefferson County to less than 29 in. along most of the lower coast. Rainfall in Cameron County averages 26 in. per year. Snowfall is exceedingly rare. The growing season lasts 320 days, with the first freeze in mid-December and the last in late January (Texas State Historical Association 2003).

Geomorphic characterization

To understand the present pattern of south Texas wetlands, it is important to review geologic history. Sixty to one hundred million years ago, the edge of the continent was located near where Dallas, Austin, and San Antonio are now. The entire region that would become the Texas coastal plain was then at the bottom of the newly opening Gulf of Mexico. Since then, the Gulf has been continuously filling in with sediment carried by rivers. These layers of gravel, sand, silt, and clay are up to 40,000 ft thick, and have extended the edge of the continent some 250 miles into the Gulf. This process of sediment deposition continues today as Texas rivers add their sediment loads (the portion that is not trapped in man-made reservoirs) to their bays or directly to the Gulf. The Texas mainland shore, coastal plain, beaches, barrier islands and peninsulas, river deltas, and bays and estuaries are all products of the processes of erosion and deposition of water-borne (alluvial) sediments (Jacob et al. 2000).

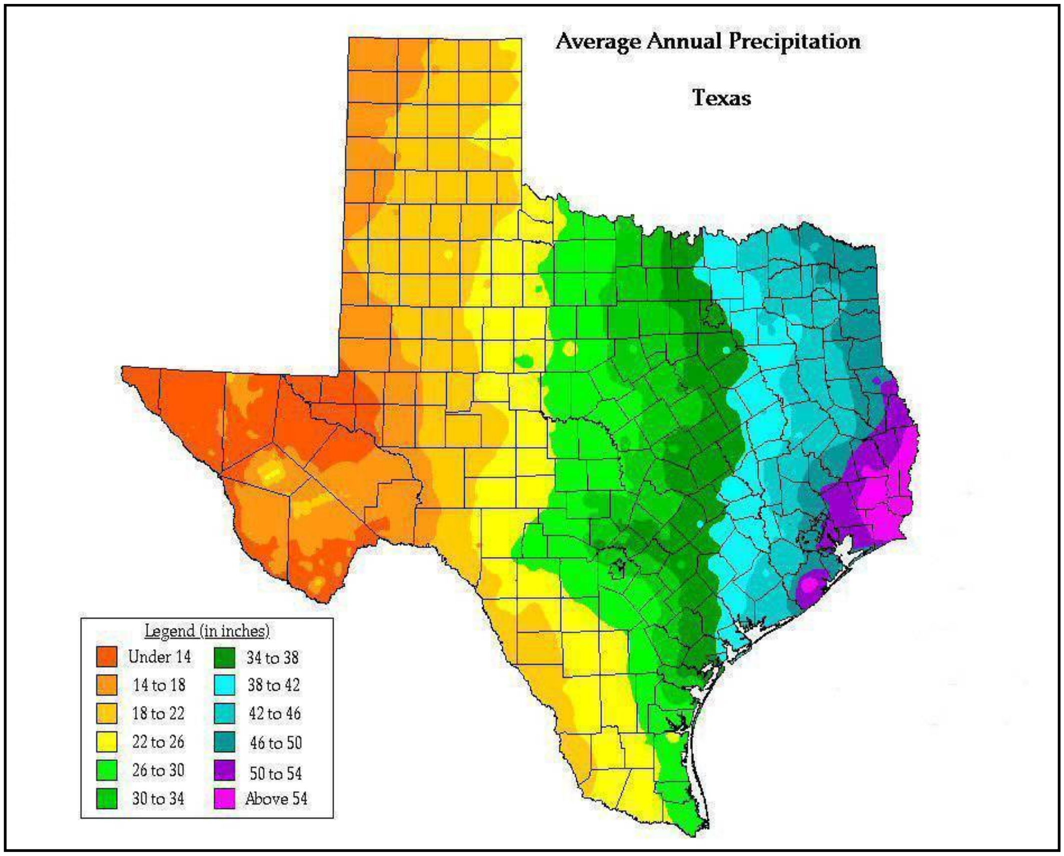

Figure 17. Average annual precipitation across the state of Texas.[1]

The building of the Coastal Plain through sedimentary deposition has taken place against a backdrop of rising and falling sea levels, and what is seen on the surface today is the result of the last two million years (the Ice Ages of the Pleistocene Epoch). The younger the sediments are, the easier it is to see the remains of the depositional processes. For example, many of the freshwater wetlands on the Gulf Coast today have formed in old sediment-filled channels that once formed the deltas and floodplains of ancient rivers. The channel remnants consist of oxbow lakes, cutoff channels, and, in the Lower Rio Grande valley, resacas.

At the height of the last Ice Age, about 18,000 years ago, sea level was 300 to 400 ft lower than it is today, and the shoreline was at least 50 miles farther out in the Gulf. During this period the coastal rivers cut deep valleys

[1] This is a map of annual precipitation averaged over the period 1961-1990. Station observations were collected from the National Oceanic and Atmospheric Administration (NOAA) Cooperative and NRCS SnoTel networks, and other state and local networks. The PRISM modeling system was used to create the gridded estimates from which this map was made. The size of each grid pixel is approximately 4x4 km. Support was provided by the NRCS Water and Climate Center. Copyright 2000 by Spatial Climate Analysis Service, Oregon State University.

into the coastal plain sediments, which flooded and filled with sediment once the climate warmed and sea level rose as a result of the melting glaciers. Most of the fringing salt marsh wetlands formed in the bays and estuaries that resulted from the flooding and filling of these river valleys (Figure 18).

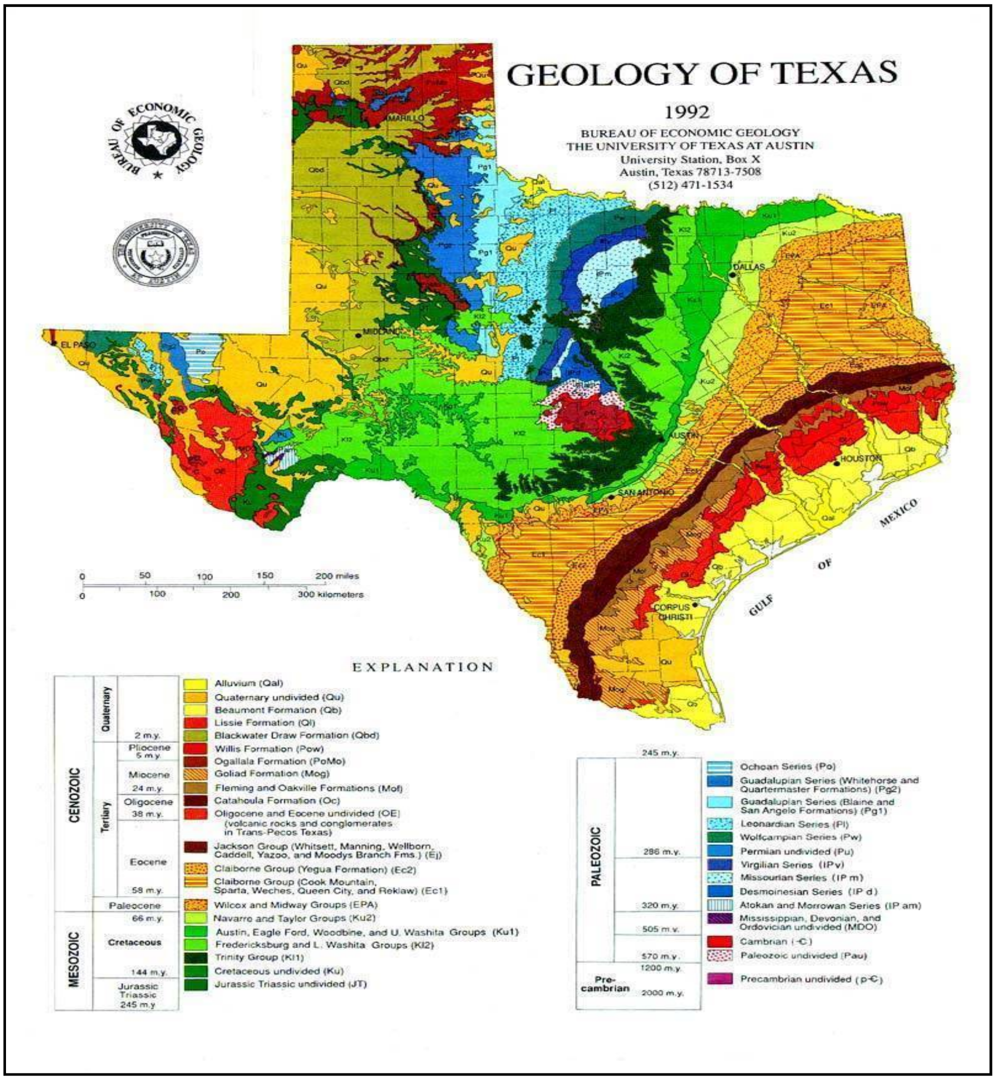

Figure 18. Geologic regions of Texas (Pepin 1998).

The distribution and characteristics of the major soil regions of Texas are determined primarily by regional differences in climatic conditions characteristic of the various sections of the state. Areal variations within the various major soil regions are determined largely by geologic and physiographic conditions, which vary from the average expression of these elements in the region. Cameron County covers 905 square miles, with an elevation range from sea level to 60 ft. Along the eastern edge of the county, the soils are sandy and saline, with some cracking clay (Figure 19).

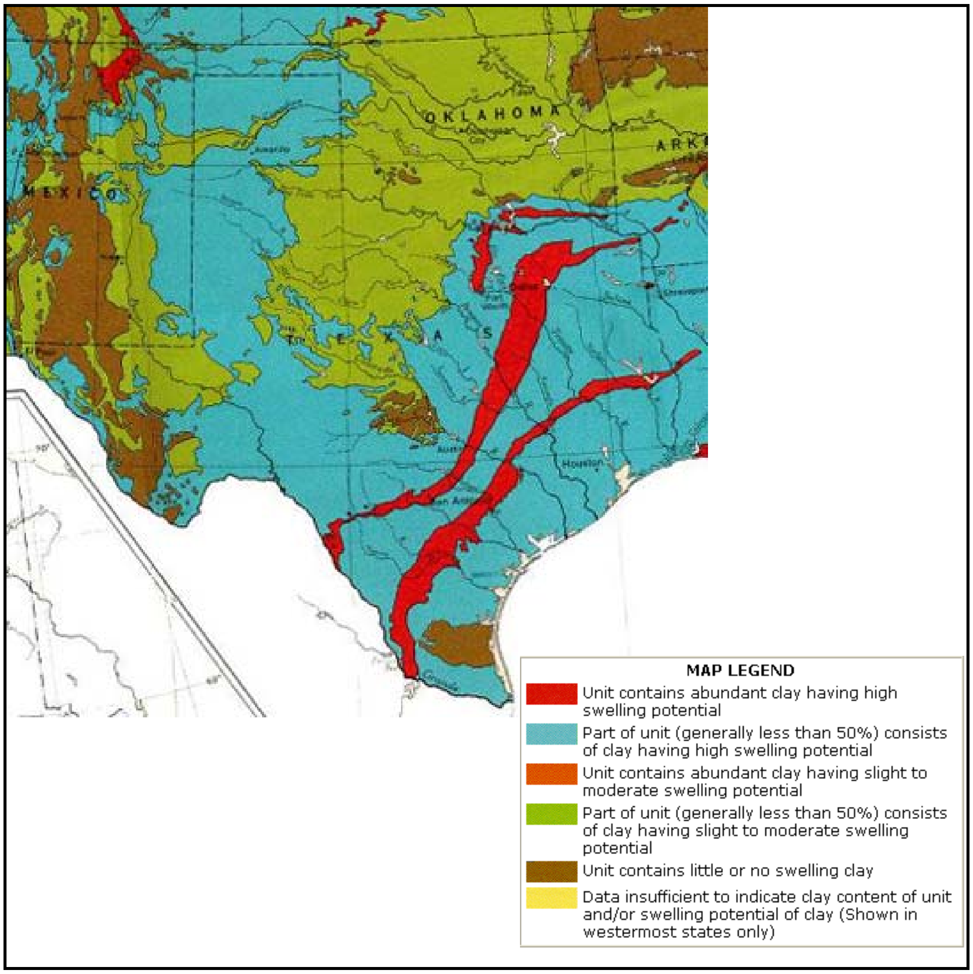

Figure 19. Clay soils in Texas.[1]

The remainder of the county has brownish to reddish soils, with loamy to clayey surface layers and clayey subsoils. The larger streams flowing across the coastal plains of Texas are generally characterized by wide valley lowlands with thick deposits of fine to moderately fine-textured alluvium. The soil materials of alluvium bear little relation to the soils of the adjacent uplands in which they occur because the alluvium has often been carried in from distant areas. The alluvium in the valley lowlands of the Coastal Plain in Texas has usually been borne down from the western part of the state, particularly from the Lower Plains. Alluvial soils are rich as a rule; where well-drained and not too severely flooded, they are highly productive. They are used for the growing of cotton and in the Lower Rio Grande valley, for citrus and other subtropical fruits, as well as numerous kinds of vegetables (Texas State Historical Association 2003).

[1] Copyright 2003 FoundationWatering.com (Foundation Watering 2003).

Hydrologic characterization

The Rio Grande is almost 3,200 km long, the second-longest river in the United States. Despite its length, it is dwarfed in discharge volume by many of the nation's other rivers. Although the Rio Grande's snow-fed beginning is in the Rocky Mountains of southern Colorado, the river winds most of its length through hot and arid regions. Because of water withdrawals and drought, some stretches occasionally are completely dry. In these arid lands, the Rio Grande's water is critical to native flora and fauna and to human development. Between 243,000 and 283,500 ha of land are irrigated each year by Rio Grande water in the Lower Rio Grande valley alone. This amount has remained fairly constant over the last 40 years because little additional appropriate uncultivated land remains (Mac et al. 1998).

The hydrology of the Rio Grande is tightly controlled for much of its length by dams and channelization. Because of upstream diversions, most of the water that the Rio Grande delivers to the lower valley is attributable to the Rio Conchos, a tributary that drains the state of Chihuahua in Mexico (Vi Risser 1995). As is true in most desert regions, annual precipitation in Chihuahua is highly variable and results in corresponding variability in the Rio Conchos discharge. The Chihuahua province was in a severe drought between 1993 and 1996. Discharge from the Rio Conchos in 1995 was extremely low, and the Rio Grande in the Big Bend National Park and the 314-km section of the Rio Grande designated as a National Wild and Scenic River were barely flowing during parts of 1995 (Mac et al. 1998).

Vegetation characterizations

An ecosystem’s vegetation at any given time is determined by a variety of factors, including climate, topography, soils, proximity to bedrock, drainage, occurrence of fire, and human activities. Because of the temporal and spatial variability of these factors and the sensitivity of different forms of vegetation to these factors, the system’s character is one of dynamic, changing juxtapositions (i.e., a fluid mosaic). Of particular concern for this effort is the state of the vegetative communities within the model domain (Figure 20).

The state hosts more than 54 distinct vegetation types (Figure 21).

The Lower Rio Grande valley’s ecology is both unique and precious. The Basin was historically prone to patterns of periodic flooding and droughts that shaped the land. The Rio Grande's flooding carried rich and fertile

Figure 21. At stake - the shallowing resaca community and its associated vegetative fringe (2004 photos taken by the field data collection team at various locations across the watershed).

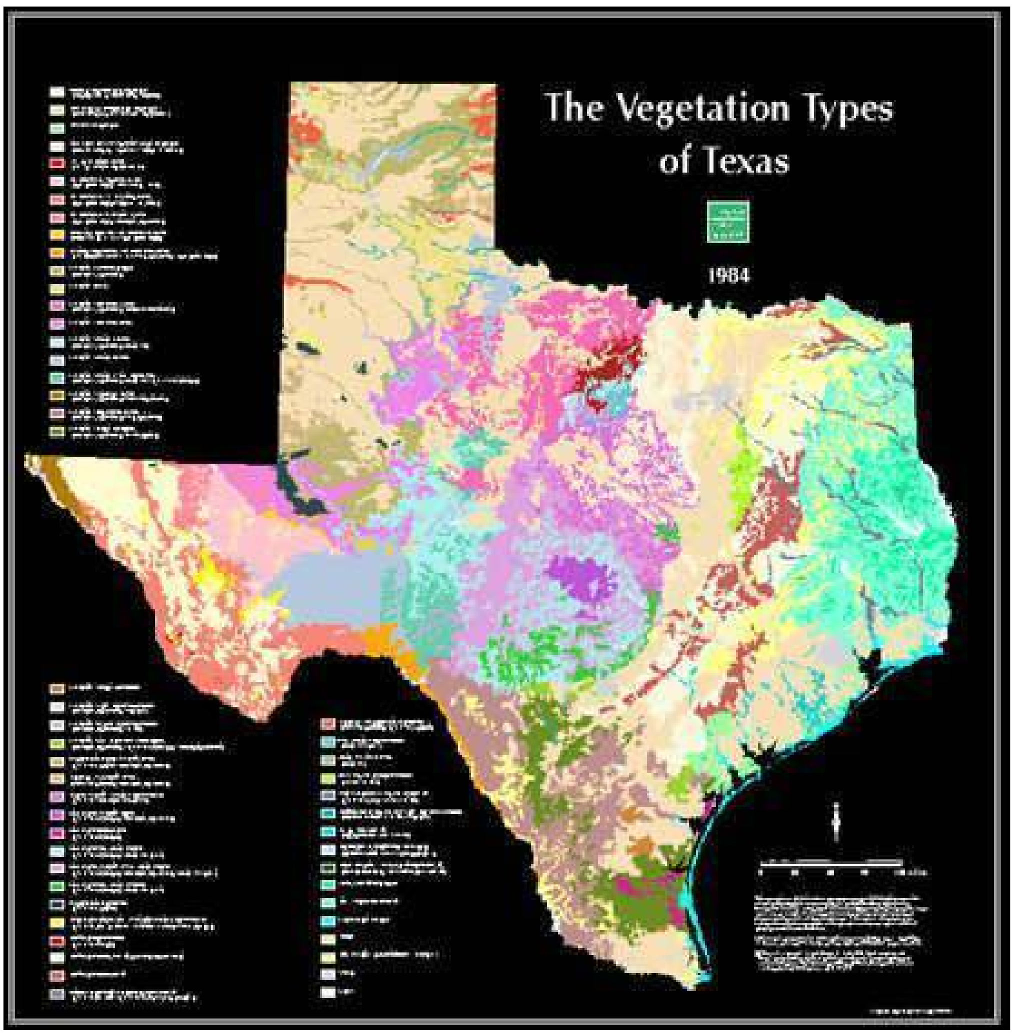

Figure 21. Vegetation types of Texas.[1]

[1] Texas Parks & Wildlife ©1984, Craig A. McMahan, Roy G. Frye, and Kirby L. Brown.

alluvial sediments, enriching the soils in the Basin and sustaining the border habitat. This habitat, in turn, attracted and supported the region's diverse wildlife. The area hosts an environment of rare and spectacular wildlife and plant species, whose growth and survival are utterly dependent upon two key limiting resources – land and water. Very few places exhibit as much diversity in biological resources as the Lower Rio Grande Valley of Texas. This diversity is a result of the subtropical climate, which supports species that are at their northern-most range. Thus, within the United States, many of these species are only found within the valley. Remnant populations of unique plants and animals exist in native brush communities that are surrounded by extensive agriculture and urban areas. In order to describe broad natural regions and to serve as a common reference point for characterizing Texas, a classification system was created during a scientific conference in 1978 at Winedale, Texas (TPWD 2005b) based on a report written by Frank Blair in 1950 (Blair 1950). The Winedale conference determined that there are 11 Natural Regions of Texas based on unique physiographic or biological differences (Figure 22).

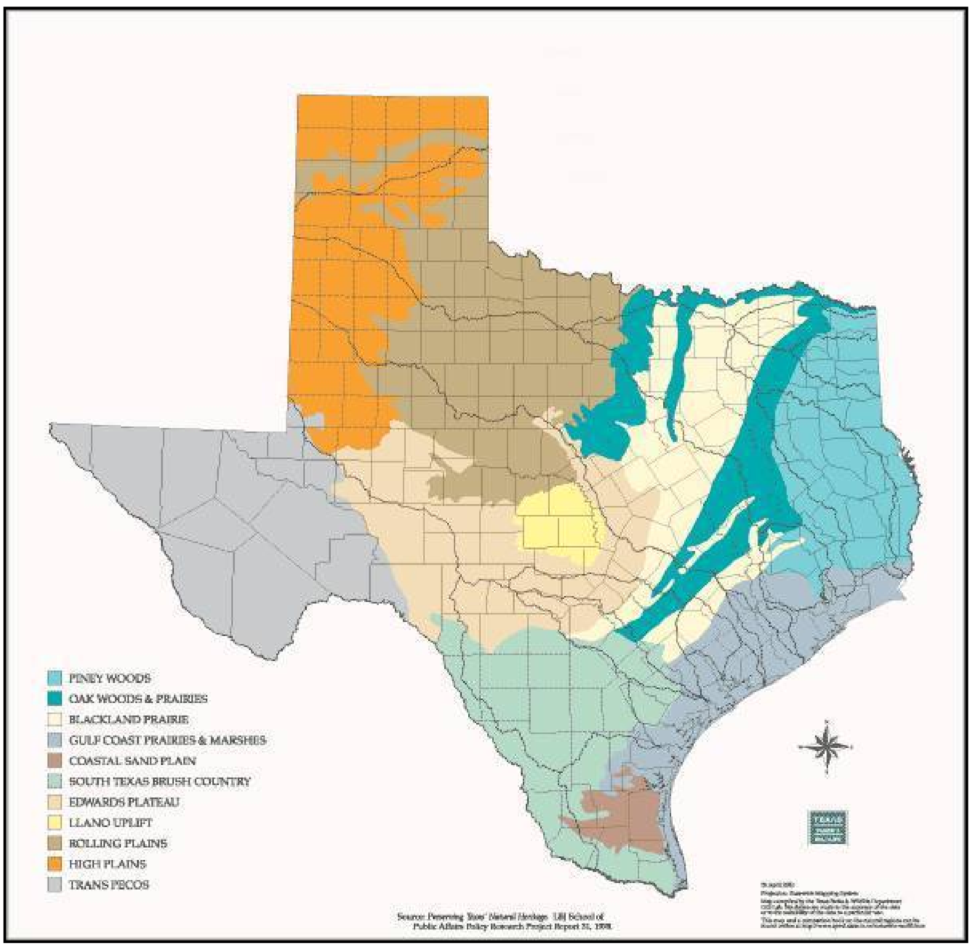

Figure 22. Biotic provinces of Texas (TPWD 2005a).

These biologic and physiographic differences are the result of interactions among geology, soils, plants, animals, and climate. The natural regions classification system was developed in order to assist in the preservation of natural diversity and locate areas with scenic, unusual, significant, and unique resources. These resources include rare or endangered species, geologic formations, and ecosystems. The Natural Regions of Texas were derived in conjunction with the widely known Biotic Provinces of Texas.

The study area is found within the South Texas Brush Country Province, an area of approximately 28,000 square miles of level to rolling terrain. As mentioned earlier, the elevation ranges from sea level to 1,000 ft above sea level and receives between 16 and 35 in. of annual rainfall. The shallow soil depth, rapid drainage, and clay loam soils support thorny brush, the predominant vegetation in this region (TPWD 2005c). The province contains a wide diversity of habitats that result in an enormous diversity of flora and fauna. Many of these flora and fauna are threatened and endangered species. The diversity present is a result of the subtropical climate, which supports species only found in the valley.

The South Texas Brush Country Province incorporates a combination of subtropical species, desert species, grassland species, and a coastal influence to produce very unique habitats. The province is composed of three separate ecological regions: the Subtropical Zone, Brush Country, and Bordas Escarpment. The area along the Rio Grande falls within the Subtropical Zone, which is identified by subtropical plant species such as Texas ebony (*Pithecellobium ebano*) and anacua (*Ehretia anacua*). As a result of the clearing of native brush for agriculture, relatively small remnant plots of native brush remain.

Wetlands are among the most important habitats in Texas. These interfaces between water and land are integral in supporting a vast array of plants, fish, and wildlife. They also perform numerous valuable functions: they collect and store water, sediments, and nutrients and therefore play a major role in improving water quality and decreasing pollution. They are invaluable for their ability to prevent and minimize flooding, protect shorelines, and replenish groundwater sources (TPWD 2002).

Urban wetlands, as is the case in the Brownsville resaca ecosystems, are continually subjected to anthropogenic disturbances such as pollution (Zedler 1992), habitat fragmentation (Zedler 1996), and recreation use

(Anderson 1995). These linear lakes are commonly utilized to provide water for irrigation while still providing critical wildlife habitat. The somewhat restricted hydrologic regime of the resaca systems dictates that the wildlife and vegetative communities must adapt to hydrologic and anthropogenic pressures or decline.

Resaca communities are valuable habitat for many wildlife species, providing shelter, water, food sources, and travel corridors to other larger contiguous communities. Lonard and Judd (2002) inventoried riparian vegetation at sites in the Rio Grande Valley. The dominant species for each of the vegetation layers are presented in Table 1.

Table 1. Dominant species in trees, shrub, and groundcover layers.[1]

Scientific Name	Common Name
Tree Layer	
Celtis laevigata	Hackberry
Leucaena pulverulenta	Leadtreee
Arundo donax	Giant Reed
Phragmites australis	Common Reed
Salix nigra	Black Willow
Sabal mexicana	Rio Grande Palmetto
Shrub Layer	
Celtis laevigata	Hackberry
Cocculus diversifolius	Snailseed
Malvaviscus drummondii	Wax Mallow
Zanthoxylum fagara	Pricklyash
Sabal mexicana	Rio Grande Palmetto
Mimosa asperata	Sensitive Briar
Salix exigua	Narrowleaf Willow
Ground Layer	
Panicum maximum	Guinea Grass
Panicum hirsutum	Hairy Panicgrass
Rivina humilis	Rougeplant
Celtis laevigata	Hackberry

Within agricultural fields and urban settings, resacas are often cleared right up to the bank (Figure 23); however, vegetation within the relatively undisturbed or natural resacas is typically dense and diverse (Figure 24).

[1] Due to multiple life forms, some species are included in more than one category.

Figure 23. An example of cleared shoreline in urban resaca settings (Town Resaca, October 2004 photo).

Figure 24. Diverse flora can be found along the banks of natural resacas (October 2004 photo).

The vegetative communities along the gradually sloping banks of the resacas include tree species such as hackberry (*Celtis laevigate*), cedar elm (*Uhmus crassifolis*), sabal palm (*Sabal texana*), and retama (*Parkinsonia aculeate*). Shrub communities under these tree communities are dominated by huisache (*Acacia smallii*), spiny hackberry (*Caltis pallido*), and Texas ebony (*Pithecellobium ebano*) (Lonard et al. 1992) (Figure 25).

Figure 25. Untouched resacas, such as those found in the Tamaulipas biotic province host a wide variety of vegetative communities along their shorelines (October 2004 photo).

The bottom of the resaca generally contains either open water or dense stands of cattails (*Typha spp.*), giant cane (*Arundinaria gigantea*), rushes (*Scirpus spp.*, *Juncus spp.*), sedges (*Carex spp.*) water millet (*Echinochloa spp.*), and sprangeltop (*Leptochloa spp.*) (Figure 26).

Figure 26. One predominant vegetative species within the resaca ecosystems of south Texas is cattails (*Typha latifolia*) (October 2004 photo).

Some of the resacas, however, fill with grass and fobs when water is absent during dry periods (Figure 27).

Figure 27. Resacas typically fill with grass and forb communities when water is absent (Resaca del Rancho Viejo, October 2004 photo).

To facilitate model development, a series of 10 unique land use/land cover types (i.e., cover types or CTs) were identified based on a classification system developed by the District with input from the E-Team on indicator species and underlying soil conditions (Table 2).

Table 2. Cover types identified and mapped for the reference domain.

No.	Code	Description
1	AGCROP	Agricultural Croplands
2	COMMERCIAL	Commercial/Industrial
3	DIRTROADS	Dirt and Gravel roads, Oil and Gas Fields
4	HIGHWAYS	Paved Roads and Highways
5	NEWRESACA[1]	Newly Created Resaca Community
6	PARKS	Parks
7	PASTURE	Pasturelands, Uninhabited Vacant Lands
8	RESACA	Existing Resaca Community
9	RESIDENTL	Residential and Golf Courses
10	RIGHTOFWAY	Utility Rights-of-Way and Rail Roads

[1]Cover types identified as “NEW” refer to newly developed areas proposed in conjunction with construction of proposed alternatives.

These existing cover types were subsequently mapped using GIS (and ground-truthed during the 2004-2005 field seasons) (Figure 28).

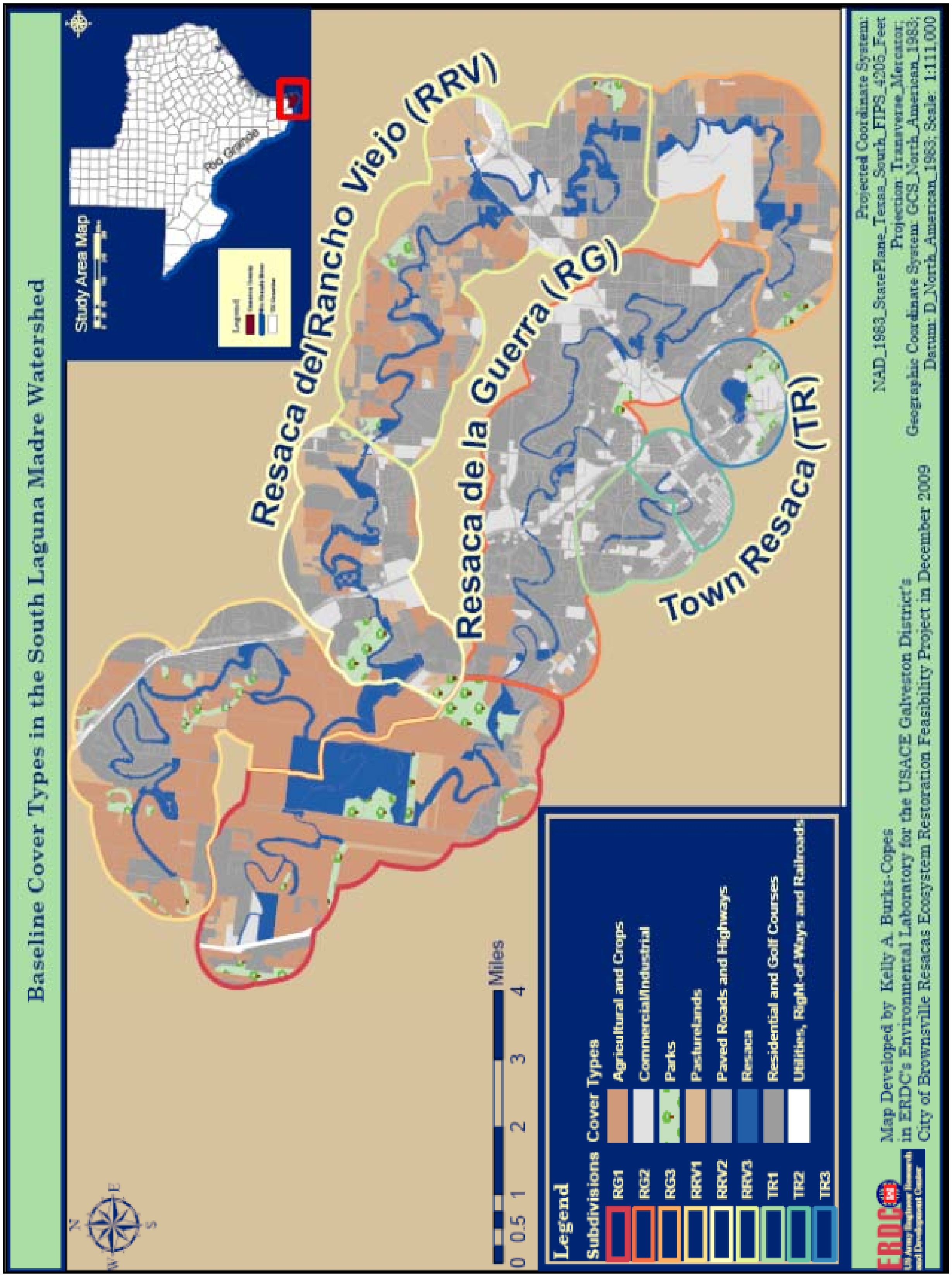

Figure 28. Cover type map for the reference domain.

It is important to note that the area is developing rapidly at the expense of agricultural croplands that are being replaced predominantly by residential development. Today, agricultural areas (including pastures and parks) total 16,648 acres (Figure 29).

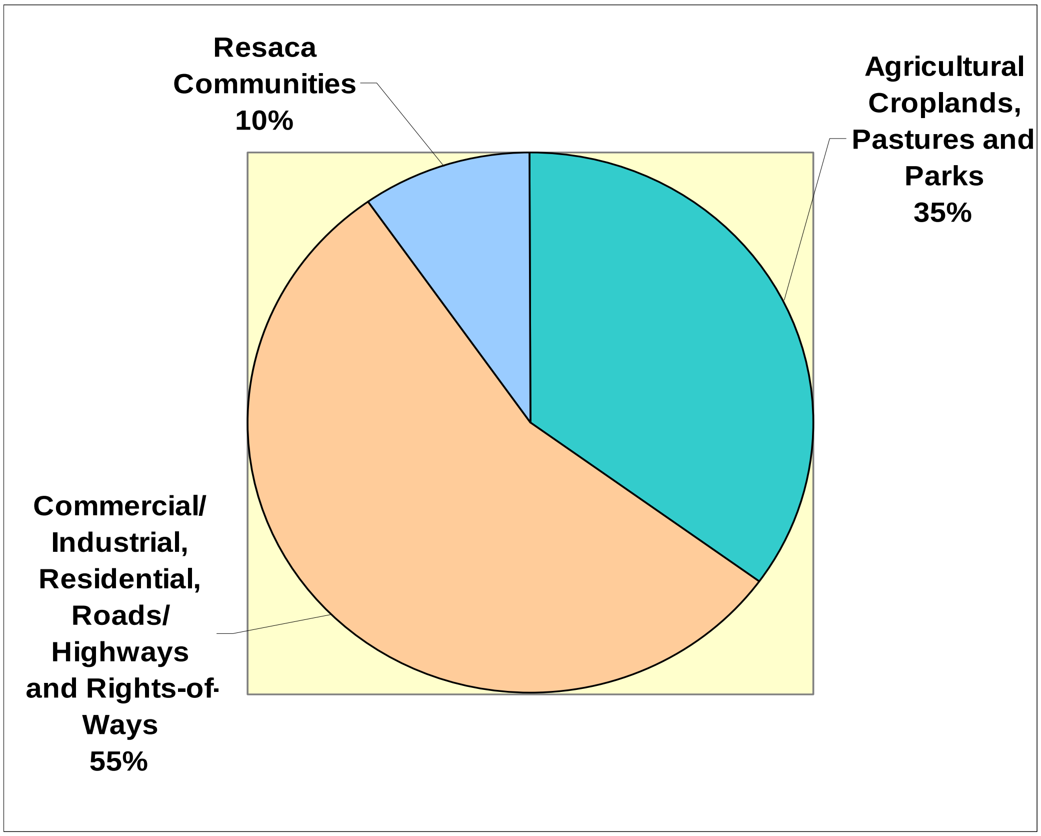

Figure 29. Breakdown of dominant land use classes in the study area.

Residential space and commercial/industrial complexes extend across 26,350 acres. The resacas communities cover only a small portion of the study area (10%), and total 4,567 acres of open water and fringe vegetation. Most of the terrestrial fringe habitat is likely to be consumed in future urban development (for more details refer to section below).

Characterization of the watershed's resacas

Resacas are naturally cut off from the river, having no inlet or outlet. Before land development and water control in Cameron County, floodwater from the Rio Grande drained into resacas from surrounding terrain. Over the years, portions of the resacas silted up and became bottomland, forming a series of unconnected horseshoe bends from the remaining stretches of channel. The channels themselves were either dry or contained stagnant ponds and marshes. Traditionally, resacas refer to old, abandoned river channels measuring from mere inches to as much as 6 ft in depth, and span 30 to 60 ft across at their widest points. Development of resacas as reservoirs and channels for irrigation water started in 1906, when COL Samuel A. Robertson began construction of a canal to connect the Resaca de los Fresnos with a pumping station on the Rio Grande at Los Indios (Texas State Historical Association 2003). Many resacas are now filled with water by pumping, among them Resaca de los Fresnos in San Benito, Resaca de los Cuates in the Los Fresnos-Bayview area, and Resaca de la Guerra, Resaca de la Palma, Town Resaca, and Resaca del Rancho Viejo in the Brownsville-Rancho Viejo area (Figure 30).

Figure 30. Resaca del Rancho Viejo near Brownsville, Texas (Cameron County) (photo taken in 2004).

Some rural resacas remain dry except in rainy weather. The ownership and administration of resacas varies according to jurisdiction. Some are owned by irrigation districts, some by municipal water corporations or utility districts, and some by owners of adjacent land who provide easement to public corporations. In urban areas resacas have been landscaped as community or residential showplaces, while those in rural areas are often left as marsh and scrubland. Resacas are often considered ephemeral (short-lived) systems – some may hold water for only short portions of the year (Figure 31) while others hold water on a more permanent basis (thus forming oxbow lakes) (Figure 32)

Figure 31. Ephemeral resacas, such as this site along Resaca del Rancho Viejo, hold water for only portions of the year (December 2004 photo).

Figure 32. Oxbow lakes in the Brownsville region hold water year-round as shown here at Resaca de La Guerra (October 2004 photo).

The extensive construction of impoundment facilities, floodway systems, and irrigation canals during the 20th century caused significant changes in the hydrology and biology of the Lower Rio Grande region. Historically, natural resaca systems were refilled when the Rio Grande flooded, but today's urbanized setting has restricted this recharge, and these isolated ecosystems must often rely on rainfall and runoff for recharge or pumping of water from the Rio Grande. All three resacas in the study rely heavily on water pumped from the Rio Grande. The water in turn is pumped from the resacas and used by agricultural and residential landowners for irrigation. Water left in the resacas then supports the natural resacas community.

The mixture of water sources and the geologic materials through which they move before reaching the oxbows and associated riparian zones determines the elemental composition, nutrient status, and biodiversity of the unique resaca community (Figure 33).

Figure 33. The challenge for the E-Team was to develop a model robust enough to capture the unique character of the Lower Rio Grande's resacas community.

Thus, the system's biogeochemistry (i.e., dissolved oxygen, water temperature, sediment deposition, salinity, and turbidity) is dependent upon the amount of water within the system. The spatio-temporal dynamics of the habitat mosaic and the interface between resacas and the human environment dictate the functionality and integrity of these unique systems. In particular, the movement of water within the resaca, the flows of water between the resacas, and the consequent exchange of materials (e.g., sediments, nutrients, propagules) that occur within the resascas literally shape these unique ecosystems.

Basic model components

A generic modeling approach was used to capture the functionality of the resaca community. In essence, the E-Team chose to focus on targeting three primary modeling components:

1. Hydrography
2. Structural Integrity
3. Disturbance

The following sections describe the underlying principles governing the selection of these critical functional components and provide customized flow diagrams to indicate how they were combined to develop a HEP-compatible index model for the application.

Functional Component #1: Hydrography (HYDRO)

Ecosystems possess natural hydrologic patterns that provide water for organisms and physical structure for wildlife habitats. Water is an essential component providing sustenance for organisms, and a driving force for physical changes to the environment [U.S. Environmental Protection Agency (USEPA) 1999]. Hydrologic regimes serve as vehicles for the transfer of abiotic and biotic materials through the system. Obviously, the resaca communities are heavily influenced by pulses of water infiltrating their boundaries throughout the year. As such, the E-Team assumed that the degree of pulsing or “wetness,” the wetlands biogeochemistry (driven by pulsing), and the adjacent land use conditions (which in turn influence the degree of pulsing) would dictate the ecosystem’s ability to support terrestrial and aquatic inhabitants as well as support the diverse plant communities indicative of health in the region (Figure 34).

The ***Hydrography (HYDRO)*** component of the model relied on local and regional water quality stressors to indicate the overall hydrographic functionality of these linear lakes. First, onsite water quality indicators

Figure 34. Hydrography (i.e., hydrologic regime, soils, and spatial context) dictates the functionality of the community. From left to right, examples of resacas in Resaca de la Guerra, Resaca del Rancho Viejo, and Town Resaca (photos taken between 2002 and 2004).

(e.g., dissolved oxygen, water temperature, sediment depth, salinity, and turbidity) were combined to characterize the hydrologic condition of the resacas at the local scale. Although these parameters could have been seen as "equally" important when characterizing local hydrography, it was the consensus of the E-Team that dissolved oxygen and temperature were more critical to this characterization – particularly because of their direct and indirect effects on aquatic resources in the resacas. Therefore, these two parameters (DO and TEMP) were first combined and a weighting of "2" was placed on their summed result.

$$2 \text{ x } \left(V_{DO} + V_{TEMP}\right) \tag{1}$$

Next, the remaining three variables (SEDIMENT, SALINITY, and TURBIDITY) were added to this weighted sum, and the entire suite of parameters was averaged. Because the dissolved oxygen and temperature values were doubled, the divisor was now "7" rather than "5" as it would have been, had there been no weighting.

$$\frac{2 \text{ x } \left(V_{DO} + V_{TEMP}\right) + V_{SEDIMENT} + V_{SALINITY} + V_{TURBIDITY}}{7} \tag{2}$$

A second series of indicators was included in the HYDRO component to capture the regional hydrographic conditions of the resacas in relation to the surrounding landscape. In this setting, surface water runoff from urban and agricultural land use provides a significant amount of input into these lakes. As such, the vegetative buffers ringing these systems are expected to "polish" or filter the inflows into these ecosystems. However, land-use conversion in the past has severely limited the aerial extent of these riparian buffers. The E-Team decided to measure the amount of buffers surrounding the resacas, and made the assumption that the degree of buffering indicated a level of hydrographic function at the regional scale. Furthermore, the E-Team was concerned with the degree of land-use conversion occurring in the watershed, and assumed that the increasing imperviousness of the surrounding landscape impeded infiltration into the underlying aquifer. As such, the E-Team assumed that increased impervious landscapes increased the overland flows into the ecosystems, and as such, could serve as a proxy for hydrographic function – again at the regional scale. Therefore, the E-Team chose to combine these two variables (IFILTRATE and WQBUFF) into a regional component of HYDRO by averaging their contributions.

$$\frac{V_{INFILTRATE} + V_{WQBUFF}}{2} \tag{3}$$

This regional score was then used to weight down the initial local score indicating that the local hydrography of the system was governed by the inputs made to the system at the regional scale.

$$\left[\frac{2\times\left(V_{DO}+V_{TEMP}\right)+V_{SEDIMENT}+V_{SALINTY}+V_{TURBIDITY}}{7}\right]\times\left(\frac{V_{INFILTRATE}+V_{WQBUFF}}{2}\right) \tag{4}$$

Functional Component #2: Structural Integrity (STRUCT)

Ecosystems possess a natural complexity of physical features that provides a variety of niches and dictates antagonistic and symbiotic interactions among resident species (USEPA 1999). Structural complexity increases with more snags in forests, more woody debris in streams, and more layers and perches in prairies. Interactions between organisms within these diverse niches are a major determinant of the distribution and abundance of species in the system. In other words, the deletion or addition of a species to an ecosystem can dramatically alter its composition, structure, and function. Biotic interactions are particularly important in maintaining community structure and ecosystem functions, and are described as “keystone” interactions in the literature (USEPA 1999). In the case of the current assessment, the native vegetative species compositions of living plant biomass, their spatial context, and their physical structures within the communities dictate the ecological integrity of the ecosystems and suggest whether the communities could support animal populations and guilds. As such, it was the intent of the E-Team to capture the resaca system's ability to provide biocomplexity (biological, physical, and spatial heterogeneity) for its numerous terrestrial and aquatic inhabitants to meet key life requisite requirements (e.g., breeding, feeding, and cover) (Figure 35).

Figure 35. Structural complexity (contiguous vegetative corridors, native species, and variable resaca widths) offers niche diversification to resident wildlife in the systems. On the other hand, erosion control in the form of bulkheads has led to a pervasive human presence in these systems. From left to right, examples of resacas in Resaca de la Guerra, Resaca del Rancho Viejo, and Town Resaca (photos taken between 2002 and 2004).

The ***Structural Integrity (STRUCT)*** component of the model was parameterized via several biocomplexity proxies measured at either the local or regional scales [e.g., contiguous vegetative patches (CONTIG), system size (WIDTH), noxious species control (NOXIOUS), and bank profile(BANKCHAR)]. The riparian zones of the natural resacas are considered to be in "good" condition when they are surrounded with gently sloping shorelines, are densely vegetated with numerous vegetative layers, and are characterized by specific spatial characteristics (i.e., large, contiguous patches of forest/shrubland habitats). This characterization is based on historical records and evidence compiled from the more natural, least disturbed resacas in the watershed (i.e., the reference standards). In contrast, the highly fragmented, narrow bands of riparian vegetation left behind as a result of urbanization have significantly degraded the system's functionality in terms of wildlife habitat provisioning, buffering, and networking, and as such, offered an indication of declining ecosystem functionality. Furthermore, the E-Team assumed that noxious species (i.e., aggressive invaders whose appearance would lead to undesirable competetion for the native communities) were likely to homogenize these relictual riparian stands as urban encroachment advanced. As such, these invaders were included in the model to characterize the antagonistic effects of species turnover in dysfunctional resaca ecosystems. The E-Team made the decision to equally weight the contribution of each variable within the component's index algorithm:

$$\frac{V_{\mathrm{BANKCHAR}} + V_{\mathrm{WIDTH}} + V_{\mathrm{CONTIG}} + V_{\mathrm{NOXIOUS}}}{4} \qquad (5)$$

Functional Component #3: Disturbance (DISTURB)

At the landscape level, natural communities have characteristic patterns and relationships to the surrounding patches and corridors within a landscape matrix (Forman (1995) and references therein). Disturbances that significantly alter these patterns in structure or function can lead to a homogenization of the matrix, and a reduction in niche diversity (Carey (2003) and references therein). To adequately characterize ecosystem functions, one must capture both the system's "place" in the landscape, as well as identify key processes that "shape" the system (i.e., habitat fragmentation) (Figure 36).

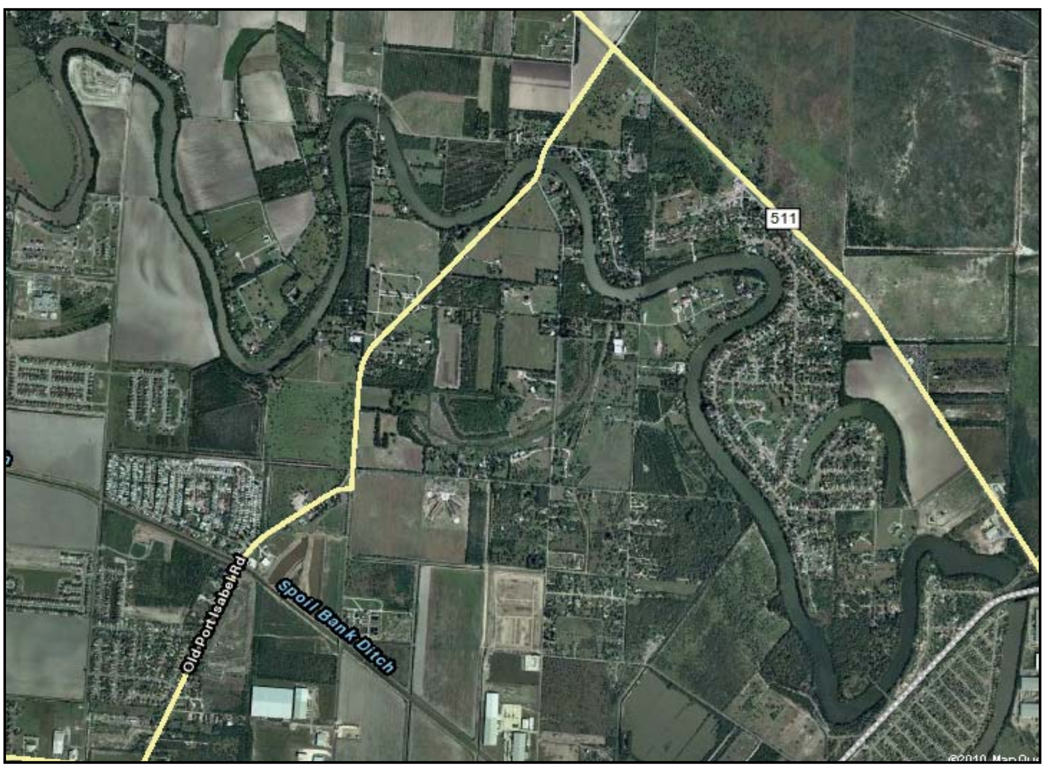

Figure 36. Fragmentation and urban encroachment are common problems for the remnant communities situated along the Resacas in Brownsville, TX (Resaca del Rancho Viejo – photo taken from Mapquest).

Human disturbance, be it agricultural practices, residential neighborhoods, or utility rights-of-way had a significant effect on the desirability of areas for multiple faunal species of the region. In general, high levels of human disturbance perturb sensitive species and reduce the system's ecological integrity. The ***Disturbance (DISTURB)*** component of the model was therefore parameterized by quantifying the degree of human activity in the landscape setting:

$$V_{ADJLANDUSE} \tag{6}$$

The predominant adjacent land-use practices immediately surrounding the resaca boundary were used as an indicator of human disturbance and development pressures on the resaca floral and faunal communities. Optimal conditions (stands of unfragmented forests and shrublands) were notably absent of human presence (stands of un-fragmented shrublands and forests). Housing and heavily disturbed areas were considered sub-optimal, as they generated higher levels of disturbance to wildlife and were likely to experience increased sedimentation and declines in both land and water availability, cumulatively stressing the system.

Model flow diagrams

The diversity and structure (biotic integrity) of the resaca community varies consistently in response to complexity of vegetation structure. The decline or absence of various compositional elements resulting from reductions in spatial heterogeneity yield declines in compositional diversity (biocomplexity) and can lead to pre-interactive niche diversification. With declines in niche diversity, faunal communities are likely to become less diverse, and the ecosystem's ability to resist or recover from disturbance (ecosystem resilience). A flow diagram best illustrates the E-Team's attempt to characterize the resaca community's biotic integrity, biocomplexity, and ecosystem resilience (Figure 37).

Variables were selected as indicators of functionality,[1] and have been color-coded here to correlate their use in specific model components (i.e., purple = hydrologic variables, orange = soil characteristics, etc.). In essence, this diagram attempts to emulate the standard diagramming protocol adopted by the USFWS in their publications for species HSI models in the late 1980's and early 1990's. Each colored line represents the normalization of a

[1] The rationale for including variables in these models is presented in greater detail in Chapter 4.

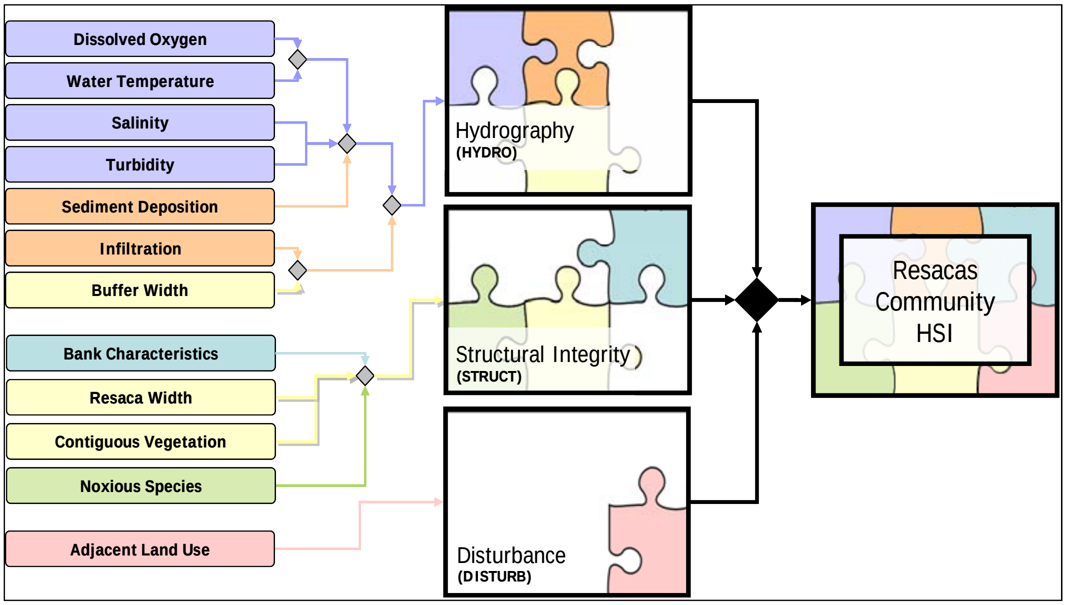

Figure 37. Flow diagram depicting combinations of model components and variables to form the resaca community index model.

variable (converting the raw data to a scale of 0-1 using suitability index curves). Once the scores are normalized, they are combined in a meaningful manner mathematically to characterize the existing reference conditions found in the watershed. These in turn can be used to capture the effects of change under proposed design scenarios (refer to the section below). Diamonds indicate weightings or merging of indices prior to full component calculation. The three components (i.e., ***HYDRO, STRUCT***, and ***DISTURB***) are combined using a second formula to produce the final HSI result.

Model formulas

After successfully diagramming the relationships between the model components and the variables therein, the E-Team was asked to use their extensive natural resources expertise to translate these flow diagrams into mathematical algorithms that would capture the functional capacity of the community in a quantifiable manner. It is important to note that this process was iterative and adaptive. Over the course of several years, the E-Team tested both the accuracy of the model to predict the suitability of known reference-based conditions as well as to test their utility in distinguishing amongst proposed restoration initiatives (contact the District POC, Andrea Catanzaro, for details regarding an ongoing application using the model on the Brownsville Resacas Ecosystem Restoration Study). Table 3 contains the final model algorithms for the resaca community.

Table 3. Index formulas for the resacas community index model.

Model Component	Variable Description	Variable Code	Formulas
Hydrography (HYDRO)	Dissolved Oxygen	DO	$\left[\frac{2\times(V_{DO}+V_{TEMP})+V_{SEDIMENT}+V_{SALINTY}+V_{TURBIDITY}}{7}\right]\times\left(\frac{V_{INFILTRATE}+V_{WQBUFF}}{2}\right)$
	Water Temperature	TEMP	
	Sediment Deposition	SEDIMENT	
	Salinity	SALINITY	
	Turbidity	TURBIDITY	
	Infiltration	INFILTRATE	
	Buffer Width	WQBUFF	
Structural Integrity (STRUCT)	Bank Characteristics	BANKCHAR	$\frac{V_{BANKCHAR}+V_{WIDTH}+V_{CONTIG}+V_{NOXIOUS}}{4}$
	Resaca Width	WIDTH	
	Contiguous Vegetation	CONTIG	
	Noxious Species	NOXIOUS	
Disturbance (DISTURB)	Adjacent Land Use	ADJLANDUSE	$V_{ADJLANDUSE}$
Overall Habitat Suitability Index (HSI):			$\frac{V_{HYDRO}+V_{STRUCT}+V_{DISTURB}}{3}$

The ***Hydrography (HYDRO)*** component of the model was based on a combination of water quality and infiltration. Dissolved oxygen and temperature were considered extremely important in capturing the water quality of the resaca, and therefore were combined and weighted by a factor of two. Shortcomings of either variable can be offset (compensated for) by the other. All five remaining variables (DO, TEMP, SEDIMENT, SALINITY, and TURBIDITY) must be present and optimal to achieve a 1.0 score. Shortcomings of one variable were likely to be offset (or compensated for) by the others. One variable could have been entirely absent, and yet some suitability was still achieved with regards to the remaining variable. The overall health of the community was determined by restrictions on infiltration at the landscape scale. The overall score was weighted down if infiltration was limited.

The ***Structural Integrity (STRUCT)*** component of the Resacas model was based on vegetative characteristics of the community or "habitat functionality" of the resaca ecosystem. The key elements identified by the E-Team for this model were diversity and health of the vegetation within these systems. Diversity was used to capture species diversity as well as shape and connectivity of the resacas at the landscape scale. Three measured variables comprise the diversity element, namely resaca bank characteristics, width of the vegetation surrounding the open water of a resaca, and the amount of contiguous vegetation surrounding a resaca. The overall health of the system was determined based upon the presence or absence of noxious vegetative species. Together, the four variables were considered compensatory and necessary to achieve optimum functionality.

The ***Disturbance (DISTURB)*** component of the Resacas model was based solely on the land uses immediately adjacent to the resaca systems. Together, the three components (Hydrography, Structural Integrity, and Disturbance) were considered equally important to capturing the functionality of the systems, and their contribution to the final score was thought to be compensatory. It is important to note that the community-based model developed herein does not subscribe to the "limiting-factor" species-based modeling paradigm of the past, but rather attempts to capture each community's integrity based on a series of component indicators (i.e., ***Hydrography***, ***Structural Integrity***, and ***Disturbance***) that together characterize the functioning of the system. This new function-based approach does not rely on a geometric mean, but rather takes into account the compensatory nature of the system's components. In other words, a degraded resaca might be considered "unsuitable" for a given species, but could potentially have value for others, and therefore would still be considered "functional" (although minimally so). Thus, the structural integrity of a resaca could be altered (possibly through land-use conversions or bulk heading), and would therefore score very low (<0.2) on the Structural Integrity Component of the model, yet the community might still retain some functionality – its hydrography (regime and chemistry) would still support aquatic niches for disturbance-tolerant species. This approach is not new, but is a common strategy for habitat suitability modeling in the scientific literature of late (Brook and Bowman (2006) and references therein, Schluter et al. 2006; Store and Jokimaki 2003; Store and Kangas 2001; Ruger et al. 2005).

4 Sampling and HSI Model Calibration Protocols

This chapter describes the variables employed within the resacas community index model. In an effort to support the future use of the model, detailed sampling protocols and rationales for variable inclusion in the model algorithms are described below. In order to use these variables within a standard HEP assessment, each must be normalized or scaled on a 0 to 1 range. Here the normalization process is described in some detail, and *Appendix E* has been included at the end of this report to further document the final index curves.

HSI model variables selection rationale

ERDC-EL used a systematic, scientifically based statistical protocol to develop and calibrate the community model using an iterative approach that involved the selection of reference sites from across the watershed and a sampling scheme that obtained numbers to assure model precision. Variables associated with the model (and justifications for their inclusion) are provided in Table 4.

A reference-based approach to model calibration

Reference sites in this instance refer to multiple sites in a defined geographic area (the reference domain) that have been selected to represent specific types of ecosystems (i.e., resacas).[1] Reference sites have been most commonly described as natural settings – lacking human disturbances (Hughes 1994, Bailey et al. 2004, Chessman and Royal 2004, Intergovernmental Task Force on Water Quality Monitoring 2005). Reference-based conditions were therefore expected to exhibit a range of physical, chemical, and biological values. When reference sites have been characterized as undisturbed ecosystems, conditions were expected to emulate the spatial and temporal variability that commonly occur in natural ecosystems (Swanson et al. 1993, Morgan et al. 1994, White and

[1] The information herein was taken from a workshop held at ERDC-EL in the summer of 2008 under the Ecosystem Management and Restoration Research Program's Environmental Benefits Analysis initiative. In that workshop, a draft manuscript was circulated to the participants for review and comment. Excerpts from that paper are provided here, and local knowledge of the watershed's reference conditions are injected where relevant.

Table 4. Variables and rationales for association in the resaca community index model.

Code	Variable Description	Rationale
ADJLANDUSE	Identification of the Predominant Adjacent Land Use Classes	**Definition:** The predominant adjacent land-use practices immediately surrounding the resaca boundary were used as a proxy to characterize the degree of human disturbance and development pressures placed on the resaca floral and faunal communities. **Rationale for variable selection:** Ecosystems do not exist in a steady-state; they are dynamic, each possessing a characteristic composition structure and function that have adapted to natural disturbances over long periods of time. At the landscape level, natural disturbances destroy patches of vegetation and restart plant succession. Human activities (both onsite and offsite) that deviate from these patterns affect individual species (and through biotic interactions many other species and ecological processes) by direct exploitation, habitat elimination, and modification of ecological processes (USEPA 1999). By changing the access of species to their food and shelter, human activities initiate a cascade of biotic interactions that can affect entire ecosystems (USEPA 1999). Impervious surfaces prevent infiltration and direct water away from subsurface pathways to overland flow, increasing the flashiness of streams. Urbanization and suburbanization commonly exceed the threshold of approximately 10 to 20% impermeable surface that is known to cause rapid runoff throughout the watershed (Center for Watershed Protection 1994). In heavily urbanized watersheds, stream channelization and large amounts of impervious surface result in rapid changes in flow, particularly during storm events. These artificially high runoff events increase flood frequency (Beven 1986), cause bank erosion and channel widening (Hammer 1972), and reduce baseflow during dry periods. Agricultural practices also greatly affect hydrologic patterns (USEPA 1999). Clearing forest environments generally decreases interception of rainfall by natural plant cover and reduces soil infiltration resulting in increased overland flow, channel incision, floodplain isolation, and headward erosion of stream channels (Prestegaard 1988). Draining and channelizing wetlands directs flow more quickly downstream, increasing the size and frequency of floods, and reducing baseflow (USEPA 1999). Such activities can actually increase the magnitude of extreme floods by decreasing upstream storage capacity and accelerating water delivery. Human activities, such as land clearing and erosion, can cause the loss of nutrients (e.g., phosphorus), disrupt natural cycling of nutrients, and limit ecosystem productivity (USEPA 1999). At the same time, agriculture and industry can discharge excessive amounts of nutrients (e.g., nitrogen) into natural ecosystems and drastically change their trophic structure, and degrade water quality.
BANCHAR	Character of the Resaca Banks	**Definition:** Bank characterization was used as a proxy to indicate the biocomplexity of the systems fringe buffers, and included descriptions of the resaca's left and right banks based on slope features and vegetation presence on the banks. **Rationale for variable selection:** High structural complexity promotes diversity in ecosystems. Species rarely occupy area – they occupy three-dimensional space (Giles 1978). The abundance of vegetative structure greatly influences the abundance and diversity of animals in both wetland and terrestrial ecosystems - complex habitats accommodate more species because they create more ways for species to survive (Norse 1990). Furthermore, studies indicate that physical structure may prevent generalist foragers from fully exploiting resources and thus promote the coexistence of more species (Werner 1984). In particular, vertical stratification diversification of forests produces stratification of light and temperature, as well as providing intricate spaces for shelter and food sources for species. Thus, structural complexity plays a critical role in the presence of microclimate, food abundance, and cover that affect organism fitness (Cody 1985). Optimum resaca wetlands had gentle sloping shorelines that were densely vegetated and highly structured. In the past, urbanization of the Brownsville resacas was often accompanied by residents altering the shoreline for aesthetic and recreational purposes.

Code	Variable Description	Rationale
CONTIG	Proportional Amount of Contiguous Vegetation Surrounding the Resaca Subdivision (%)	**Definition:** The amount of contiguous vegetation surrounding the resaca subdivision in proportion to the total perimeter of the resaca subdivision was used as a proxy to indicate spatial integrity or the degree of habitat fragmentation across the system. **Rationale for variable selection:** Fragmentation of remnant habitats is of key concern in this watershed. Simple geometry dictates that small fragments have more edge in relation to their area than large transects, and that the less like a circle the fragment is, the greater is its perimeter. The consequences of decreased core and increased edge include: (1) the change in physical conditions (organisms near the edge are subjected to more wind, less moisture, and greater temperature extremes) and (2) invasion by species from the surrounding habitat (USEPA 1999). Edges are artifacts of man-modified landscapes which are permanent, yet dynamic, and are highly associated with the universal impacts of urbanization in forested and grassland regions (Ranney et al. 1981). It has been conclusively shown that there is a selective effect on tree composition and forest island dynamics when edges are created (Ranney et al. 1981). Edges have high cover densities (Schreiber et al. 1976; Johnson et al. 1979) and represent convergence of contrasting habitats (Odum 1959; States 1976). A higher percent of edge area is a clear indication of habitat fragmentation that results in smaller, isolated biogeographical "islands." As these islands become smaller, edge species replace interior species, which can lead to extirpation of interior-dependent species. The creation of edges will lead to a regression from mature, mesic conditions to dryer, pioneer conditions in the interior (Ranney et al. 1981). Forest edges generate microclimatic gradients which result in a physical environment that differs from both open fields and interior forests. As such, many species of wildlife are attracted to edges where two or more of these habitats adjoin (Herkert et al. 1993). Edge is a line value, but must be visualized as a condition (i.e., edge is a zone) (Giles 1978). Fragmentation of key habitat corridors in the Lower Rio Grande Valley was a serious concern for the team at the onset of the model development process because the contiguousness of a particular habitat was thought to dictate its use by various migratory bird species and ranging mammals.
DO	Average Dissolved Oxygen (ppm) for the Resaca in June/July	**Definition:** The amount (ppm) of dissolved oxygen that was present in the resacas during the summer months (June/July) was a critical factor for determining water quality in these systems. **Rationale for variable selection:** The overall value of a wetland and its associated aquatic floral and faunal communities can be directly attributed to the general water quality of the system. High dissolved oxygen concentrations were the desired outcome. Increased anthropogenic stressors have been known to significantly alter water quality conditions. This variable was included to capture the degraded situation at baseline, and to demonstrate how urban encroachment would lead to further degradation.
INFILTRATE	Proportion of the Resaca Study Area that is Impervious to Infiltration (%)	**Definition:** The proportion of the area surrounding the resaca that would impede infiltration of precipitation and storm water runoff (i.e., impervious surfaces) was used as a proxy to indicate the degree of hydrologic alteration experienced with the system. **Rationale for variable selection:** Impervious surfaces are artificial structures, such as pavements and building roofs, which replace naturally pervious soil with impervious construction materials. They are an environmental concern because, with their construction, a chain of events is initiated that modifies urban air and water resources (Rosenberg 2006). Impervious surfaces seal the soil surface, eliminating rainwater infiltration and natural groundwater recharge. Stream-flow in dry summers declines, leaving some cities with local water shortages. Stormwater runs directly across the impervious surfaces, raising flood peaks into destructive bursts. Stream channels erode; sediment loads are high. The shifting substrate eliminates aquatic habitats. Oil and heavy metals,

Code	Variable Description	Rationale
		which leak and corrode from automobiles, flush into streams without modification. In some cities, the flood waters get into combined sewers, causing them to overflow, flushing their raw sewage into streams. Impervious construction materials collect solar heat in their dense mass. When the heat is released, it raises air temperatures, producing urban "heat islands", and increasing energy consumption in buildings. The warm runoff from impervious surfaces reduces dissolved oxygen in stream water, making aquatic life still harder (Rosenberg 2006). Impervious pavements deprive tree roots of aeration, eliminating the "urban forest" and the canopy shade that would otherwise moderate urban climate. Because impervious surfaces displace living vegetation, they reduce ecological productivity, and interrupt atmospheric carbon cycling (Rosenberg 2006). Stream flow can increase as the amount of impervious surface expands during land development for commercial and residential uses (USEPA 1999). Impervious surfaces prevent infiltration and direct water away from subsurface pathways to overland flow, increasing the flashiness of streams. Urbanization and suburbanization commonly exceed the threshold of approximately 10% to 20% impermeable surface that is known to cause rapid runoff throughout the watershed (Center for Watershed Protection 1994). In heavily urbanized watersheds, stream channelization and large amounts of impervious surface result in rapid changes in flow, particularly during storm events. These artificially high runoff events increase flood frequency (Beven 1986), cause bank erosion and channel widening (Hammer 1972), and reduce baseflow during dry periods. These modifications of natural hydrologic patterns are perhaps the most pervasive effects of human activities. Although the resaca systems in this region were dependant upon recharge from the Rio Grande and its tributaries, precipitation was considered a key secondary source of water for these systems. The proportion of the landscape surrounding the resacas that impeded infiltration due to impervious conditions was important to the recharge scenario. High proportions of impervious landscape limited recharge to a significant degree.
NOXIOUS	Percent Frequency of Noxious Species Occurrence (%)	**Definition:** The frequency of noxious flora species was measured as the percent of occurrence within the resaca. Noxious species were thought to be indicators of disturbance in the region. This variable was critical for identification of potential restoration sites. **Rationale for variable selection:** Noxious species were considered aggressive invaders whose appearance was likely to lead to undesirable competition for the native communities. In the expert's opinion, the result was likely to be homogenous stands of less suitable habitat. One anticipated affect of advancing urban encroachment was noxious species introduction into the area. This variable was included to capture the threat of invasion and competition by noxious species, that would, in turn, lead to a decline in the overall habitat. The variable was also used to develop planting lists and offered suggestions for management strategies for the proposed restoration alternatives such that noxious species were removed or contained.
SALINITY	Average Salinity (ppm) for the Resaca in June/July	**Definition:** The salinity levels in the resacas during the summer months (June/July) were critical factors in determining water quality and aquatic habitat conditions in these ecosystems. **Rationale for variable selection:** The overall value of a wetland and its associated aquatic floral and faunal communities was directly attributed to the general water quality of the system. Increased agricultural practices in the adjacent landscape, and evaporation of the limited volumes in the resacas in the past, led to increased salinity concentrations in these wetlands. This variable was included to capture the degraded conditions at baseline, and to demonstrate the effects of land-use practices on water quality in the future.

Code	Variable Description	Rationale
SEDIMENT	Potential Proportion of Sediment Deposition in the Resaca (%)	**Definition:** The sediment deposition in the resaca was measured as the proportion of the resaca volume filled with silt. Increased sediment deposition was indicative of urban disturbance. **Rationale for variable selection:** The volume of water available to aquatic floral and faunal communities was key in the arid setting of the Lower Rio Grande Valley. Urban encroachment and agricultural practices in the past had caused the Brownsville resacas to silt in, leaving very shallow pools to support the remaining wildlife and vegetation communities. This variable was included to capture this shallowing, and relate future population growth and urban encroachment to the overall decline in habitat suitability within these ecosystems.
TEMP	Average Water Temp for the Resaca in June/July (Co)	**Definition:** The temperature (Co) of the water during the summer months (June/July) was considered a critical factor for determining water quality and aquatic habitat suitability. **Rationale for variable selection:** The overall value of a wetland and its associated aquatic floral and faunal communities was directly attributed to the general water quality of the system. Low summer temperatures were the desired outcome, and were linked indirectly to the level of water in each resaca. The shallowing process described in the sedimentation variable above was likely to lead to increased temperatures and the decline in habitat suitability overall. This variable was included to capture the degraded conditions at baseline, and to show how decreases in volume would lead to further degradation of the resaca systems.
TURBIDITY	Average Turbidity for the Resaca (ppm)	**Definition:** The levels of turbidity present in the system during the summer months (June/July) were considered to be critical factors in the determination of habitat suitability based on water quality. **Rationale for variable selection:** The overall value of a wetland can be directly attributed to the general water quality of the system. Low levels of turbidity were thought to be the desired outcome. Increased agricultural practices and urban runoff from the adjacent landscape was expected to exacerbate turbidity levels in these wetlands. This variable was included to capture the degraded conditions at baseline, and to demonstrate how changes in land-use practices would lead to further degradation in the future.
WIDTH	Average Width of the Vegetation Surrounding the Open Water of the Resaca Subdivision (m)	**Definition:** Average width (in meters) of the vegetation surrounding the open water of the resaca subdivision was a key factor in determining habitat suitability. **Rationale for variable selection:** The value of buffers was considered a well-accepted and documented phenomenon in wetland ecology. A minimum threshold or size of buffer was studied, and has been shown to shield wetlands from the anthropogenic effects of urban encroachment. This variable was included to characterize the existing fringe buffer of the Brownsville resaca ecosystems, and provide direction for future design of these vegetative safeguards against the eminent threat of human disturbance.
WQBUFF	Percent of the Resaca that is Surrounded by a 30-m Vegetative Buffer	**Definition:** The proportion of the 30-m buffer surrounding a resaca consisting of suitable vegetation to provide a degree of water quality buffering or polishing for the resaca wetlands. **Rationale for variable selection:** The vegetated buffers surrounding resacas are becoming an increasingly important option for improving water quality and conserving wildlife populations for the region. There is solid evidence that providing buffers of sufficient width (0-30 m) protects and improves water quality by intercepting non-point sources of pollution in surface and shallow subsurface water flow (Fischer and Fischenich 2000 and references therein).

Walker 1997, Landres et al. 1999). When reference sites included altered or disturbed ecosystems (as is the case in most urban-based ecosystem restoration efforts), the reference conditions exhibited a wider range of values that reflect both natural variability and variability due to human activities. In these instances, optimal conditions or "virtual" references have been established using a variety of techniques including literature values, historical data, paleoecological data, and expert opinion [Society for Ecological Restoration International (SERI) 2004; Ecological Restoration Institute 2008]. Regardless of how reference conditions have been established, ecosystem evaluations have used a reference-based approach as a template for model development, planning, and alternative analysis.

Various types of reference-based approaches have been developed for a variety of ecosystems including streams (Barbour et al. 1999, Karr and Chu 1999, Bailey et al. 2004b), large rivers (Angradi 2006, Flotemersch et al. 2006), wetlands (Smith et al. 1995, Brinson and Rheinhardt 1996, Smith 2001, USEPA 2002), grasslands (Prober et al. 2002), forests (Fule et al. 1997, Moore et al. 1999, Tinker et al. 2003, Ecological Restoration Institute 2008), tidal marshes/estuaries (Findlay et al. 2002, Merkey 2003), and coral reefs (Jameson et al. 1998). Reference-based approaches have also been used to evaluate ecosystems in a landscape or watershed context (Warne et al. 2000, Andreasen et al. 2002, Reindardt et al. 2007, Wardrop et al. 2007, Whigham et al. 2007, Smith 2008).

Reference site selection strategy

Choosing the relevant reference conditions in a region is a matter of judgment (Andreasen et al. 2002). In some instances, the natural state might be reconstructed from historical records or based on scientific knowledge such as reconstruction of potential vegetation. ERDC-EL assisted the District in locating a series of sample sites across the entire study area that were considered either reference standard (optimal) or degraded (sub-optimal) and represented the range of conditions existing within the reference domain.

Early in the process, ERDC discussed the selection of reference sites with the District for the community model. The directives given to the District can be summarized as follows:

A. Definitions

1) ***Reference*** sites serve several purposes in HEP. First, they function as the physical representation of the communities from the region that can be observed and measured repeatedly. Second, they make it possible to establish the range of variability exhibited by the measures of the model variables, which make it possible for calibration of variables and indices. Third, they serve as a template for restoration by providing design specifications.

2) ***Reference standard*** areas are those optimum conditions in the region that are then used to establish the highest standard of comparison for calibrating assessment model variables and indices. In HEP, the least altered areas in the least altered landscapes are selected as *reference standard* sites. This is based on the assumption that these areas sustain the highest level of function across the suite of habitats within the community that are inherent to the system.

B. General Selection Strategy

1) ***Conduct field reconnaissance*** to screen potential candidate reference sites. The objective is to identify sites that represent the range of conditions that exist in the reference area from highly altered sites in highly altered landscapes to unaltered (pristine) sites in unaltered landscapes.

2) ***Determine the number*** of reference sites to be included. A variety of factors influence the number of reference sites to be included in the process. Large projects will require more reference sites. Reference areas with a wide variety of alteration scenarios will require more sites. Detail of resolution to detect the types of impacts that typically affect riparian areas in the region is another factor. Lastly, the ideal number of sites dictated by the foregoing considerations must be balanced against the realities of budgets, time, and personnel.

C. Criteria for Defining Reference Conditions

1) Must be politically palatable and reasonable;

2) Must include a large number of sites from the region;

3) Must represent important aspects of pre-historical conditions;

4) May use minimal disturbance as the surrogate for pre-historical conditions, given the difficulty of establishing pre-historical conditions;

5) Must be uniform across political boundaries and bureaucracies (e.g., Federal, State, and local); and

6) When the areas have experienced extensive alteration, it may be possible to reconstruct a reference standard area using historical accounts and photography.

Desired reference standard conditions

Reference site characterization and model calibration for this study included gathering data on water quality, hydrology, substrate conditions, flora, and fauna, and to the greatest extent possible, identifying underlying stressors in the region. In particular, land-use activities, physical habitat alterations, and native species were identified. In addition to the physical and chemical characteristics of the study area, land ownership and regulatory jurisdictions played an important role in determining impacts/ mitigation and opportunities for restoration. Some of this information was geographically based and was assessed using documented protocols in an ArcGIS environment. Based on this inventory and reconnaissance effort (completed by the District in early 2004), the reference standard conditions for the Brownsville resacas community were characterized in the following manner:

Water Quality – Water quality characteristics (dissolved oxygen, salinity, turbidity, temperature, sedimentation) were not altered by human disturbances that would lead to changes in hydroregime (flood frequency, duration, or magnitude) or sediment transport. Flood pulsing and overland flow mimicked the climatic/natural regime. Vegetation was present to resist flow downstream, and together with topographic relief and subsurface water flow, promoted surface water storage. The flood-prone area was undisturbed by humans. Surface hydraulic connections existed between the subdivisions. Surface water ponded throughout the drier season (May-August) in these areas. Groundwater and the managed water supply were appropriate to establish and maintain a diverse cover type.

Biogeochemical – A range of vegetation types and sediment combined with suitable topographic relief to support detention of particulates. Sufficient water flow through the riparian zone (surface and subsurface) was evident as well as substrates with enough silt to adsorb elements, promote propagule recruitment, and supply organic materials. In addition, presence of organic matter indicated that nutrient cycling was occurring within the ecosystems.

Spatial Configuration – Spatially-explicit landscape characteristics within the ecosystems associated with patch geometry and distribution were optimized. Landscape simplification was absent – a mosaic or heterogeneic suite of habitat types was present in both sufficient size and numbers to promote both core area stability and edge diffusion (a blurring of the edge contrast). Habitat connectivity was evident and supported the persistence of both plant and animal populations. Distances between high quality patches were minimized, and a mixture of age classes were present within a reasonable distance of one another to promote niche diversification and offer escape routes during stochastic disturbances. Land adjacent to the reference areas was undeveloped and unperturbed by human disturbances such as agricultural activities.

Biotic Integrity and Structure – An abundance of native trees, shrubs, and herbaceous vegetation was readily apparent. Invasive plant species were absent. Guild representatives (i.e., indicators) included a wide variety of growth forms (trees, shrubs, vines, grasses, forbs, algae, and lichens). Plant vertical configuration and foliage profile (canopy cover) presented a variety of vertical layers. Vegetation provided vertical and horizontal connectivity the length of the system. All age classes of trees (seedlings, saplings, and trees) were represented in the forested communities. Biotic legacies from preceding communities, propagules from adjacent stands, ecosystem structuring processes, and the generation of spatial heterogeneic complexes combined to produce both overall compositional diversity and patch diversity (habitat breadth).

Reference site selection

Once the inventory and reconnaissance were completed, the E-Team used the strategy outlined above to filter and screen the potential sites down to a manageable number. Because the community-based index model was developed to operate on a larger watershed scale, it was important to calibrate it at its intended operational level – in this case at a subdivision level. The District used criteria such as degree of human disturbance, land use, resaca morphology (resaca width, bank characteristics, flow patterns, and water depth) as well as current flow control/pumping stations to delineate unique resaca conditions across the watershed. In total, nine individual subdivisions were defined (Figure 38).

To assure adequate sampling size, the District was asked to locate ~30 individual sites spanning the range of reference conditions and representing the relative variation found across the system as well as across the domain. An attempt was made to evenly distribute these sites across the entire domain and amongst the subdivisions. The experts were then asked to rank the reaches based on perceived functionality where 1 = "best" and 9 = "worst" (Table 5).

Initial rankings (high vs. medium vs. low) were based upon the consensus of the "on-the-ground" resource managers who had actual knowledge of each site's level of disturbance, species composition, land ownership, and the presence or absence of hydrologic alterations as indicated. These scores were further stratified based on the degree of urbanization experienced in each of the subdivisions. The subdivision with the highest degree of disturbance (based on urban and agricultural land use (TR2) was given a score of 9, and the subdivision with the lowest percent (RG1) was given a score of 1. The remaining subdivisions were arrayed between these two subdivisions.

Field sampling scheme and transect layouts

To develop a baseline characterization of the South Laguna Madre watershed, hydrologic, floristic, and spatially-explicit data were collected system-wide. To the greatest extent possible, underlying stressors in the region were also identified. In particular, land-use activities, physical habitat alterations, and indicator species were described in detail. Some of this information was geographically based and was assessed using documented protocols in a GIS environment. As part of the basic site characterization efforts, historical data on landscape-scale habitat conditions, land-use characteristics, and ownership patterns were collected as well. Site- and landscape-level data were collected in 2004 using a systematic random sampling approach. A total of 210 cross-sectional transects were randomly arrayed across the resaca subdivisions (Figure 39).

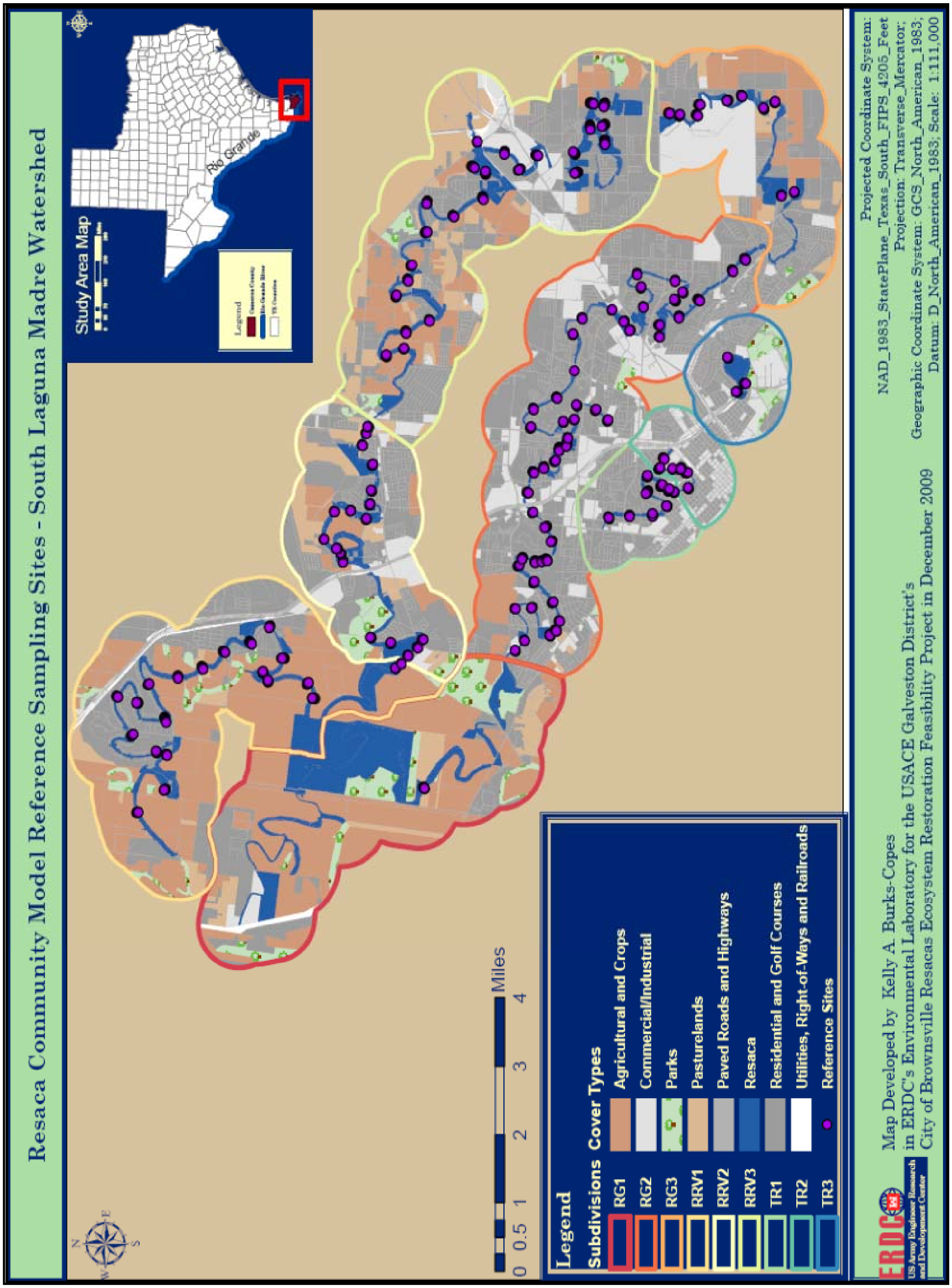

Figure 38. Brownsville resaca reference sites used to calibrate the community index model.

Table 5. Brownsville resaca reference site characterization based on expert opinion.

Subdivision	Expert Rank	Justification
RG1	1	High functionality was anticipated based on the lower degree of urban settlement around this subdivision (27%). The surrounding landscape was predominantly agricultural croplands. As such, the water quality of the system was likely to be less polluted by sewage releases during floods, but runoff from fields will likely degrade the water quality conditions. Salinity and sediment inputs were expected to be higher as well. This subdivision had the largest remaining relictual riparian stands in the system (18% of the subdivision).
RRV1	2	High functionality was anticipated based on the lower degree of urban settlement surrounding this subdivision (36%). The surrounding landscape was predominantly agricultural croplands. Runoff from these croplands contributed to water quality degradation (e.g., increased salinity and sedimentation), leading to shallowing of the pool and increased water temperatures. Approximately 11% of the subdivision's footprint provided riparian habitat.
RRV3	3	Moderate functionality was anticipated due to the moderate levels of urbanization in this subdivision (54%). Water quality was considered a problem, and relictual habitat was considered sub-optimal due to a high degree of noxious species invasion. Approximately 9% of the subdivision's footprint provided riparian habitat.
RRV2	4	Moderate functionality was anticipated due to the moderate levels of urbanization in these subdivisions (62%). Water quality was considered a problem, and relictual habitat was considered sub-optimal due to a high degree of noxious species invasion. Approximately 10% of the subdivision's footprint provided riparian habitat.
RG3	5	Moderate functionality was anticipated due to the moderate degree of urban settlement surrounding this subdivision (70% of the footprint had been urbanized). Water quality was thought to be degraded, but not to the degree experienced in the more populated areas of the system. Approximately 7% of the subdivision's footprint provided riparian habitat.
RG2	6	Low functionality was anticipated due to the higher degree of urban settlement surrounding this subdivision (91% of the footprint was considered urbanized). The direct inputs of sewage and sediment during flooding events were thought to have severely degraded the water quality conditions, and the relictual habitat was highly colonized by noxious species. Approximately 5% of the subdivision's footprint provided riparian habitat.
TR3	7	Low functionality was anticipated due to the higher degree of urban settlement around these subdivisions. Water quality was severely degraded as a direct result of sewage releases and sediment transport into the systems during flood events. The shallowing of this subdivision led to steadily increasing water temperatures and increased salinity. Approximately 7% of the subdivision area remains in a quasi-natural state – the remaining 93% of the study area was urbanized. The majority of the shoreline had been cleared or filled with bulkheads and planted with ornamentals and/or grass. Noxious species have colonized a great deal of the remaining habitat.
TR1	8	Low functionality was anticipated due to the higher degree of urban settlement around these subdivisions. Water quality was severely degraded as a direct result of sewage releases and sediment transport into the systems during flood events. The shallowing of this subdivision led to steadily increasing water temperatures and increased salinity. Less than 4% of the subdivision area remains in a quasi-natural state – the remaining 96% of the study area was urbanized. The majority of the shoreline had been cleared or filled with bulkheads and planted with ornamentals and/or grass. Noxious species have colonized a great deal of the remaining habitat.
TR2	9	Low functionality was anticipated due to the high degree of urban settlement around these subdivisions. Water quality was severely degraded as a direct result of sewage releases and sediment transport into the systems during flood events. The shallowing of this subdivision had led to steadily increasing water temperatures and increased salinity. Less than 2% of the subdivision area remains in a quasi-natural state – the remaining 98% of the study area was urbanized. The majority of the shoreline had been cleared or filled with bulkheads and planted with ornamentals and/or grass. Noxious species have colonized a great deal of the remaining habitat.

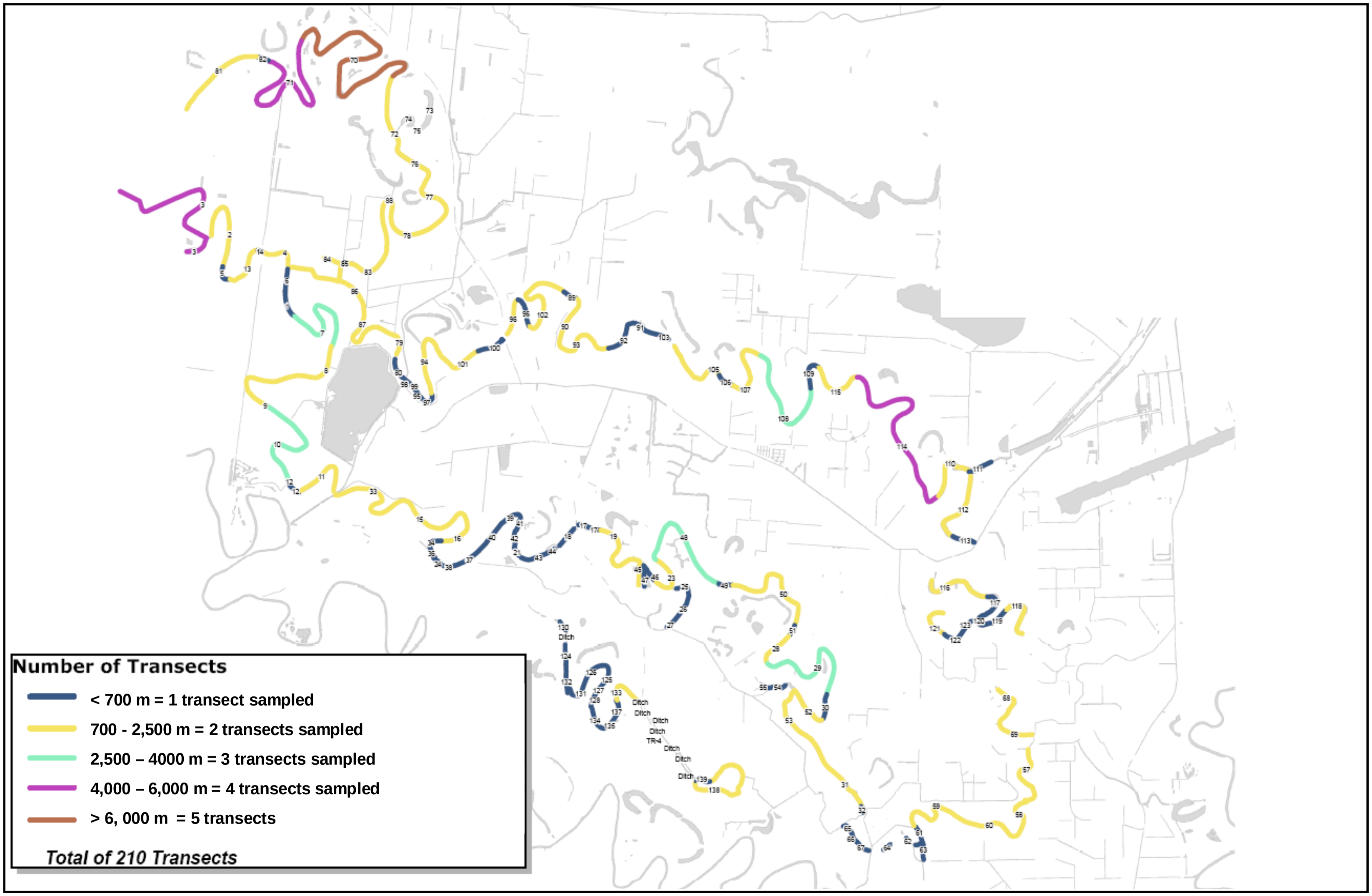

Figure 39. The random array of transects sampled across the study area are depicted here. The number and distribution of transects was based upon the contiguous length of each polygon. In other words, transects were randomly arrayed across each polygon, and longer polygons had more transects.

The first sampling point along a transect was always taken at 1 m waterward from the resaca bank (e.g. left bank), then the second at 10 m, 20 m, etc., with the last sampling point located 1 m in (waterward) from the opposite resaca bank (e.g. right bank). Given this method of locating sampling points, the following guidelines were used to estimate the number of sampling points for transects on resacas polygons of varying widths:

1. If the length of the transect was ≤ 25 m, a total of four points maximum were sampled along the transect;
2. If the length of the transect was > 25 m and ≤ 35 m, a total of five points maximum were sampled along the transect;
3. If the length of the transect was > 35 m and ≤ 45 m, a total of six points maximum were sampled along the transect;
4. If the length of the transect was > 45 m and ≤ 55 m, a total of seven points maximum were sampled along the transect;
5. If the length of the transect was > 55 m and ≤ 65 m, a total eight points maximum were sampled along the transect; etc.

For example, a resaca polygon less than 25 m in width would be sampled as indicated in Figure 40 below.

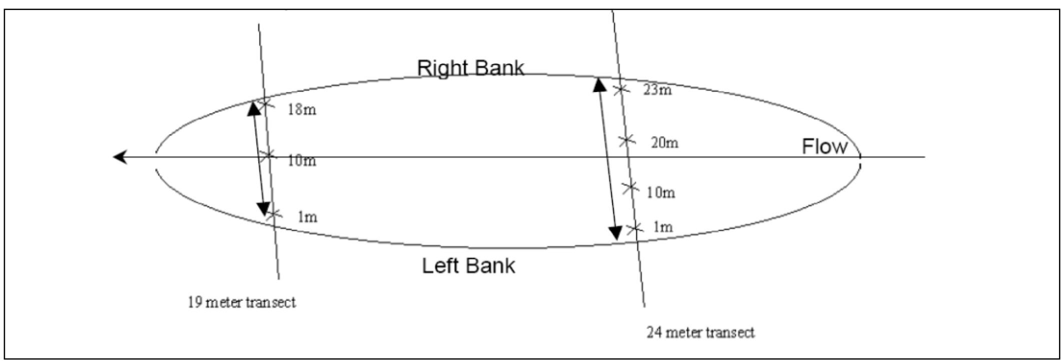

Figure 40. Field sampling protocol for the resacas baseline inventory.

To reduce data collection variability, a three-person sampling team (a recorder and two data collectors) collected all field data. To the greatest extent possible, underlying stressors in the region were described in the notes section of the field data collection sheets. In particular, land-use activities, physical habitat alterations, and indicator species were described in detail. Table 6 provides specific information regarding samples collected in the field.

Table 6. Field sampling protocols summarized for the variables associated with the resaca community index model.

Code	Variable Description	Sampling Methodology
BANKCHAR	Character of the Resaca's Left and Right Banks	Using GIS, aerial photographs, and field observations, the banks (i.e. shorelines) of the resaca were categorized on the basis of slope, cover, and land/water interface. Photo-documentation of each transect was collected as well. 1. Bank Characteristic Categories: The category that most resembled the bank condition of the bank characteristic was selected: Gentle Slope vs. Steep Slope vs. Cut Bank or Bulkhead 2. Vegetation Zone Categories: a. Submergent/in-water (aquatic) – submergent or floating vegetation growing at or below the water surface. b. Emergent Fringe (aquatic) – herbaceous vegetation c. Scrub/shrub (woody) – woody vegetation less than 6 m (20 ft) in height and less than 15 cm in diameter d. Forest (woody) – woody vegetation greater than or equal to 6 m (20 ft) in height and greater than or equal to 15 cm in diameter e. Yard (grass or landscaped) – residential and commercial/industrial areas, golf courses, parks, etc., that are mowed and maintained.
DO	Average Dissolved Oxygen (ppm) for the Resaca in June/July	Measured DO (ppm) at each sampling point along the transect.
NOXIOUS	Percent Frequency of Noxious Species Occurrence (%)	Recorded presence(+) or absence(-) of noxious species at each sampling point along the transect within the identified vegetation zones.
SALINITY	Average Salinity (ppm) for the Resaca in June/July	Measured salinity (ppm) at each sampling point along the transects.
SEDIMENT	Potential Proportion of Sediment Deposition in the Resaca (%)	Measured the water depth and depth of unconsolidated sediment/silt at each point along the transects. Calculated the proportion of sediment deposition in the resaca by dividing the depth of unconsolidated sediment/silt (cm) (SD) by the depth to hard bottom (DWA) (unconsolidated sediment/(unconsolidated sediment + water)). The water surface elevation at the time of sampling was documented for each resaca polygon relative to a permanent nearby reference elevation (e.g. permanent control station (monument) or structure such as a spillway, culvert, etc).
TEMP	Average Water Temp for the Resaca (C°)	Measured temperature (C°) at each sampling point along the transects.

Character of the resaca's left and right banks (BANKCHAR)

Data on bank characteristics were collected using GIS, aerial photographs, and field observations to categorically describe the banks (i.e., shorelines) of the resacas on the basis of slope and cover along the land/water interface. At each transect sampled, photos were taken to document and categorize each bank within a 10-m buffer surrounding the resaca. Details of the slope and vegetative categories are found below.

a) Slope Categories: the category that most resembles the bank condition, as described below, was determined.

   Gentle Slope – banks with minimal degrees of elevation to the plane of the horizon (Figure 41).

   Steep Slope – any elevated bank sloping with a large angle to the plane of the horizon (Figure 42).

   Cut Bank or Bulkhead –an excavated bank to the top of the undisturbed slope, or a bank on the outside bend of the resaca channel that has been cut by erosion (Figure 43). A bulkheaded bank refers to vertical partitions that forcibly held the banks in place (Figure 44).

Figure 41. Slope Characteristics – example of a gently sloping bank (Town Resaca, October 2004 photo).

Figure 42. Slope Characteristics – example of a steep sloping bank (Town Resaca, October 2004 photo).

Figure 43. Slope Characteristics – example of a cut bank (Resaca de La Guerra, October 2004 photo).

Figure 44. Slope Characteristics – example of a bulkhead bank (Town Resaca, October 2004 photo).

b) Vegetation Zone Categories: the total number of vegetation layers present on the banks was recorded. The following vegetation zones were recognized:

1. Submergent/in-water (aquatic) – submergent or floating vegetation growing at or below the water surface.
2. Emergent fringe (aquatic) – herbaceous vegetation.
3. Scrub/shrub (woody) – woody vegetation that was less than 6 m (20 ft) in height and less than 15 cm in diameter.
4. Forest (woody) – woody vegetation greater than or equal to 6 m (20 ft) in height and greater than or equal to 15 cm in diameter.
5. Yard (grass or landscaped) – residential and commercial/industrial areas, golf courses, parks, etc., that were mowed and maintained.

Three assumptions are associated with this classification protocol. First, the left and right banks were considered equal and compensatory (i.e., the score was equal to the average of left and right banks). Second, islands were included in scores when present, but the site was not penalized for the absence of islands. Last, the variable was measured at the subdivision level (i.e., all transects within the subdivision were assigned the same score).

Average dissolved oxygen (NTU) for the resaca in June/July (DO)

Using a multiple-probe meter (e.g., Hydrolab or YSI meter), dissolved oxygen (DO) was measured in parts per million (ppm) at each sampling point along each cross-sectional transect sampled. All measurements were taken from the mid-water column between the hours of 7 am and 11 am to assure standardization.

Percent frequency of noxious species occurrence (%) (NOXIOUS)

At sampling points occurring within the vegetation zones identified above, the presence or absence of noxious species was estimated visually. The term noxious included native and non-native terrestrial and aquatic species that, under certain conditions, affected some component of the ecosystem that was undesirable or harmful, thereby reducing suitability and inhibiting or prohibiting restoration success. Table 7 shows the initial list of noxious species drafted for the field reconnaissance team.

Table 7. Noxious species thought to inhabit the Brownsville resaca ecosystems.

Scientific Name	Common Name	Growth Form
Arundo donax L.	Giant Cane	Emergent
Colocasia esculenta (L.) Schott	Elephant-Ear	Emergent
Hydrilla verticillata (L.f.) Royle	Hydrilla	Submersed
Lyngbya wollei	Snotweed or Black Moss	Submersed
Myriophyllum aquaticum (Vell.) Verd	Parrotfeather	Submersed/ Emergent
M. spicatum L. Eurasian	Watermilfoil	Submersed
Phragmites australis (Cav.) Trin.ex Steud	Common Reed	Emergent
Schinus terebinthifolius	Brazilian Pepper-Tree	Emergent
Tamarisk spp.	Salt Cedar	Emergent

Average salinity (ppm) for the resaca (SALINITY)

Using a multiple-probe meter (i.e., Hydrolab), salinity was measured in parts per million (ppm) at each sampling point along the transects. All measurements were taken from the mid-water column between the hours of 7 am and 11 am to assure standardization.

Potential proportion of sediment deposition in the resaca (%) (SEDIMENT)

This variable measured the proportion of sediment deposition in the resacas. At each sampling point along the transects, the water depth and the depth of the unconsolidated sediment/silt within the resaca were recorded (Figure 45).

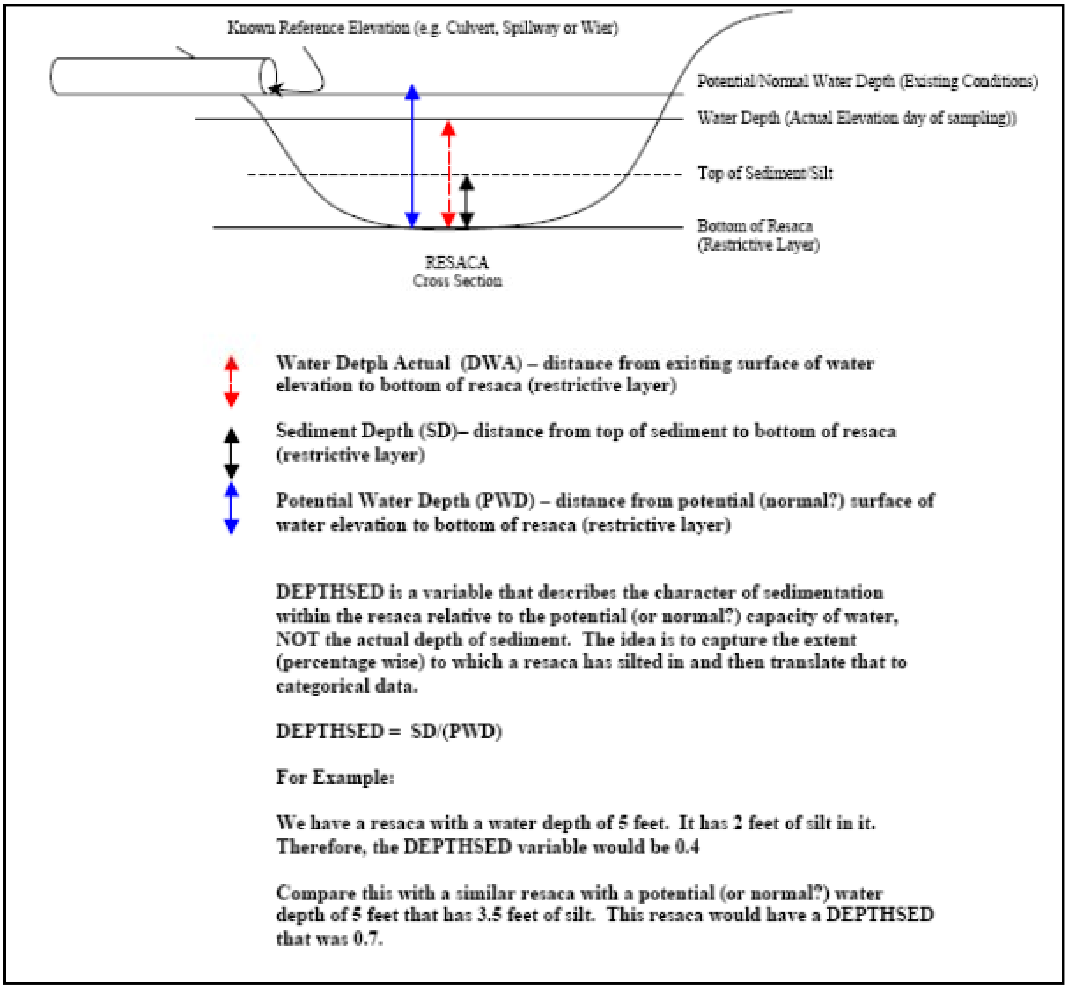

Figure 45. Example of how sediment depth (DEPTHSED) is measured and calculated.

The proportion of sediment deposition was calculated by dividing the depth of unconsolidated sediment/silt (cm) by the total water depth (cm). The water surface elevation at the time of sampling was documented for each resaca polygon relative to a permanent nearby reference elevation (e.g. permanent control station (monument) or structure such as a spillway, culvert, etc.). The particular reference datum used was described and documented for each resaca polygon using GIS.

Average water temperature for the resaca in June/July (C°) (TEMP)

Using a multiple-probe meter (e.g., Hydrolab or YSI meter), the water temperature was measured in degrees Celsius at each sampling point along the transects. All measurements were taken from the mid-water column between the hours of 7 am and 11 am to assure standardization.

Running means

Running means were taken to verify that adequate sample sizes were obtained from this field exercise (Figures 46-52).

Spatially explicit variables and GIS analysis protocols

Landscape variables were determined based on a combination of onsite reconnaissance, interpretation of maps and aerial photos, and analysis of GIS data layers using ArcGIS 9.3. Landscape variable data were collected by the Galveston District.[1] GIS data (Table 8) were collected using year 2000 1-ft resolution orthographic aerial photos. Cover types were digitized at the subdivision level, and values were averaged to represent subdivision means.

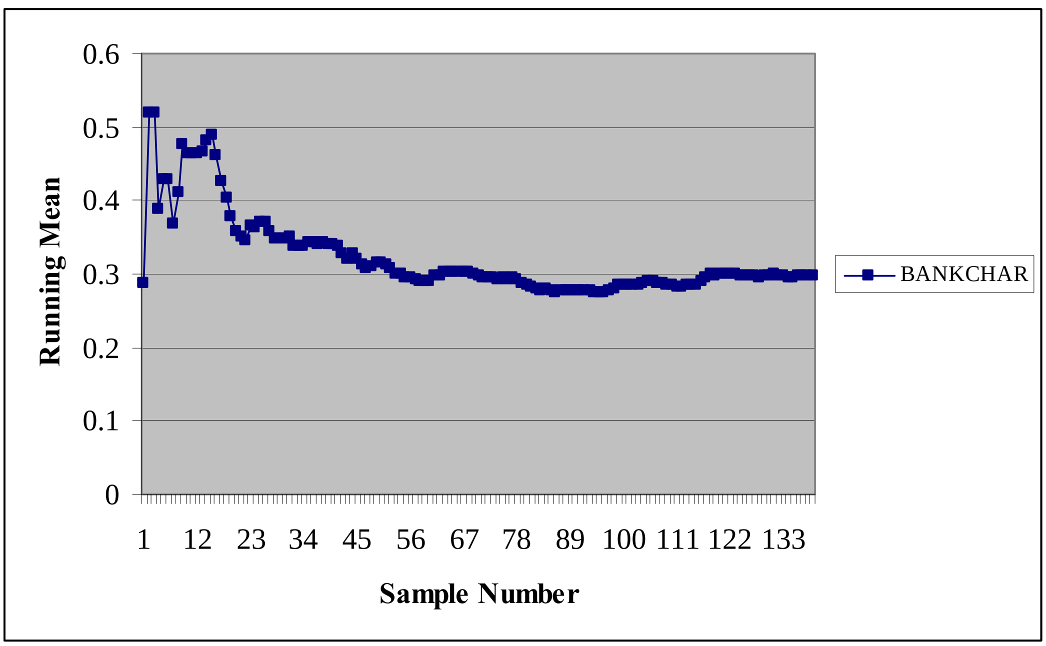

Figure 46. Running means derived for the samples taken in Brownsville resacas for the variable *BANKCHAR – character of the resaca's left and right banks*.

[1] The following information was provided by Andrea Catanzaro in response to a request from ERDC-EL for assessment methodology and documentation. Any questions surrounding this information should be addressed to Ms. Catanzaro (refer to Appendix D for point of contact information).

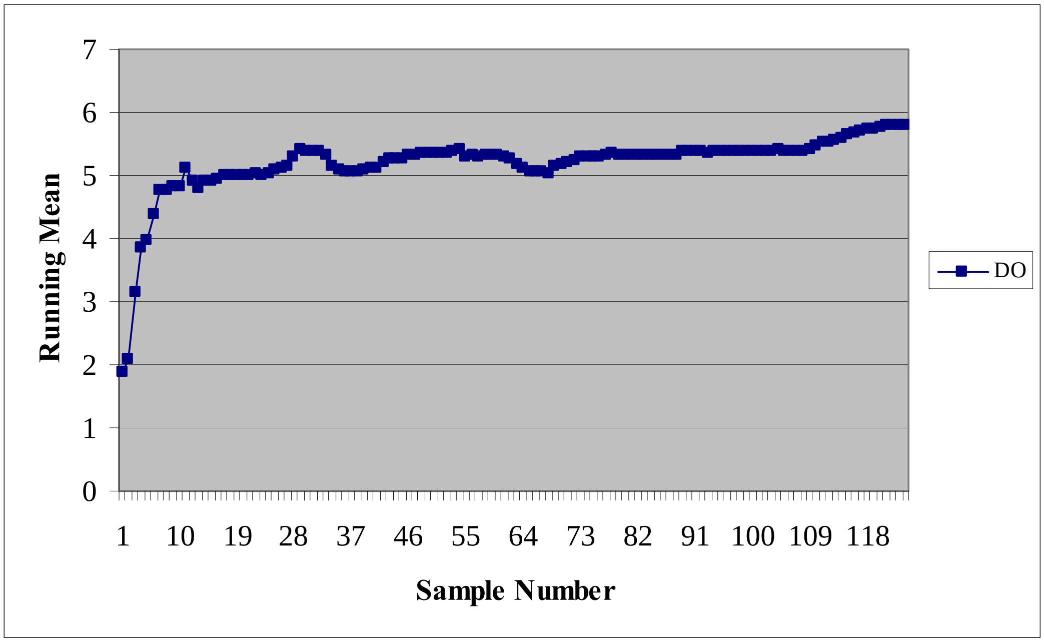

Figure 47. Running means derived for the samples taken in Brownsville resacas for the variable *DO – average dissolved oxygen (NTU) for the resaca in June/July.*

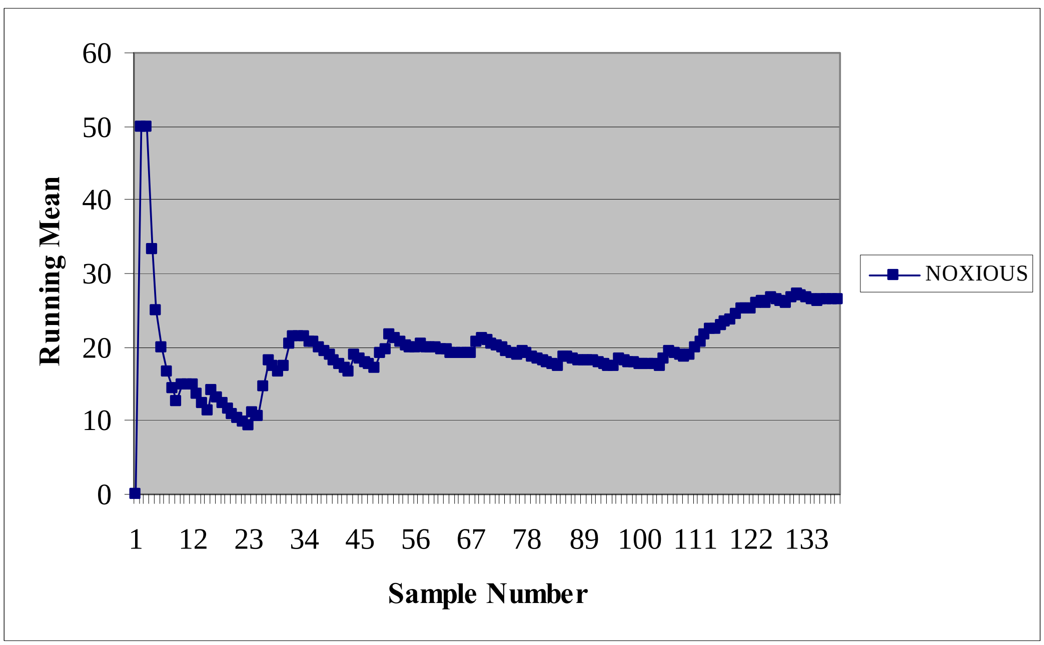

Figure 48. Running means derived for the samples taken in Brownsville resacas for the variable *NOXIOUS – percent frequency of noxious species occurrence (%).*

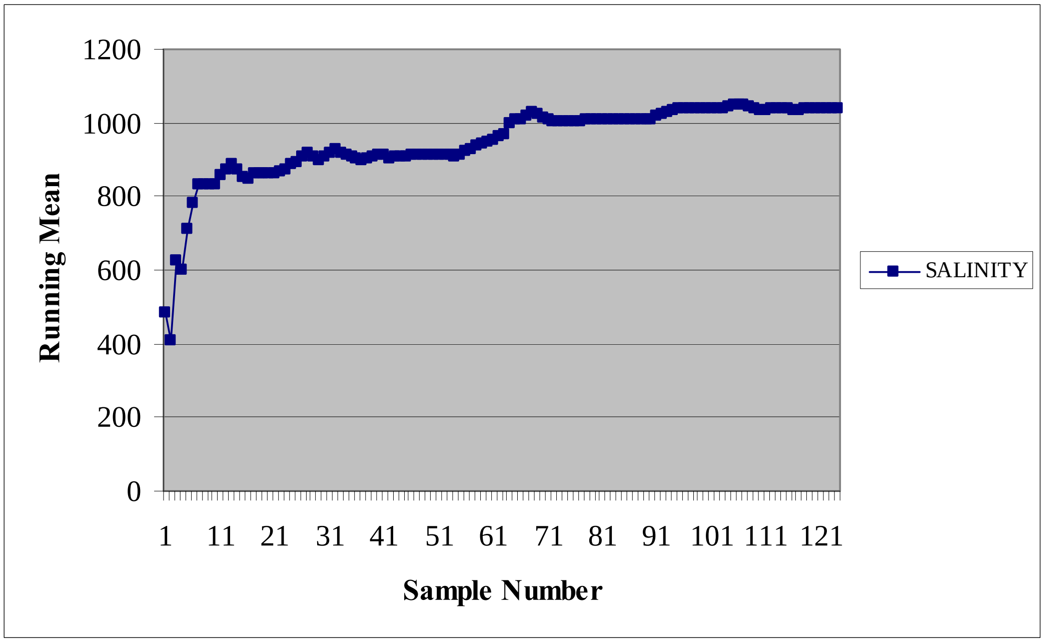

Figure 49. Running means derived for the samples taken in Brownsville resacas for the variable *SALINITY - average salinity (ppm) for the resaca*.

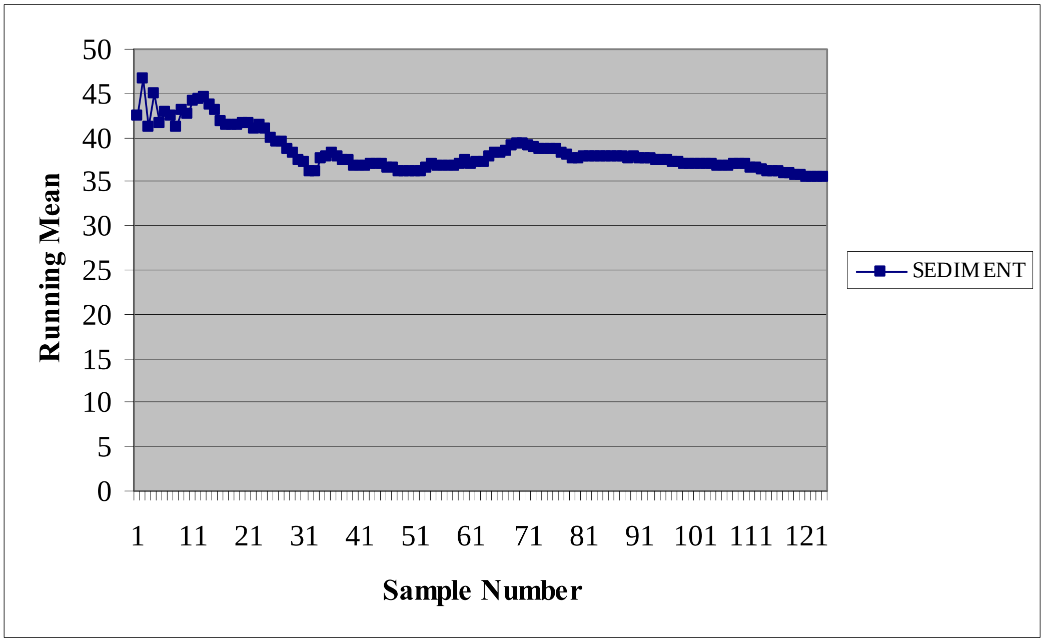

Figure 50. Running means derived for the samples taken in Brownsville resacas for the variable *SEDIMENT – potential proportion of sediment deposition in the resaca (%).*

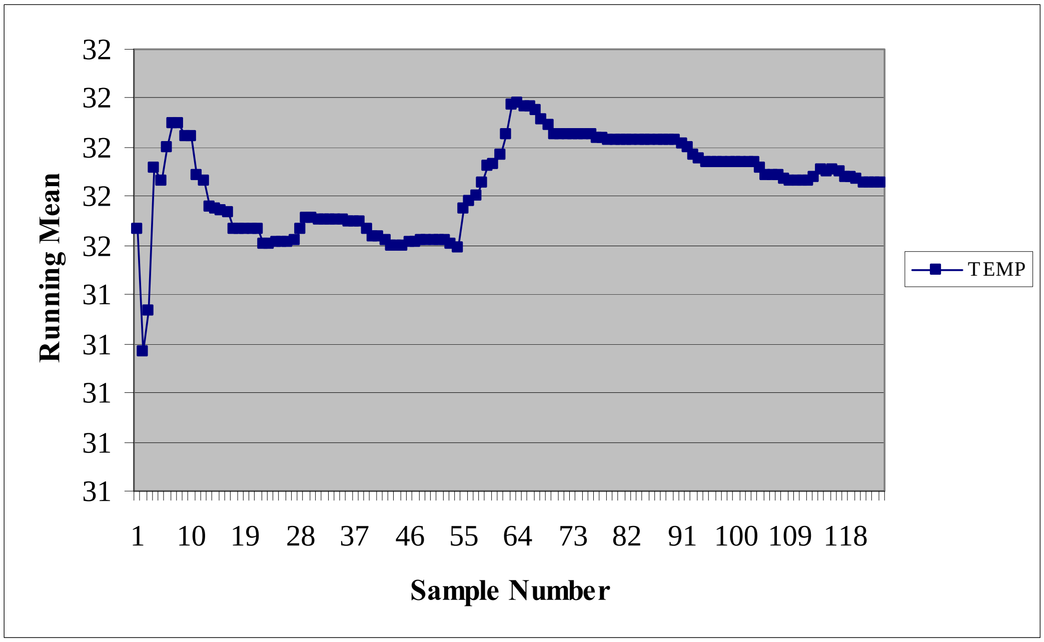

Figure 51. Running means derived for the samples taken in Brownsville resacas for the variable *TEMP – average water temp for the resaca in June/July (C°)*.

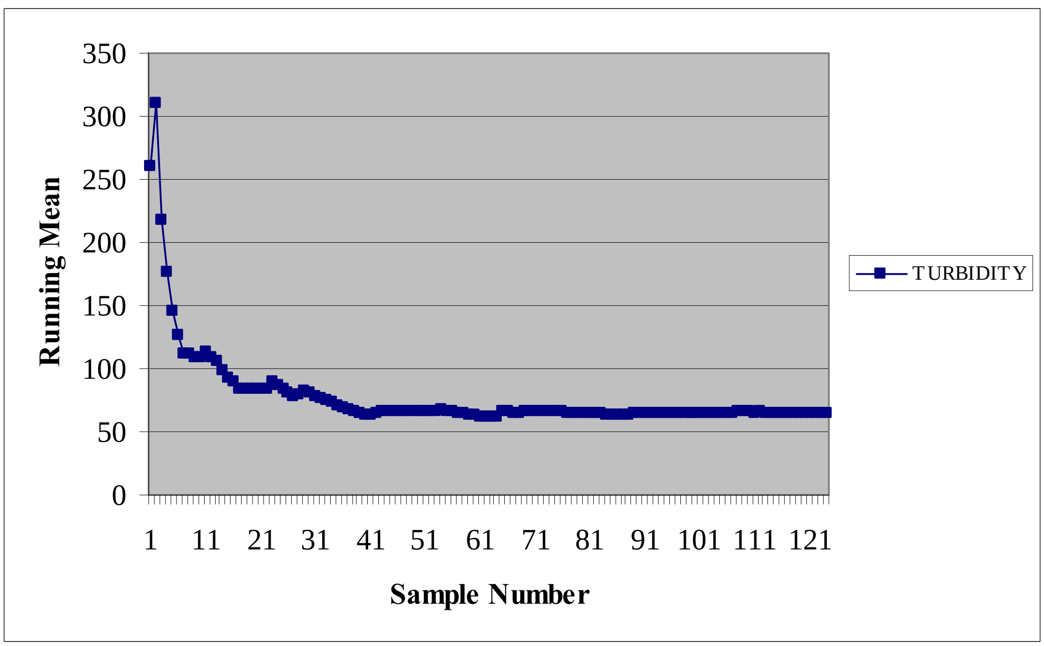

Figure 52. Running means derived for the samples taken in Brownsville resacas for the variable *TURBIDITY – average turbidity for the resaca (ppm)*.

Table 8. GIS sampling protocols summarized for the variables associated with the resaca community index model.

Code	Variable Description	Sampling Methodology
ADJLANDUSE	Identification of Adjacent Land Use	Classified and quantified (in m of the perimeter) the predominant adjacent land use practices immediately surrounding the resaca boundary (which included not only the open water, but the adjacent fringe vegetation (scrub/shrub and forest) using the following categories (1-9) using GIS. Land-Use Categories: 1 = Pristine, Uninhabited Areas 2 = Parks 3 = Pasturelands 4 = Utility Rights-of-way and Railroads 5 = Dirt and Gravel roads, Oil and Gas Fields 6 = Agricultural Croplands 7 = Residential and Golf Courses 8 = Paved Roads and Highways 9 = Commercial/Industrial
CONTIG	Proportional Amount of Contiguous Vegetation Surrounding the Resaca Subdivision (%)	Determined the proportion of the resaca subdivision that has contiguous vegetation using GIS by first measuring the length (m) of contiguous vegetation for each polygon (emergent fringe, scrub/shrub, and forest). This length was then divided by the perimeter length (m) of the polygon. A single value for contiguousness was calculated for each resaca subdivision by adding the length of the continuous vegetation and dividing by the perimeter of the subdivision.
INFILTRATE	Proportion of the Resaca Study Area that is Impervious to Infiltration (%)	Measured the proportion of the area surrounding the resaca subdivision that impeded infiltration of rainfall or runoff using GIS by creating a 1-km buffer around the perimeter of each resaca subdivision. The proportion of the area within this buffer that was considered impervious was then divided by the total acres within the buffered area. Note - area occupied by buildings or paved was considered "impervious."
WIDTH	Average Width of the Vegetation Surrounding the Open Water of the Resaca Subdivision (m)	Measured the width (m) of the vegetation surrounding the resaca subdivision using GIS. Note - the width measurement included any scrub/shrub, forest, and/or emergent fringe vegetation zones.
WQBUFF	Percent of the Resaca that is Surrounded by a 30-m Vegetative Buffer	Measured the width (m) of the vegetation surrounding the resaca subdivision using GIS. Note - the width measurement included any scrub/shrub, forest, and/or emergent fringe vegetation zones.

Adjacent land use (ADJLANDUSE)

With respect to adjacent land use practices (ADJLANDUSE), categories (1 through 9) provided by the master variable list were assigned using observations of land uses adjacent to resaca polygons. Distance along the perimeter of each category was measured (provided in a spreadsheet) using the Land use/Land class file and aerial imagery. The category with the largest distance (highest percentage) was considered the predominant land use.

Proportional amount of contiguous vegetation surrounding the resaca subdivision (%) (CONTIG)

For each resaca polygon, GIS was used to measure the length, in meters, of contiguous vegetation zones comprising the perimeter of the resaca polygon and was then divided by the total perimeter length of the resaca polygon in meters (Figure 53).

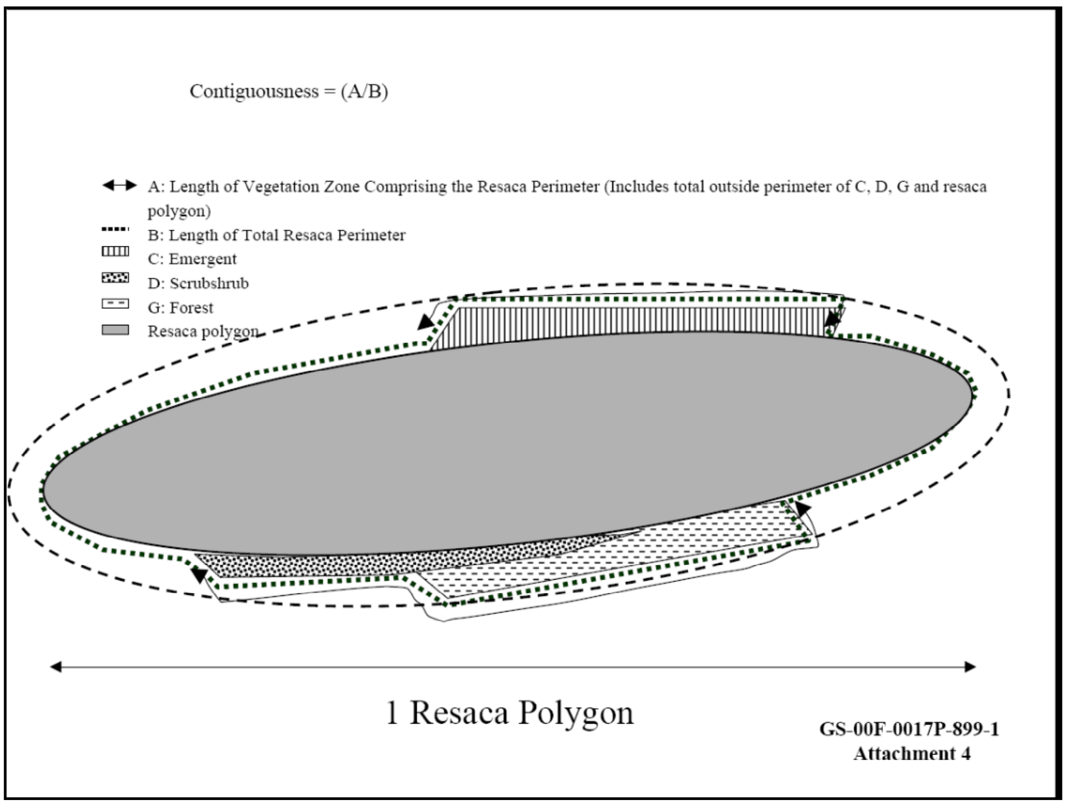

Figure 53. Delineation of contiguous habitat surrounding the resaca polygons indicating the approach to capture this variable using GIS.

A single value for contiguousness was calculated and reported for each resaca subdivision by adding the acres for each vegetation zone and resaca water polygon within a subdivision.

Proportion of the resaca study area that is impervious to infiltration (%) (INFILTRATE)

The percentages of areas adjacent to resacas that were identified as "urbanized" land uses in the baseline Land Use/Land Cover (LULC) shapefiles were considered impervious for the purposes of this effort. The ArcGIS 9.3 *Buffer* tool was used to draw a 1-mile buffer around each polygon. The total area within that buffer classified as "URBAN" was exported to a spreadsheet, along with total buffer area. Urban (i.e., impervious area) was then divided by total buffer area and multiplied by 100 to generate the IMPERVIOUS outputs.

Average width of the vegetation surrounding the open water of the resaca subdivision for the biotic community (m) (WIDTH)

Using GIS and aerial photographs, the width (in meters) of the resaca polygon at each cross-sectional transect sampled was measured. The width measurement included the area of open water as well as any scrub/shrub-land, forest, and emergent fringe vegetation zone immediately adjacent to the open water.

Percent of the resaca that is surrounded by a 30-m vegetative buffer (%) (WQBUFF)

Using GIS and aerial photographs, the contiguous resaca coverages (namely open water, submergent, and emergent fringe habitats) were buffered by a 30-m polygon, and acreages of natural (i.e., forest and shrub fringe) versus other coverages (urban, agricultural cropland, etc) were compared.

Statistical analysis and curve calibrations

Once the data were collected and entered into spreadsheets, average values and standard deviations were calculated per variable. These were reported on a "cover type-by-cover type" basis for each reference site in the watershed. The averages (and standard deviations) were also calculated on a subdivision-by-subdivision basis and reported with the site statistics. To develop curves for each variable, the E-Team used existing water quality information from the Texas Surface Water Quality Standards (Texas

Natural Resource Conservation Commission 2000) combined with expert opinion to calibrate each suitability index. Ultimately, the curves were the result of an iterative process where the E-Team gradually incorporated modifications to break points over the course of several applications to better reflect reality as they perceived it "in the field." A conscious effort was made to fully document these changes as they evolved (contact the authors for more details).

Calculating HEP outputs – An example

An analysis of subdivision-level functionality was performed to test the veracity of the model.

Baseline data inputs

Data for each variable per cover type within the community were recorded and the variable means/modes were calculated to generate baseline HSIs on a subdivision basis. Twelve variables were measured according to the sampling protocols described above at the reference sites for the community. The means for each variable are summarized in Table 9 below.

Table 9. Baseline variable data for the resaca communities across subdivisions.

Resaca	Subdivision	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
Resaca de La Guerra	RG1	6	0.489	100	3.8	5	10	939	45	32	65	595	77
	RG2	7	0.154	35	3.8	40	25	939	35	32	65	70	24
	RG3	7	0.097	85	7.0	15	35	840	40	31	90	170	64
Town Resaca	TR1	7	0.241	35	4.6	50	5	1,128	40	35	35	15	30
	TR2	7	0.047	20	3.4	50	0	1,764	65	31	110	15	21
	TR3	7	0.169	55	9.1	45	50	707	45	31	100	345	65
Resaca del Rancho Viejo	RRV1	6	0.132	80	7.0	20	10	921	30	32	55	480	68
	RRV2	7	0.200	80	8.8	30	70	1,101	35	32	75	165	71
	RRV3	7	0.150	75	7.8	40	35	981	30	32	55	110	58

The mathematical protocol used to generate the HSI and HUs using standard HEP protocols is described below.

Calculating SIs in the baseline HEP analysis

The mean/mode for each variable in Table 9 was normalized using the SI graphs presented in *Appendix E*. The basic mathematical premise is fairly straightforward and easy to complete. For example, if the proportional amount of contiguous vegetation surrounding the resaca subdivision (CONTIG) was 35%, the value "35" was entered into the "X-axis" on the SI curve below, and the resultant SI score (Y-axis) was determined (SI = 0.33) (Figure 54).[1]

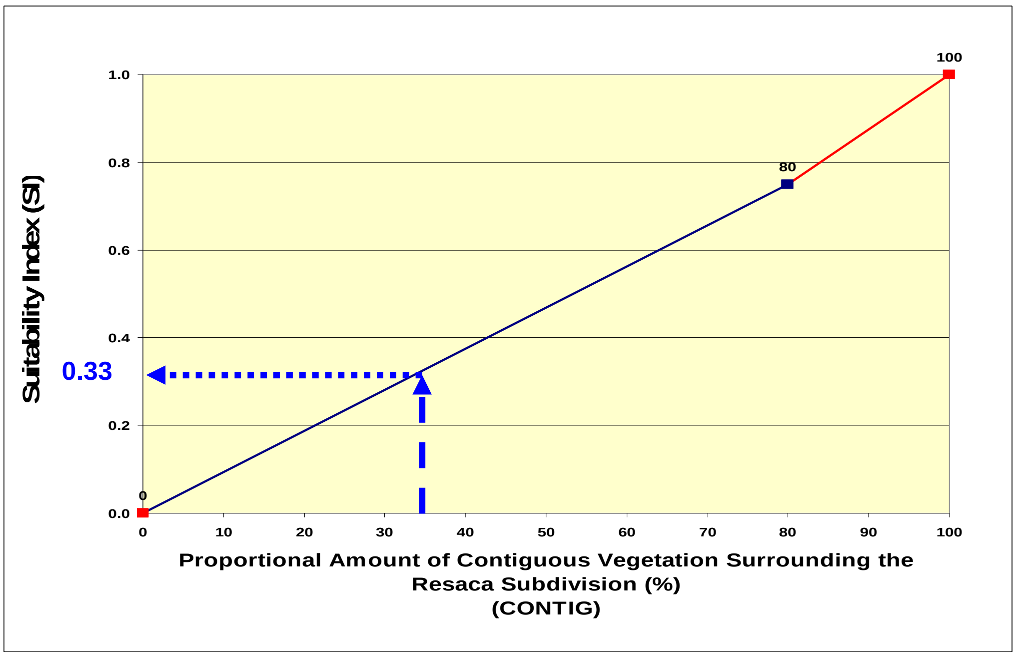

Figure 54. Example Suitability Index (SI) curve.

The process was repeated for every variable for the baseline cover type "resaca" (Table 10).

Calculating life requisite suitability indices (LRSIs) in the baseline HEP analysis

The SI scores are then entered into the individual component (LRSI) formulas (HYDRO, STRUCT, and DISTURB). For example, in the RG1 site, the following formulas were calculated:

1 HEAT software was used to normalize the raw data inputs. In other words, HEAT receives direction from the users (i.e., curve breakpoints) and converts the raw data values to SI scores. It is important to note that the HEAT software does not round outputs. In this instance, HEAT would have calculated an SI value of 0.328125.

Table 10. Baseline Suitability Indices (SIs) for the resaca communities across subdivisions.

Resaca	Subdivision	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
Resaca de La Guerra	RG1	0.50	0.49	1.00	0.95	1.00	0.90	0.54	0.59	0.80	0.64	1.00	1.00
	RG2	0.40	0.15	0.33	0.95	0.20	0.60	0.54	0.70	0.80	0.64	0.21	0.78
	RG3	0.40	0.10	0.81	1.00	0.94	0.52	0.67	0.64	0.90	0.38	0.51	1.00
Town Resaca	TR1	0.40	0.24	0.33	1.00	0.17	1.00	0.29	0.64	0.50	0.92	0.04	0.82
	TR2	0.40	0.05	0.19	0.85	0.17	1.00	0.20	0.38	0.90	0.16	0.04	0.76
	TR3	0.40	0.17	0.52	1.00	0.18	0.40	0.83	0.59	0.90	0.27	0.87	1.00
Resaca del Rancho Viejo	RRV1	0.50	0.13	0.75	1.00	0.88	0.90	0.56	0.75	0.80	0.75	1.00	1.00
	RRV2	0.40	0.20	0.75	1.00	0.75	0.20	0.33	0.70	0.80	0.54	0.50	1.00
	RRV3	0.40	0.15	0.70	1.00	0.20	0.52	0.48	0.75	0.80	0.75	0.33	1.00

$LRSI_{HYDRO}$ =

$$\left[\frac{2\times\left(V_{DO}+V_{TEMP}\right)+V_{SEDIMENT}+V_{SALINITY}+V_{TURBIDITY}}{7}\right]\times\left(\frac{V_{INFILTRATE}+V_{WQBUFF}}{2}\right) \quad (7)$$

$$= \left(\left(\left(2 * (0.95 + 0.80)\right) + 0.59 + 0.54 + 0.64\right) / 7\right) * \left(\left(1.00+1.00\right)/2\right)$$
$$= 0.75$$

$$LRSI_{STRUCT} = \frac{V_{BANKCHAR}+V_{WIDTH}+V_{CONTIG}+V_{NOXIOUS}}{4}$$
$$= \left(0.49 + 1.00 + 1.00 + 0.90\right) / 4 \quad (8)$$
$$= 0.85)$$

$$LRSI_{DISTURB} = V_{ADJLANDUSE}$$
$$= 0.50 \quad (9)$$

Calculating HSIs in the baseline HEP analysis

Next, the individual LRSI scores for each site were entered into the HSI formula (Table 3 above) and the baseline HSI was developed for each site. Continuing with the RG1 site example above, the HSI was calculated as follows:

$$\begin{aligned}\text{HSI} &= \frac{V_{\text{HYDRO}} + V_{\text{STRUCT}} + V_{\text{DISTURB}}}{3} \\ &= (0.75 + 0.85 + 0.5)/3 \\ &= 0.70\end{aligned} \quad (10)$$

Calculating HUs in the baseline HEP analysis

The final step was to multiply the HSI results by the habitat acres (i.e., resaca acres in each site). The final results, referred to as HUs, quantified the quality and quantity of the baseline ecosystem conditions for each resaca community per site. For the RG1 example, the following calculations were performed:

$$\begin{aligned}\text{HU} &= \text{HSI} \times \text{Acres} \\ &= 0.70 * 1{,}468 \\ &= 1{,}028\end{aligned} \quad (11)$$

Final baseline model results

The results of the baseline HEP assessment for the subdivisions have been summarized below. As described above, the HSIs captured the quality of the acreage within the subdivision. Units (i.e., HUs) are derived for the governing area through multiplication (Quality X Quantity = Units). Both HSIs and HUs are reported for each subdivision. Interpretations of these findings can be generalized in the following manner (Table 11).

Table 11. Interpretation of HSI scores resulting from the HEP assessment.

HSI Score	Interpretation
0.0	Not-suitable - the community does not perform to a measurable level and will not recover through natural processes
Above 0.0 to 0.19	Extremely low or very poor relative functionality (i.e., habitat suitability) - the community functionality can be measured, but it cannot be recovered through natural processes
0.2 to 0 .29	Low or poor relative functionality
0.3 to 0.39	Fair to moderately low relative functionality
0.4 to 0 .49	Moderate relative functionality
0.5 to 0.59	Moderately high relative functionality
0.6 to .79	High or good relative functionality
0.8 to 0.99	Very high or excellent relative functionality
1.0	Optimum relative functionality - the community performs functions at the highest level - the same level as reference standard settings

In the majority of instances, the individual model component indices (***Hydrography***, ***Structural Integrity***, and ***Disturbance***) scored lower than 0.5. Six of the nine subdivisions scored low (HSI < 0.5). Taken together, these results indicate the resacas are functioning poorly across the watershed (Table 12 and Figure 55). In six of nine subdivisions, the limiting or driving factor was the Disturbance component, which regularly scored between 0.5 (Agricultural Croplands) and 0.4 (Residential Housing and Golf Courses). The highest functioning subdivision was RG1 (HSI = 0.70). This was to be expected – the last vestiges of healthy resaca wetlands were found in this area. Not surprisingly, TR2 generated the lowest HSI score (HSI = 0.33). The overall poor water quality conditions and the overwhelming urban encroachment this system was experiencing offered incite into the lack of functioning resaca community.

Table 12. Baseline tabular results (HSIs and HUs) for the resaca community.

Resaca	Subdivision	LRSI Code	Model Component Score	Habitat Suitability Index (HSI)	Applicable Acres	Baseline Habitat Units (HUs)
Resaca de La Guerra	RG1	HYDRO	0.75	0.70	1,468	1,028
		STRUCT	0.85			
		DISTURB	0.50			
	RG2	HYDRO	0.38	0.37	475	174
		STRUCT	0.32			
		DISTURB	0.40			
	RG3	HYDRO	0.76	0.55	334	183
		STRUCT	0.49			
		DISTURB	0.40			
Town Resaca	TR1	HYDRO	0.34	0.38	59	23
		STRUCT	0.40			
		DISTURB	0.40			
	TR2	HYDRO	0.28	0.33	21	7
		STRUCT	0.32			
		DISTURB	0.40			
	TR3	HYDRO	0.46	0.45	102	46
		STRUCT	0.49			
		DISTURB	0.40			

Resaca	Subdivision	LRSI Code	Model Component Score	Habitat Suitability Index (HSI)	Applicable Acres	Baseline Habitat Units (HUs)
Resaca del Rancho Viejo	RRV1	HYDRO	0.76	0.65	898	585
		STRUCT	0.70			
		DISTURB	0.50			
	RRV2	HYDRO	0.65	0.49	454	220
		STRUCT	0.41			
		DISTURB	0.40			
	RRV3	HYDRO	0.48	0.44	846	368
		STRUCT	0.43			
		DISTURB	0.40			

Model verification using reference conditions and expert opinion

Once the baseline reference site analysis was completed, the veracity of the model (i.e., determining whether the model "related to reality") was assessed. In modeling vernacular, this step is considered to be ***model verification*** or:

> ***Verification*** *(Confirmation) is the comparison of the model output to data from well-known, published test cases to confirm that the algorithms and computer code accurately represent system dynamics.* [1]

For purposes of this effort, *verification* asked whether the model responded as the experts believed it should. Sites deemed by experts to be highly functional wetlands should have produced high HSI scores. Sites deemed dysfunctional should have produced low HSI scores. Again, the model calibration effort described above was an iterative process, and as such, changes to the model's curves and algorithms were made in an attempt to bring these results as close to the expected outcome as possible. Admittedly, this process was somewhat subjective. However, the experts working on the process were the best in the region, and where possible, actual reference conditions and/or historical data sets and literature-based studies were used to refine the model throughout the process.

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[1] Personal Communication (regarding American Society of Civil Engineers' definitions) August 2009. Dr. John Nestler, Research Ecologist, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

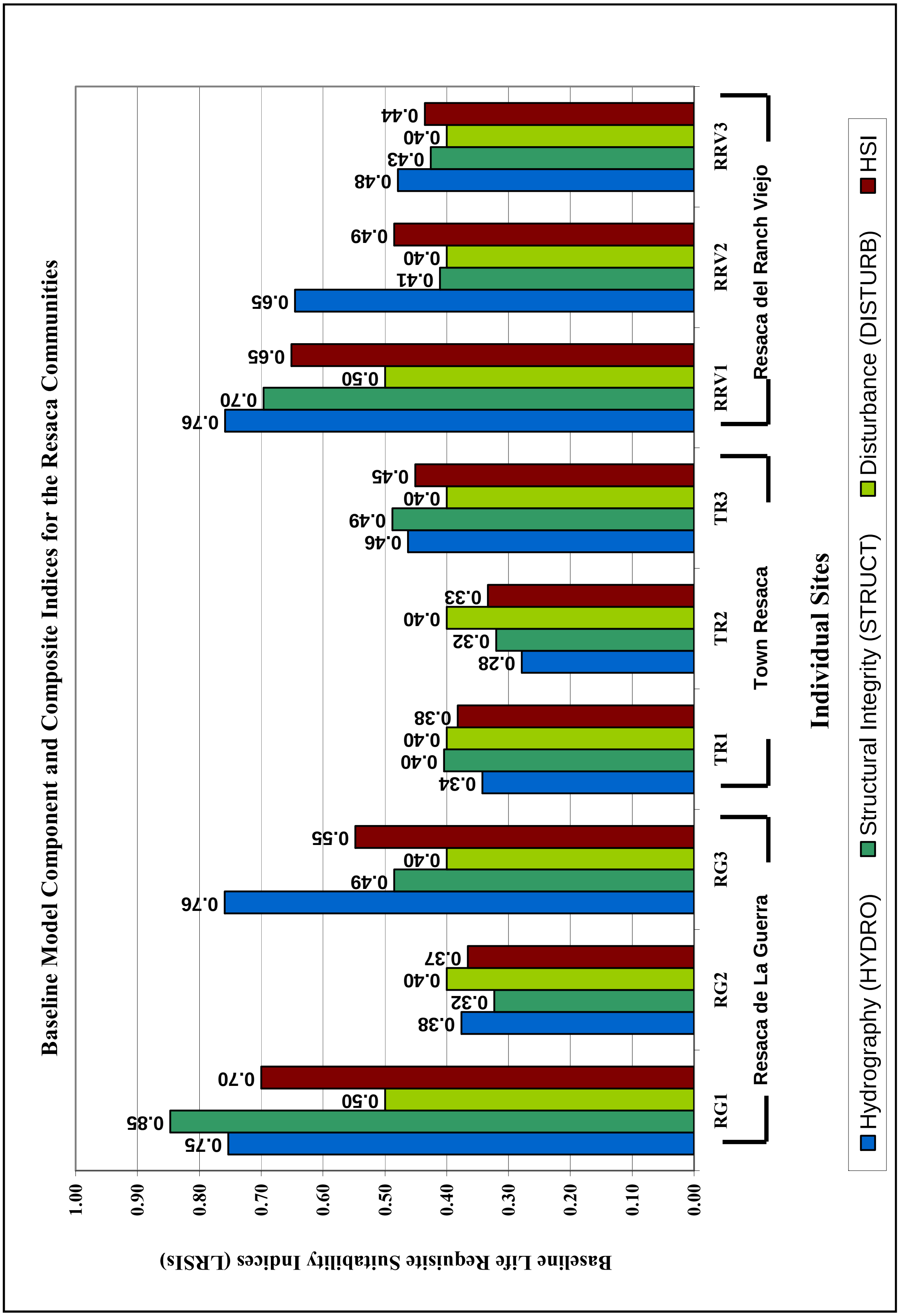

Figure 55. Baseline graphical results for the resaca community.

Spearman's rank correlation

As a simple measure of model verification, an analysis was performed using a Spearman's rank correlation coefficient[1] or Spearman's rho (denoted by the Greek letter ρ). Considered a non-parametric measure of statistical dependence of population features in ordinal format (i.e., the ranks of sites based on the model's HSI outputs versus the ranks provided by the experts), this statistic measured how well the model performed when compared to the expert's opinion of site functionality.

In essence the approach used the Null hypothesis:

$$H_0 : \rho = 0 \ (\text{no correlation}) \text{ vs. } H_1 : \rho \neq 0, \ (\text{correlation}) \qquad (12)$$

Correlation interpretations

Spearman correlation values range from +1 to −1. The sign of the correlation indicates the direction of association between X (the independent variable) and Y (the dependent variable). If Y tends to increase when X increases, the Spearman correlation coefficient is positive. If Y tends to decrease when X increases, the Spearman correlation coefficient is negative. A Spearman correlation of zero indicates that there is no tendency for Y to either increase or decrease when X increases (i.e., the Null Hypothesis is true). The Spearman correlation increases in magnitude as X and Y become closer to being perfect monotone functions of each other. When X and Y are perfectly monotonically related, the Spearman correlation coefficient becomes 1. A perfect monotone increasing relationship implies that for any two pairs of data values (X_i, Y_i and X_j, Y_j), $X_i - X_j$ and $Y_i - Y_j$ will always have the same sign. A perfect monotone decreasing relationship implies that these differences always have opposite signs.

Correlation methods

To perform the Spearman's correlation, the individual sites were ranked based on HSI output (e.g., 1-7 where 1 = highest HSI and 7 = lowest HSI). These ranks were then compared against those provided by the expert elicitation exercises described earlier in *Chapter 4* of this report (Table 13).

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[1] Background information was retrieved from http://www.statsoft.com/textbook/statistics-glossary/s/button/s/ (MAY 2010).

Table 13. Comparison of the baseline reference results to the E-Team's expectation of reference conditions (data sorted by HSI score and color-coded red-amber-green).

Subdivision Code	Habitat Suitability Index (HSI)	Rank Based on HSI	Rank Based on Expert Opinion
RG1	0.7000	1	1
RRV1	0.6510	2	2
RRV3	0.4350	6	3
RRV2	0.4850	4	4
RG3	0.5480	3	5
RG2	0.3660	8	6
TR3	0.4510	5	7
TR1	0.3820	7	8
TR2	0.3330	9	9

A Spearman's rho was calculated based on the following equation:

$$\rho = 1 - \frac{6\sum d_i^2}{n\left(n^2 - 1\right)} \tag{13}$$

where:

n = sample size
d_i = difference between each set of ranks (HSI-based - Expert ranking).

Correlation results

Based on this analysis, the model was demonstrated to be highly correlated to expert opinion of site conditions ($\boldsymbol{\rho = 0.817}$) (Figure 56).

A *t-test* was used to determine whether the correlation coefficient was statistically significant using the following equation:

$$t = \frac{r - \rho}{s_r} \tag{14}$$

where:

r = sample correlation coefficient
ρ = population correlation coefficient
s_r = standard error of the sample correlation coefficient

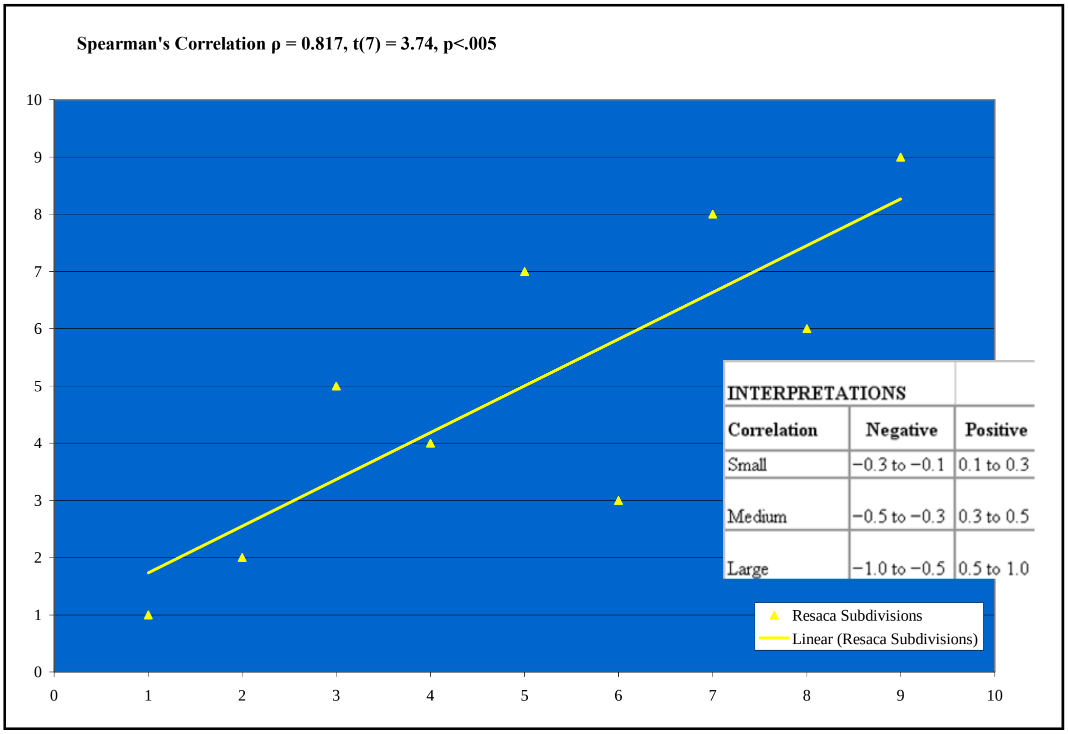

Figure 56. Spearman's correlation of the expert team's opinion of site functionality and the HEP results indicate that they are positively related to a statistically significant degree ($\rho = 0.817$, $t(7) = 3.74$, $p<.005$).

determined using the following equation:

$$s_r = \sqrt{\left(1 - r^2\right) + \left(n - 2\right)} \tag{15}$$

where:

r^2 = correlation coefficient squared
n = number of cases in the sample where degrees of freedom is the number of cases in the sample minus 2 (e.g., $df = n$-2 or 7-2 = 5 in this instance).

Significance (*p-value*) of the *t-test* was determined using a lookup table of *t-test* distributions given the degrees of freedom.[1] For interpretation purposes, the lower the *p-value*, the less likely the null hypothesis could be considered "true," and consequently results were then considered "statistically significant." As a general rule-of-thumb, the null hypothesis was rejected when the *p-value* was less than 0.05 or 0.01, corresponding to

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[1] Significance of the t-test was determined (p) using http://www.statsoft.com/textbook/distribution-tables/#t

a 5% or 1% chance, respectively, of an outcome at least that extreme, given the null hypothesis.

Based on this analysis [$t(7) = 3.74, p < 0.005$], it can be concluded that the model's outputs are highly correlated to the expert opinion to a statistically significant degree. As a result, the E-Team concluded it was reasonable to assume that the model offered a solid, scientifically driven means to characterizing conditions and assessing alternative plans.

Model testing – Proof of concept

The utility of a model can oftentimes only be demonstrated through the direct application of the tool to a problem. Unfortunately, a great deal of time and resources must be used to verify model efficacy via comprehensive (long-term) applications. However, a "proof of concept" application (i.e., engaging in a "mock" plan formulation exercise to generate a handful of alternatives on which to test the model) can offer an effective and efficient means to determine whether a model is capable of "informing" the planning process in a meaningful manner. For purposes of USACE planning activities, model utility can be demonstrated if or when model outputs:

1. Can be used to distinguish amongst plans,
2. Adequately capture the ecosystem responses at an appropriate scale, and
3. Can be used themselves to establish performance measures.[1]

However, it is important to note that these types of tests are purely subjective in nature – even well-designed models will have difficulty distinguishing amongst poorly designed plans and inaccurate forecasts can lead to misdirection and inaccurate results. With this caveat in mind, a "controlled experiment" was undertaken to formulate and assess a series of five unique plans on one Brownsville Resaca (namely Resaca del Rancho Viejo). This test serves as a "proof of concept," verifying that the model can adequately distinguish among plans, that the subdivision is an appropriate scale for alternative formulation, and that the variables within the model can be used to set performance measures or targets based on study objectives to measure restoration success. *Appendix F* has been included in

[1] Personal Communications. 2011. Scott Estergard, Project Manager, U.S. Army Engineer District, Los Angeles, and Ondrea Hummel, Ecologist, U.S. Army Engineer District, Albuquerque.

this report to document this "proof of concept" test, and the results therein are conclusive – the model can be used to inform the planning process.

Model validation

To date, the resaca community index model has not been validated. Model validation is defined herein as:

> ***Validation*** *is accomplished by establishing an objective yet independent line of evidence that the model specifications conform to the user's needs and intended use(s). The validation process questions whether the model is an accurate representation of the system based on independent data not used to develop the model in the first place. Validation can encompass all of the information that can be verified, as well as all of the things that cannot -- i.e., all of the information that the model designers might never have anticipated the user might want or expect the product to do.* [1]

For purposes of this effort, *validation* refers to independent data collections (bird surveys, water quality surveys, etc.) that can be compared to the model outcomes to determine whether the model is capturing the essence of the ecosystem's functionality. As independent measures of function for the model herein, three options or directions are proposed for future research opportunities:

1. A few "relevant" HSI Blue Book (species) models could be used to assess the baseline conditions of the area, comparing their outputs to the community models' outputs. As these are already "approved" for use under the USACE model certification program, their outputs should provide relevant cross-validation. Unfortunately, most of the HSI Blue Books lack validation, so this approach may not be appropriate either. Because the Blue Book models were designed to measure only limiting "life requisites" of these key species, they might not be inclusive enough to capture community function and processes.
2. An extremely expensive and time-consuming approach could be undertaken to assess biodiversity (both species richness and diversity) in an attempt to identify an "independent measure of function." However, to validate the communities modeled herein, a majority of the faunal groups

[1] Personal communication regarding American Society of Civil Engineers' definitions with Dr. John Nestler, ERDC-EL, August 2009.

present would need to be surveyed (mammals, birds, fish, reptiles, amphibians, plants, and possibly even insects). This in turn leads to the question, if we had time and funds to do this level of inventory, why use models at all?

3. Alternatively, validation of the models could potentially be accomplished by assessing patch dynamics using a transition model at the landscape scale (Acevedo et al. 1995). Again, this would be validating models with models, which might not be considered a true validation exercise.

Sensitivity analysis

Variability analysis

Admittedly, the inputs of any community-based index model are subject to error and the outputs by definition are a mere abstraction of reality. Sensitivity analysis,[1] broadly defined here as an exploration of these potential errors and their impacts on the conclusions drawn from the model's outputs, is one way of acknowledging uncertainty in the model that can be easily communicated to the end user. Numerous techniques have been developed and their various strengths and weaknesses have been thoroughly reviewed in the literature (Pannell 1997 and references therein). To begin, the authors consulted with Dr. Greg Kiker at the University of Florida, and based on his recommendations, one of the techniques described by Hamby (1994, 1995) was chosen for this effort. The technique advocates the use of a "one-at-a-time" sensitivity assessment of the model's individual variables to generate a range of potential outcomes and thus quantify the uncertainty of the model's output. Basically, this technique suggests that a 20% error estimation be applied to each parameter's mean, resulting in a recalculation of the HSI at its greatest and lowest potential outcome. In other words, every variable in the model was subjected to a 20% increase (and decrease) in its mean, and the suitability indices per variable were recalculated and then reapplied to the overall HSI algorithm. In this manner, the "best" and "worst" possible HSI values were calculated, providing a quantification of the degree of certainty associated with the model's results. Several assumptions were made during the sensitivity assessment including:

[1] Sensitivity analysis is the study of how the variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model (Saltelli et al. 2008). In other words, sensitivity analysis is a technique for systematically changing parameters in a model to determine the effects of such changes. In more general terms, uncertainty and sensitivity analyses investigate the robustness of a study when the study includes some form of mathematical modeling.

1. Non-linear variables were assigned a +/- 20% factor based on the shape of their SI curves. In other words, an inverse factor was applied when the SI score was inversely related to the raw data.
2. It was further assumed that all variables were independent and that the change in one did not have a compounding or cascading effect on any other within the individual LRSI and HSI algorithms.

Table 14 details the results of the sensitivity analysis. These results have been graphically depicted in Figure 57 as well.

Table 14. Results of the sensitivity analysis for the resaca model.

Resaca	Subdivision	HSI	Best	Worse
Resaca de La Guerra	RG1	0.70	+0.09	-0.17
	RG2	0.37	+0.15	-0.10
	RG3	0.55	+0.10	-0.15
Town Resaca	TR1	0.38	+0.09	-0.08
	TR2	0.33	+0.07	-0.09
	TR3	0.45	+0.11	-0.11
Resaca del Rancho Viejo	RRV1	0.65	+0.10	-0.14
	RRV2	0.49	+0.12	-0.15
	RRV3	0.44	+0.15	-0.11

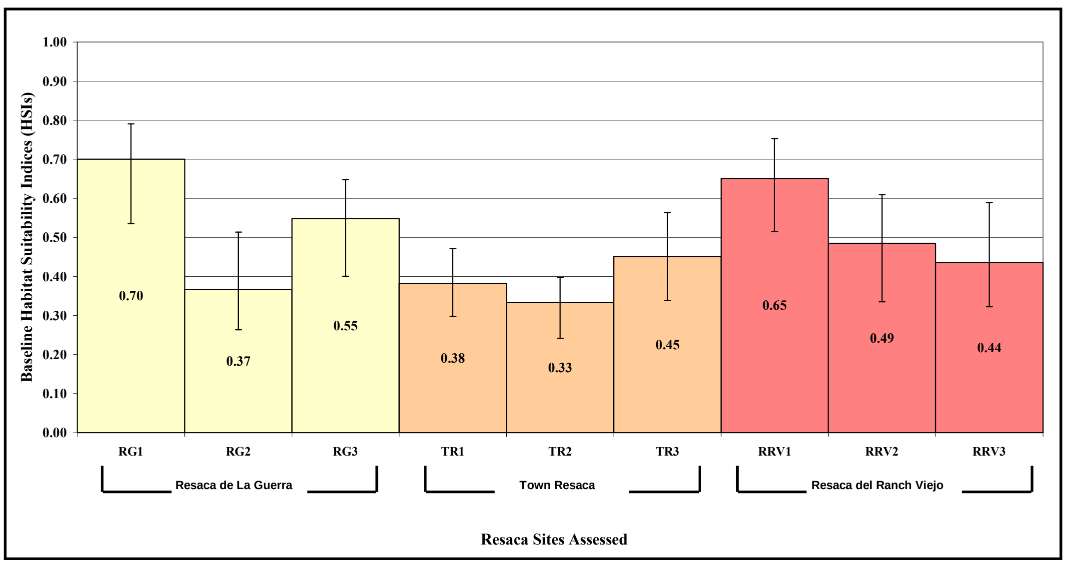

Figure 57. Graphic results of the sensitivity analysis for the resaca model.

Overall, the model's uncertainty is relatively low depending on the location of application. Generally speaking, the results could be 0.15 higher or 0.17

lower than the reported HSI values. For example, RG1's HSI could be as high as 0.79 or as low as 0.54.

Data rounding and effects on the results

In most instances, the authors advocated the use of rounding of means of data when presenting, analyzing, and forecasting the data used in this model. A second sensitivity analysis was run to assure the users that this practice would not significantly affect the outcomes of the model's applications. In no instance was rounding determined to significantly affect the outcomes, and the E-Team agreed that the use of rounded values did not deter (and in fact improved) their ability to forecast the future ecosystem responses to proposed alternative designs.

Model drivers and cautions for future users

It is important to note that six of the nine subdivisions assessed with the resaca model were driven by the low results generated in the ***Disturbance Component*** analysis of the HSI model. This is not a surprising result, as the E-Team developed this model to be particularly sensitive to the surrounding landscape matrix, and the current applications have been made in highly urbanized settings. As such, future users of this model are cautioned with regards to the GIS variables in this model – it is important that the sampling of these particular variables be performed in a robust and accurate manner. In other words, time and resources should be put to the accurate measurement of variables such as contiguousness, adjacent land use, water quality buffering, infiltration, and resaca width to increase confidence in the model's outcomes.

In addition, a review of the variable inputs revealed a high degree of variability in the field data collected for two variables, namely percent frequency of noxious species occurrence and potential proportion of sediment deposition in the resaca. It is strongly suggested that users of this model should focus additional effort on collecting the field data for these variables in future applications. It should also be noted that the water quality variables in the model (namely temperature, salinity, turbidity, and dissolved oxygen) vary temporally, and the model was designed to respond to measurements taken in the hottest months (June/July).

Further reflection on the model's algorithms reveals that multiple variables "drive" the final results because of the mathematical operations performed on them in the analysis. Of particular note are the variables that are multiplied (weighted) or dependent upon other variables within the formulas, namely:

1. Dissolved oxygen (i.e., is multipled by a factor of 2);
2. Temperature (i.e., is multipled by a factor of 2); and
3. Adjacent land use (serves as the only proxy for the *Disturbance* component, and therefore accounts for 33.3% of the entire HIS score).

These mathematical relationships were specifically designed by the E-Team to better characterize the functionality of the community, but users must be cognizant of these multiplicative relationships (i.e., formula weightings) and realize the power they have on the final outcomes. For example, a community that has optimal structural integrity and hydrography is only fully functioning (HSI = 1.0) if the resaca is predominantly surrounded by natural, uninhabited areas according to this model.

Furthermore, the normative efforts to scale the individual variables in the model resulted in varying degrees of "sensitivity" among the variables therein (i.e., some SI curves are steeper in inclination than others). As a result, a handful of these variables can be considered "drivers" of the results, and as such, users should pay particular attention to both the acquisition of these data and their statistical management. In other words, take particular care when sampling and assessing the following variables:

1. Dissolved oxygen,
2. Proportion of the resaca study area that is impervious to infiltration,
3. Salinity, and
4. Potential proportion of sediment deposition in the resaca.

One final note to future users regarding the use of "means of SIs" versus the means of raw data and the normalization of this data with the curves provided in *Appendix E*. The current model was designed to operate at the landscape level. As such, means of data must be generated at this scale prior to normalization with the model's SI curves. Controversy continues to surround this debate, but it is important to note that USACE planning applications mandate the forecasting of future conditions at the means of the data level – not the means of the SIs. An example of the problem can be illustrated here. If two data points are taken (10° and 35°, respectively), this model's application protocol dictates that the mean of the raw data be taken prior to normalizing the data – the mean therefore represents the average characterization of the subdivision (x = 22.5°, SI = 1.0) (Figure 58).

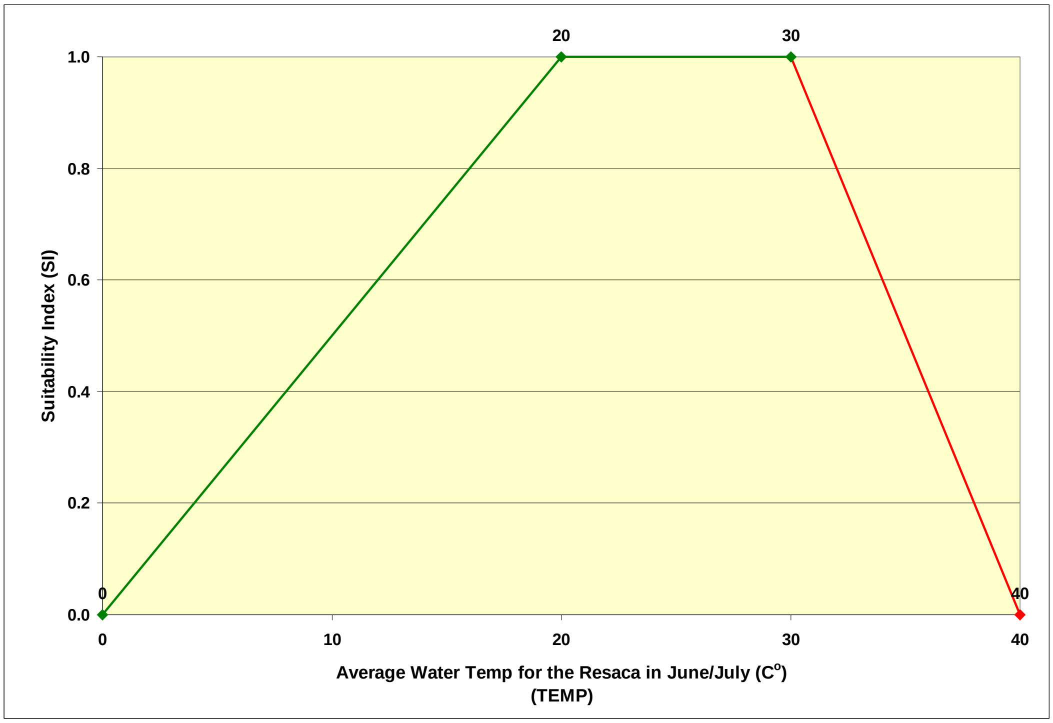

Figure 58. The model protocol dictated that the mean of the data at the subdivision level was applied to the SI graph for normalization.

Past HEP protocols have called for the normalization of the data prior to taking the average (if data = 10°, then SI_1 = 0.5, and if data = 35°, then SI_2 = 0.5, and the mean of the SIs or the overall subdivision score = 0.5). Although valid, this approach does not accommodate the application of the model in a USACE planning study where the next step in the process would be to forecast the future condition of the parameter. If the "means of the data" protocol is employed, users can easily forecast future conditions based on the mean of the data (TY_0 = 22.5°, TY_1 = 22.5°, TY_{51} = 20° for example). If the "means of the SIs" protocol is used, it is virtually impossible to forecast future conditions based on data because the mean SI = 0.50 cannot be converted back to a meaningful forecastable output – should the baseline value be 10° or 35°? Thus, it is important to note that this model was developed to deploy the "means first" protocol of data management and normalization.

5 Summary and Conclusions

The implications of this report's findings are rather straightforward. First, the results support the conceptual premise surrounding the model and indicate its representative capabilities. In other words, scientific literature characterizing the state of the resaca community in southern Texas points to an overall decline in ecosystem integrity (i.e., health, biodiversity, stability, sustainability, naturalness, etc.) – a finding the model can now quantify (less than optimal HSI values in all subdivisions). Furthermore, the results indicate an opportunity to redress impacts. There is great potential to improve water quality and rehabilitate or restore resaca communities across the system, thereby addressing the challenge of ecosystem restoration in the area by implementing appropriate and sustainable activities targeting these sub-functional communities.

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Appendix A: Notation

AAHU	Average Annual Habitat Unit
AFY	Acre-feet-per-year
BPUB	Brownsville Public Utilities Board
CAR	Coordination Act Report
COBRES	The City of Brownsville Resacas Ecosystem Restoration Study
CT	Cover Type
District	Galveston District
EA	Environmental Assessment
ELEMRS	EL Electronic Manuscript Review System
EOA	Equivalent Optimum Area
ERDC	U.S. Army Engineer Research and Development Center
ESM	Ecological Services Manual
E-Team	Interagency Ecosystem Assessment Team
EXHEP	EXpert Habitat Evaluation Procedures Software
GIS	Geographic Information System
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HSI	Habitat Suitability Index
HU	Habitat Unit
LPDT	Laboratory-based Project Delivery Team
LRSI	Life Requisite Suitability Index
LTR	Laboratory-based Technical Review
LTRT	Laboratory-based Technical Review Team
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service

SI	Suitability Index
TAMU	Texas A&M University
TPWD	Texas Parks and Wildlife Department
TY	Target Year
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service

Appendix B: Glossary

Activity

The smallest component of a management measure that is typically a nonstructural, ongoing (continuing or periodic) action in USACE planning studies (Robinson et al. 1995).

Alternative (or Alternative Plan, Plan, or Solution)

An alternative can be composed of numerous management measures that, in turn, are comprised of multiple features, activities, or treatments. Alternatives are mutually exclusive, but management measures may or may not be combinable with other management measures or alternatives (Robinson et al. 1995).

In HEP analyses, this is the "with-project" condition commonly used in restoration studies. Some examples of Alternatives include:

<u>Alternative 1:</u> Plant food plots, increase wetland acreage by 10 percent, install 10 goose nest boxes, and build a fence around the entire site.

<u>Alternative 2:</u> Build a dam, inundate 10 acres of riparian corridor, build 50 miles of supporting levee, and remove all wetlands in the levee zone.

<u>Alternative 3:</u> Reduce the grazing activities on the site by 50 percent, replant grasslands (10 acres), install a passive irrigation system, build 10 escape cover stands, use 5 miles of willow fascines along the stream bank for stabilization purposes.

Assessment Model

A simple mathematical tool that defines the relationship between ecosystem/landscape scale variables and either functional capacity of a wetland or suitability of habitat for species and communities. Habitat Suitability Indices are examples of assessment models that the HEAT software can use to assess impacts/benefits of alternatives.

Average Annual Habitat Units (AAHUs)

A quantitative result of annualizing Habitat Unit (HU) gains or losses across all years in the period of analysis.

AAHUs = Cumulative HUs ÷ Number of years in the life of the project, where:

Cumulative HUs =

$$\sum (T2 - T1)[\{((A1\ H1 + A2\ H2) / 3)\} + \{((A2\ H1 + A1\ H2) / 6)\}]$$

and where:

T1 = First Target Year time interval
T2 = Second Target Year time interval
A1 = Area of available wetland assessment area at beginning of T1
2 = Area of available wetland assessment area at end of T2
H1 = HSI at beginning of T1
H2 = HSI at end of T2.

Baseline Condition (Existing Conditions)

The point in time before proposed changes are implemented in habitat assessment and planning analyses. Baseline is synonymous with Target Year (TY = 0).

Blue Book

In the past, the USFWS was responsible for publishing documents identifying and describing HSI models for numerous species across the nation. Referred to as "Blue Books" in the field, due primarily to the light blue tint of their covers, these references fully illustrate and define habitat relationships and limiting factor criteria for individual species nationwide. Blue Books provide: HSI Models, life history characteristics, SI curves, methods of variable collection, and referential material that can be used in the application of the HSI model in the field. For copies of Blue Books, or a list of available Blue Books, contact the local USFWS office.

Calibration

The use of known (reference) data on the observed relationship between a dependent variable and an independent variable to estimate other values of the independent variable from new observations of the dependent variable.

Combined NED/NER Plan (Combined Plan)

Plans that produce both types of benefits such that no alternative plan or scale has a higher excess of NED plus NER benefits over total project costs (USACE 2003a).

Cover Type (CT)

Homogenous zones of similar vegetative species, geographic similarities, and physical conditions that make the area unique. In general, cover types are defined on the basis of species recognition and dependence.

Ecosystem

A biotic community, together with its physical environment, considered as an integrated unit. Implied within this definition is the concept of a structural and functional whole, unified through life processes. Ecosystems are hierarchical, and can be viewed as nested sets of open systems in which physical, chemical, and biological processes form interactive subsystems. Some ecosystems are microscopic, and the largest comprises the biosphere. Ecosystem restoration can be directed at different-sized ecosystems within the nested set, and many encompass multi-states, more localized watersheds, or a smaller complex of aquatic habitat.

Ecosystem Assessment Team (E-Team)

An interdisciplinary group of regional and local scientists responsible for determining significant resources, identification of reference sites, construction of assessment models, definition of reference standards, and calibration of assessment models. In some instances the E-Team is also referred to as the Environmental Assessment Team or simply the Assessment Team.

Ecosystem Integrity

The state or condition of an ecosystem that displays the biodiversity characteristic of the reference, such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning (Society for Ecological International (SERI) 2004). These characteristics are often defined in terms such as health, biodiversity, stability, sustainability, naturalness, wildness, and beauty.

Equivalent Optimal Area (EOA)

The concept of equivalent optimal area (EOA) is used in HEP applications where the composition of the landscape, in relation to providing life requisite habitat, is an important consideration. An EOA is used to weight the value of the LRSI score to compensate for this inter-relationship. For example, for optimal wood duck habitat conditions, at least 20% of an area should be composed of cover types providing brood-cover habitat (a life requisite). If an area has less than 20% in this habitat, the suitability is adjusted downward.

Existing Condition

Also referred to as the baseline condition, the existing condition is the point in time before proposed changes, and is designated as Target Year (TY = 0) in the analysis.

Feature

A feature is the smallest component of a management measure that is typically a structural element requiring construction in USACE planning studies (Robinson et al. 1995).

Field Data

This information is collected on various variables in the field, and from aerial photos, following defined, well-documented methodology in typical HEP applications. An example is the measurement of percent herbaceous cover, over ten quadrats, within a cover type. The values recorded are each considered "field data." Means of variables are applied to derive suitability indices and/or functional capacity indices.

Goal

A goal is defined as the end or final purpose. Goals provide the reason for a study rather than a reason to formulate alternative plans in USACE planning studies (Yoe and Orth 1996).

Guild

A group of functionally similar species with comparable habitat requirements whose members interact strongly with one another, but weakly with the remainder of the community. Often a species HSI model is selected to represent changes (impacts) to a guild.

Habitat Assessment

The process by which the suitability of a site to provide habitat for a community or species is measured. This approach measures habitat suitability using an assessment model to determine an HSI.

Habitat Suitability Index Model (HSI)

A quantitative estimate of suitability habitat for a site. The ideal goal of an HSI model is to quantify and produce an index that reflects functional capacity at the site. The results of an HSI analysis can be quantified on the basis of a standard 0-1.0 scale, where 0.00 represents low functional capacity for the wetland, and 1.0 represents high functional capacity for the wetland. An HSI model can be defined in words, or mathematical equations, that clearly describe the rules and assumptions necessary to combine functional capacity indices in a meaningful manner for the wetland.

For example:

$HSI = (SI\ V_1 * SI\ V_2) / 4$,

where:
$SI\ V_1$ is the Variable Subindex for variable 1;
$SI\ V_2$ is the SI for variable 2

Habitat Unit (HU)

A quantitative environmental assessment value, considered the biological currency in HEP. Habitat Units (HUs) are calculated by multiplying the area of available habitat (quantity) by the quality of the habitat for each species or community. Quality is determined by measuring limiting factors for the species (or community), and is represented by values derived from Habitat Suitability Indices (HSIs).

HU = AREA (acres) X HSI.

Changes in HUs represent potential impacts or improvements of proposed actions.

Life Requisite Suitability Index (LRSI)

A mathematical equation that reflects a species' or community's sensitivity to a change in a limiting life requisite component within the habitat type in HEP applications. LRSIs are depicted using scatter plots and bar charts (i.e., life requisite suitability curves). The LRSI value (Y axis) ranges on a scale from 0.0 to 1.0, where an LRSI = 0.0 means the factor is extremely limiting and an LRSI = 1.0 means the factor is in abundance (not limiting) in most instances.

Limiting Factor

A variable whose presence/absence directly restrains the existence of a species or community in a habitat in HEP applications. A deficiency of the limiting factor can reduce the quality of the habitat for the species or community, while an abundance of the limiting factor can indicate an optimum quality of habitat for the same species or community.

Locally Preferred Plan (LPP)

The name frequently given to a plan that is preferred by the non-Federal sponsor over the National Economic Development (NED) plan (USACE 2000).

Management Measure

The components of a plan that may or may not be separable actions that can be taken to affect environmental variables and produce environmental outputs. A management measure is typically made up of one or more features or activities at a particular site in USACE Planning studies (Robinson et al. 1995).

Measure

The act of physically sampling variables such as height, distance, percent, etc., and the methodology followed to gather variable information in HEP applications (i.e., see "Sampling Method" below).

Multiple Formula Model (MM) (Life Requisite Model)

In HEP applications, there are two types of HSI models, the Single Formula Model (SM) (refer to the definition below) and the Multiple Formula Model (MM). In this case a multiple formula model is, as one would expect, a model that uses more than one formula to assess the suitability of the habitat for a species or a community. If a species/community is limited by the existence of more than one life requisite (food, cover, water, etc.), and the quality of the site is dependent on a minimal level of each life requisite, then the model is considered an MM model. In order to calculate the HSI for any MM, one must derive the value of a Life Requisite Suitability Index (LRSI) (see definition below) for each life requisite in the model – a process requiring the user to calculate multiple LRSI formulas. This Multiple Formula processing has led to the name "Multiple Formula Model" in HEP.

Multi-Criteria Decision Analysis (MCDA)

The study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the "management planning process," as defined by the International Society on Multiple Criteria Decision Making (http://www.terry.uga.edu/mcdm/ MAY 2008).

MCDA is also referred to as Multi-Criteria Decision Making (MCDM), Multi-Dimensions Decision-Making (MDDM), and Multi-Attributes Decision Making (MADM).

National Economic Development (NED) Plan

For all project purposes except ecosystem restoration, the alternative plan that reasonably maximizes net economic benefits consistent with protecting the Nation's environment, the NED plan. The Assistant Secretary of the Army for

Civil Works (ASACW) may grant an exception when there are overriding reasons for selecting another plan based upon other Federal, State, local, and international concerns (USACE 2000).

National Ecosystem Restoration (NER) Plan

For ecosystem restoration projects, a plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective. The selected plan must be shown to be cost effective and justified to achieve the desired level of output. This plan shall be identified as the National Ecosystem Restoration (NER) Plan. (USACE 2000).

No Action Plan (No Action Alternative or Without-Project Condition)

Also referred to as the without-project condition, the No Action Plan describes the project area's future if no Federal action is taken to solve the problem(s) at hand. Every alternative is compared to the same without-project condition (Yoe and Orth 1996).

Objective

A statement of the intended purposes of the planning process; it is a statement of what an alternative plan should try to achieve. More specific than goals, a set of objectives will effectively constitute the mission statement of the Federal/non-Federal planning partnership. A planning objective is developed to capture the desired changes between the without- and with-project conditions that, when developed correctly, identify effect, subject, location, timing, and duration (Yoe and Orth 1996).

Plan (Alternative, Alternative Plan, or Solution)

A set of one or more management measures functioning together to address one or more planning objectives (Yoe and Orth 1996). Plans are evaluated at the site level with HEP or other assessment techniques and cost analyses in restoration studies (Robinson et al. 1995).

Program

Combinations of recommended plans from different sites make up a program. Where the recommended plan at each site within a program is measured in the same units, a cost analysis can be applied in a programmatic evaluation (Robinson et al. 1995).

Project Area

The area that encompasses all activities related to an ongoing or proposed project.

Project Manager

Any biologist, economist, hydrologist, engineer, decision-maker, resource project manager, planner, environmental resource specialist, limnologist, etc., who is responsible for managing a study, program, or facility.

Reference Domain

The geographic area from which reference communities or wetlands are selected in HEP applications. A reference domain may, or may not, include the entire geographic area in which a community or wetland occurs.

Reference Ecosystems

All the sites that encompass the variability of all conditions within the region in HEP applications. Reference ecosystems are used to establish the range of conditions for construction and calibration of HSIs and establish reference standards.

Reference Standard Ecosystems

The ecosystems that represent the highest level of habitat suitability or function found within the region for a given species or community in HEP applications.

Relative Area (RA)

The relative area is a mathematical process used to "weight" the various applicable cover types on the basis of quantity in HEP applications. To derive the relative area of a model's CTs, the following equation can be utilized:

$$\text{Relative Area} = \frac{\text{Acres of Cover Type}}{\text{Total Applicable Area}}$$

where:

Acres of Cover Type = only those acres assigned to the cover type of interest within the site
Total Applicable Area = the sum of the acres associated with the model at the site.

Risk

The volatility of potential outcomes. In the case of ecosystem values, the important risk factors are those that affect the possibility of service flow disruptions and the reversibility of service flow disruptions. These are associated with controllable and uncontrollable on-site risk factors (e.g., invasive plants, overuse, or restoration failure) and landscape risk factors (e.g., changes in adjacent land uses, water diversions) (King et al. 2000).

Sampling Method

The protocol followed to collect and gather field data in HEP and HGM applications. It is important to document the relevant criteria limiting the collection methodology. For example, the time of data collection, the type of techniques used, and the details of gathering this data should be documented as much as possible. An example of a sampling method would be:

Between March and April, run five random 50-m transects through the relevant cover types. Every 10 m along the transect, place a 10-m² quadrat on the right side *of the transect tape and record the percent herbaceous cover within the quadrat. Average the results per transect.*

Scale

In some geographical methodologies, the scale is the defined size of the image in terms of miles per inch, feet per inch, or pixels per acre. Scale can also refer to different "sizes" of plans (Yoe and Orth 1996) or variations of a management measure in cost analyses. Scales are mutually exclusive, and therefore a plan or alternative may only contain one scale of a given management measure (Robinson et al. 1995).

Sensitivity Analysis

The study of how variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model (Saltelli et al. 2008). In other words, it is a technique for systematically changing variables in a model to determine the effects of such changes. In more general terms, uncertainty and sensitivity analyses investigate the robustness of a study when the study includes some form of mathematical modeling.

Single Formula Model (SM)

In habitat assessments, two potential types of models are selected to assess change at a site – the Single Formula Model and the Multiple Formula Model (refer to the definition above). In this instance, an HSI model is based on the existence of a single life requisite requirement, and a single formula is used to depict the relationship between quality and carrying capacity for the site.

Site

The location upon which the project manager will take action, evaluate alternatives, and focus cost analysis (Robinson et al. 1995).

Solutions (Alternative, Alternative Plan, or Plan)

A solution is a way to achieve all or part of one or more planning objectives (Yoe and Orth 1996). In cost analysis, this is the alternative (see definition above).

Spreadsheet

A type of computer file or page that allows the organization of data (alpha-numeric information) in a tabular format. Spreadsheets are often used to complete accounting/ economic exercises.

Suitability Index (SI)

A mathematical equation that reflects a species' or community's sensitivity to a change in a limiting factor (i.e., variable) within the habitat type in HEP applications. These indices are depicted using scatter plots and bar charts (i.e., suitability curves). The SI value (Y-axis) ranges on a scale from 0.0 to 1.0, where an SI = 0.0 means the factor is extremely limiting, and an SI = 1.0 means the factor is in abundance (not limiting) for the species/community (in most instances).

Target Year (TY)

A unit of time measurement used in HEP that allows the project manager to anticipate and direct significant changes (in area or quality) within the project (or site). As a rule, the baseline TY is always TY = 0, where the baseline year is defined as a point in time before proposed changes would be implemented. As a second rule, there must always be a TY = 1, and a TY = X_2. TY_1 is the first year that land- and water-use conditions are expected to deviate from baseline conditions. TY_{X2} designates the ending target year. A new target year must be assigned for each year the project manager intends to develop or evaluate change within the site or project. The habitat conditions (quality and quantity) described for each TY are the expected conditions at the end of that year. It is important to maintain the same target years in both the environmental and economic analyses.

Trade-offs (TOs)

Trade-offs are used to adjust the model outputs by considering human values. There are no right or proper answers, only acceptable ones. If trade-offs are used, outputs are no longer directly related to optimum habitat or wetland function (Robinson et al. 1995).

Validation

Establishing by objective, yet independent, evidence that the model specifications conform to the user's needs and intended use(s). The validation process questions whether the model is an accurate representation of the system based on independent data not used to develop the model in the first place. Validation can encompass all of the information that can be verified, as well as all of the things that cannot -- i.e., all of the information that the model designers might never have anticipated the user might want or expect the product to do.

For purposes of this effort, *validation* refers to independent data collections (bird surveys, water quality surveys, etc.) that can be compared to the model outcomes to determine whether the model is capturing the essence of the ecosystem's functionality.

Variable

A measurable parameter that can be quantitatively described, with some degree of repeatability, using standard field sampling and mapping techniques. Often, the variable is a limiting factor for a wetland's functional capacity used in the development of SI curves and measured in the field (or from aerial photos) by personnel, to fulfill the requirements of field data collection in a HEP application. Some examples of variables include: height of grass, percent canopy cover, distance to water, number of snags, and average annual water temperature.

Verification

Model verification refers to a process by which the development team confirms by examination and/or provision of objective evidence that specified requirements of the model have been fulfilled with the intention of assuring that the model performs (or behaves) as it was intended.

Sites deemed to be highly functional wetlands according to experts should produce high index scores. Sites deemed dysfunctional (by the experts) should produce low index scores.

Without-Project Condition (WOP) (No Action Plan or No Action Alternative)

Often confused with the terms “Baseline Condition” and “Existing Condition,” the Without-Project Condition is the expected condition of the site without implementation of an alternative over the life of the project, and is also referred to as the “No Action Plan” in traditional planning studies (Yoe and Orth 1996, USACE 2000).

With-Project Condition (WP)

In planning studies, this term is used to characterize the condition of the site after an alternative is implemented (Yoe and Orth 1996, USACE 2000).

Appendix C: Model Certification Crosswalk

Information necessary to address model certification/one-time-use approval under EC 1105-2-407 is presented in *Table 2* of *Planning Models Improvement Program: Model certification* (USACE 2005, pages 9-11).[1] In an effort to streamline the review of the resaca community-based (HSI) index model, the authors have provided a table to crosswalk the EC requirements and the information contained in this report (Table C1). One-time-use approval is being sought via the Eco-PCX, and the final documenttation regarding this decision will be included below the table when received.

Table C1. Crosswalk between EC 1105-2-407 model certification requirements and information contained in this report.

Cover Sheet		
	a.	**Model Name(s):** Community Model for Resacas of the Lower Rio Grande (South Laguna Madre Watershed), Brownsville, Texas
	b.	**Functional Area:** Ecosystem Restoration; Impact Assessment /Mitigation
	c.	**Model Proponent:** Galveston District
	d.	**Model Developers** ERDC-EL and Galveston District (with support from interagency and stakeholder participants)
1. Background		
	a.	**Purpose of Model:** The model was developed in an effort to quantify the value of diverse biological resources in this study area with the intent of capturing complex biotic patterns of the landscape. Refer to *Chapter 1*, "Purpose of the Models" for more detail.
	b.	**Model Description and Depiction:** The model was rendered in a HEP-compatible format. Model components were comprised of combinations of relevant variables to characterize the hydrology, soils, biotic integrity, structure, spatial complexity, and disturbance regimes of the unique resaca (oxbow lake) ecosystem occurring along the Lower Rio Grande Reach in southern Texas. Model components (and their underlying variables) were normalized (scaled from 0.0 to 1.0) as required by traditional HEP procedures. Both flow charts ("ecosystem puzzles") and mathematical algorithms were used to depict the model herein. Refer to *Chapter 3* (*Model Flow Diagram*), *Chapter 4* (*Model Formulas*), and *Chapter 5* (*Model Concept* and *Steps 1-5)* for details relating to the individual model components and format.
	c.	**Contribution to Planning Effort:** The model helped to characterize the baseline conditions (in a quantitative manner) of the unique and significant ecological resources along the Lower Rio Grande Reach in southern Texas. When applied within the HEP assessment paradigm, the study team will be able to evaluate and compare the benefits of proposed ecosystem restoration initiatives. Future applications in the watershed could also use the model to evaluate and compare flood risk management measures and determine the ability of the proposed mitigation measures to offset these losses.

[1] http://www.usace.army.mil/cw/cecw-cp/models/protocols_cert_7-02-07.pdf

	d.	**Description of Input Data:** Both field and spatially-explicit (GIS) data are necessary to calculate the outputs. Refer to *Chapter 4* for a list of variables and appropriate sampling protocols and statistical data management activities.
	e.	**Description of Output Data:** Habitat Suitability Indices are output on a normalized scale of 0-1 in compliance with the traditional HEP paradigm. Within a standard HEP application, these indices can be multiplied by area to produce Habitat Units (HUs), and can be assessed over time under both With- and Without-project scenarios to generate Average Annual Habitat Units (AAHUs) (Refer to *Chapter 2 HEP Overview*).
	f.	**Statement on the capabilities and limitations of the model:** The model has been tested using reference data and conditions along the Lower Rio Grande Reach. It can be used to assess baseline conditions as well as assess both a No Action condition and proposed alternative designs in either an Impact/Mitigation study or within an Ecosystem Restoration context. The model should not be applied outside of the South Laguna Madre Watershed (Brownsville, TX and environs) without review and recalibration.
	g.	**Description of model development process including documentation on testing conducted (Alpha and Beta tests):** A series of workshops were convened and experts contributed to the development of both the conceptual framework and the final index model presented here. The model was calibrated using reference data from across the model domain (South Laguna Madre Watershed in the vicinity of Brownsville, TX – refer to Figure 38). Internal (ERDC-EL) peer review has commenced, and the authors are considering the development of several peer-reviewed journal articles for publication. *Appendix G* discusses the internal/external peer review process standard for ERDC-EL publications and model building efforts. *Chapter 3* discusses the model building process. *Chapter 4* discusses the model calibration process as well as the alpha/beta tests of the model to quantify baseline conditions for the study area.
2. Technical Quality		
	a.	**Theory:** In theory, ecosystem function in these communities can be quantified by using indicators of ecosystem integrity and applying these in the well-documented and accepted HEP-based framework. The U.S. Fish and Wildlife Service (USFWS) published quantifiable procedures in 1980 to assess planning initiatives as they relate to change of fish and wildlife habitats (USFWS 1980a, 1980b, 1980c). These procedures, referred to collectively as Habitat Evaluation Procedures and known widely as HEP, use a habitat-based approach to assess ecosystems and provide a mechanism for quantifying changes in habitat quality and quantity over time under proposed alternative scenarios. Habitat Suitability Indices (HSIs) are simple mathematical algorithms that generate a unitless index derived as a function of one or more environmental variables that characterize or typify the site conditions (i.e., vegetative cover and composition, hydrologic regime, disturbance, etc.) and are deployed in the HEP framework to quantify the outcomes of restoration or impact scenarios. These tools have been applied many times over the course of the last 30 years (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Store and Jokimaki 2003, Shifley et al. 2006, Van der Lee et al. 2006). Virtually all attempts to use HSI models have been heavily criticized, and many criticisms are well deserved. In most instances, these criticisms have focused on the lack of: (a) identification of the appropriate context (spatial and temporal) for the model variables, (b) a conceptual framework for what the model is indicating, (c) integration of science and values, and (d) validation of the models (Kapustka 2005, Barry et al. 2006, Hirzel et al. 2006, Inglis et al. 2006, Ray and Burgman 2006, Van der Lee et al. 2006). A fundamental problem with these approaches continues to be the inability to link species presence or relative abundance with significant aspects of habitat quality (VanHorne and Wiens 1991) such as productivity. Despite such criticisms, HSI models have played an important role in the characterization

of ecosystem conditions nationwide. They represent a logical and relatively straightforward process for assessing change to fish and wildlife habitat (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Kapustka 2005). The controlled and economical means of accounting for habitat conditions makes HEP a decision-support process that is superior to techniques that rely heavily upon professional judgment and superficial surveys (Williams 1988, Kapustka 2005). They have proven to be invaluable tools in the development and evaluation of restoration alternatives (Williams 1988, Brown et al. 2000, Store and Kangas 2001, Kapustka 2003, Store and Jokimaki 2003, Gillenwater et al. 2006, Schluter et al. 2006, Shifley et al. 2006), managing refuges and nature preserves (Brown et al. 2000, Ortigosa et al. 2000, Store and Kangas 2001, Felix et al. 2004, Ray and Burgman 2006, Van der Lee et al. 2006) and others), and mitigating the effects of human activities on wildlife species (Burgman et al. 2001, NRC 2001, Van Lonkhuyzen et al. 2004). These modeling approaches emphasize usability. Efforts are made during model development to ensure that they are biologically valid and operationally robust. Most HSI models are constructed largely as working versions rather than as final, definitive models (VanHorne and Wiens 1991). Simplicity is implicitly valued over comprehensiveness, perhaps because the models need to be useful to field managers with little training or experience in this arena. The model structure is therefore simple, and the functions incorporated in the models are relatively easy to understand. The functions included in models are often based on published and unpublished information that indicates they are responsive to species density through direct or indirect effects on life requisites. The general approach of HSI modeling is valid, in that the suitability of habitat to a species is likely to exhibit strong thresholds below which the habitat is usually unsuitable and above which further changes in habitat features make little difference. And as such, most HSI models should be seen as quantitative expressions of the best understanding of the relations between easily measured environmental variables and habitat quality. Habitat suitability models, then, are a compromise between ecological realism and limited data and time (Radeloff et al. 1999, Vospernik et al. 2007).

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	b.	**Description of system being represented by the model:** The Lower Rio Grande resaca ecosystem has been modeled here. *Chapter 3* offers community (ecosystem) characterization garnered from peer-reviewed literature and gray literature generated by federal/local resource management agencies.
	c.	**Analytical requirements and assumptions:** Adequate sample sizes (30+ per variable) must be obtained to assure some level of precision (reduction of uncertainty). It is assumed that the user will adopt and follow the suggested sampling protocols detailed herein. Follow-on data management (calculation of means per variable) is straightforward and should not be difficult to emulate.
	d.	**Conformance with Corps policies and procedures:** As indicated in the PMIP, HEP is an accepted and approved approach to quantifying benefits/impacts for these types of studies (Refer to *Chapter 1 Planning Model Certification*). The protocol described herein was fully vetted through the ERDC review process, and participants in the workshops, as well as external reviewers have been included in the process (Refer to *Chapter 2 – Model Review Process*). Outputs conform to Corps policies and procedures.
	e.	**Identification of formulas used in the model and proof that the computations are appropriate and done correctly:** Formulas can be found in *Chapter 3*. All spreadsheets used to organize data and the datafiles used to calculate outputs can be obtained from the District upon request (contact Steve Ireland or Seth Jones – see *Appendix D* for contact information). ERDC-EL performed QA/QC on all spreadsheet and datafile operations and can describe these to the reviewers upon request.
3. System Quality		
	a.	**Description and rationale for selection of supporting software tool/programming language and hardware platform:** The **HEAT** software is a fully vetted software package currently undergoing model certification. The model described here is not software per se (Refer to *Chapter 1 – Planning Model Certification*), and as such does not contain any programming. ArcMap, ArcToolbox, and Spatial Analyst are all commercially developed off-the-shelf software programs readily available to the user base.
	b.	**Proof that the programming was done correctly:** NA
	c.	**Description of process used to test and validate model:** Verification of the model can be found in *Chapter 4– Model Verification*.
	d.	**Discussion of the ability to import data into other software analysis tools (interoperability issue):** NA
4. Usability		
	a.	**Availability of input data necessary to support the model:** All data (presented in spreadsheet and database format) can be obtained from the District upon request (contact Steve Ireland or Seth Jones – see *Appendix D* for contact information).
	b.	**Formatting of output in an understandable manner:** Outputs of the model are standard indices (HSI) - compatible with traditional HEP applications (scaled 0-1).
	c.	**Usefulness of results to support project analysis:** Model results have been successfully utilized in plan formulation and alternative comparison analyses for the City of Brownsville Resacas Ecosystem Restoration Study (COBRES).
	d.	**Ability to export results into project management documentation:** All outputs are MS Office-compatible and easily imported into MS Word and MS PowerPoint for documentation and distribution.

	e.	**Training availability:** **HEAT** software training was been provided to the Galveston District in March of 2004. ERDC-EL also provides model building workshops at the local, regional, and national level through PROSPECT courses and/or on a reimbursable basis. The District was also required to perform 1/3 of all calculations and 1/3 of all spreadsheet management activities to assure successful technology transfer ("ownership") of the model and the evaluations thereafter.
	f.	**User's documentation availability and whether it is user friendly and complete:** This document serves as the model "manual." A draft manual for the **HEAT** software is currently undergoing certification (Burks-Copes et al., in preparation). Ecological Service Manuals (ESMs) are available to support HEP applications (USFWS 1980a, 1980b, 1980c).
	g.	**Technical support availability:** ERDC-EL provides technical support on all products upon request and on a reimbursable basis.
	h.	**Software/hardware platform availability to all or most users:** The model was provided in both MS Word and MS Excel format and in **HEAT** datafiles to all study participants (including contractors and stakeholders). All data (presented in spreadsheet and database format) can be obtained from the District upon request (contact Steve Ireland or Seth Jones – see *Appendix D* for contact information). The GIS data utilized herein is available upon request from the Galveston District.
	i.	**Accessibility of the model:** The model is accessible now, and will be posted on the System-Wide Water Resources Program's (SWWRP) Water Resources Depot website upon completion of ERDC-EL technical review (https://swwrp.usace.army.mil/DesktopDefault.aspx).
	j.	**Transparency of model and how it allows for easy verification of calculations and outputs:** The mathematical operations in the model have been clearly documented herein and can be easily transferred into any spreadsheet program for verification (a step ERDC-EL uses to QA/QC every model development activity). The outputs are scaled from 0-1 (1 = optimal functionality and 0 = not functioning). An interpretative table has been provided in *Chapter 4* to assist the user in conclusions.
	k.	**Accessibility (where is model physically located?:** Both the Galveston District and ERDC-EL will maintain separate and relatively permanent copies of all model information (NTE 7 years). The model will also be posted on the SWWRP website.

Appendix D: E-Team Participants

As described in the main report, a series of workshops were used to facilitate the development of the community-based index model compatible with the HEP application paradigm for the current study. Formal minutes were developed for each workshop and can be provided upon request from the Galveston District (contact Andrea Catanzaro – refer to contact information below). Several federal, state, and local agencies, as well as local and regional experts from the stakeholder organizations, and private consultants, participated in the model workshops. A complete list of participants can be found in Table D1 below. It is important to note that attrition over the course of the study led to many changes in this original roster. Table D1 includes both the names of original participants as well as replacements and additions.

Table D1. Model development workshop(s) participants.

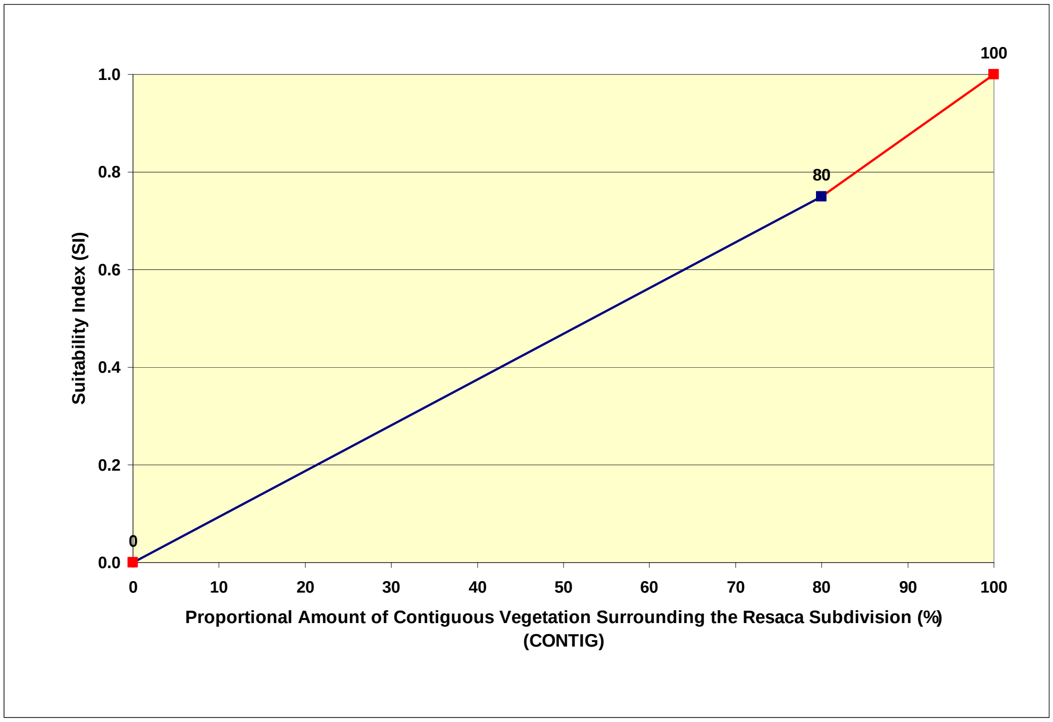
E-Team Members	Agency	Phone	Email Address
Alfaro, Jesus	BPUB		jalfaro@brownsville-pub.com
Brooks, Tammy	TGLO	512-463-9212	tammy.brooks@glo.state.tx.us
Campirano, Edward	BPUB		ecampirano@brownsville-pub.com
Catanzaro, Andrea	USACE	409-766-6346	Andrea.Catanzaro@usace.army.mil
Ford, Larissa	USFWS	361-994-9005	Larisa_Ford@fws.gov
Gomez, Albert Jr.	BPUB	956-982-6251	agomez@brownsville-pub.com
Heinly, Bob	USACE	409-766-3992	Robert.W.Heinly@usace.army.mil
Hinojosa, Joe A.	City of Brownsville	956-548-6092	johino@cob.us
Hunt, Shane[1]	USACE*		
Ireland, Steve	USACE	409-766-3131	Steven.K.Ireland@usace.army.mil
Jenkins, Kay[1]			
Jones, Seth	USACE	409-766-3068	Seth.W.Jones@usace.army.mil
Judd, Frank	University of Texas Pan-American (UTPA)	956-316-7001	fjudd@utpa.edu
Lonard, Robert[1]	University of Texas Pan-American (UTPA)	512-381-3537	
Marin, Carlos	Ambiotec Civil Engineering Group	956-548-9333	cmarin@ambiotec.com

Perales, Julia	BPUB		jperales@brownsville-pub.com
Reyes, Ernesto	USFWS	956-784-7560	Ernesto_Reyes@fws.gov
Stinnett-Herczeg, Terri	USACE	907-753-2794	Terri.L.Stinnett-Herczeg@usace.army.mil
Werth, Adam	GEC, Inc.	337-232-5011	
Whisenant, Steve	TAMU	979-845-5579	s-whisenant@tamu.edu
Woodrow, Jarret[1]			
Wu, Ben	TAMU	979-845-7334	xbw@tamu.edu

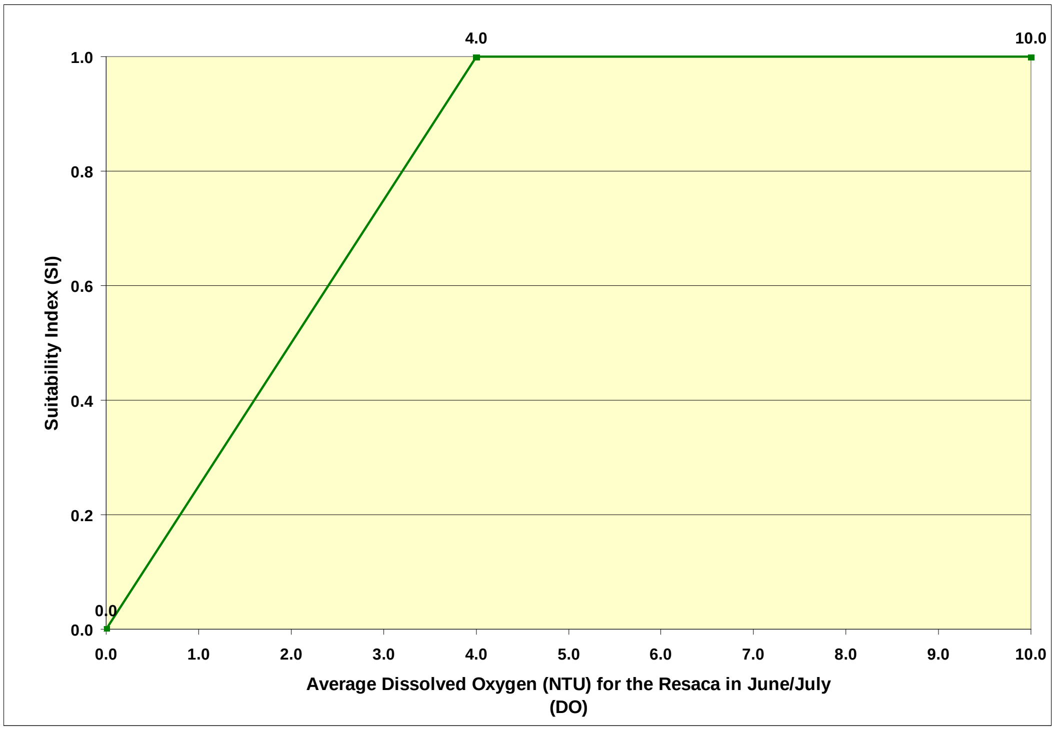
[1] Indicates an E-Team member no longer affiliated with the indicated agency.

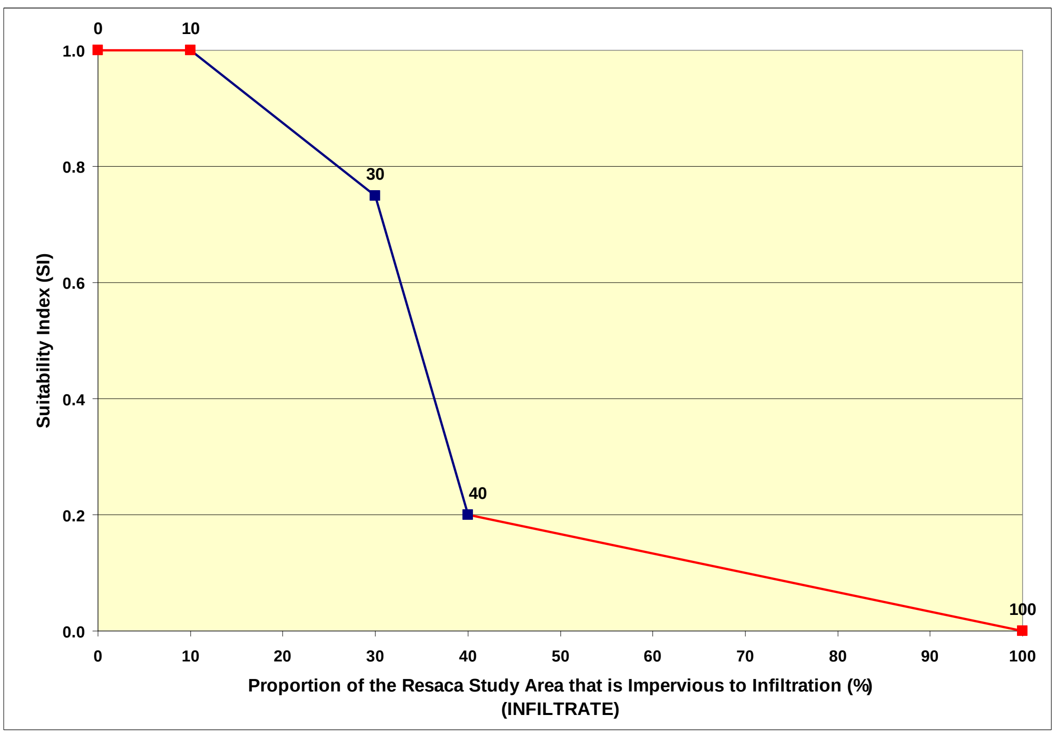
Appendix E: HSI Curves for the Resacas Model

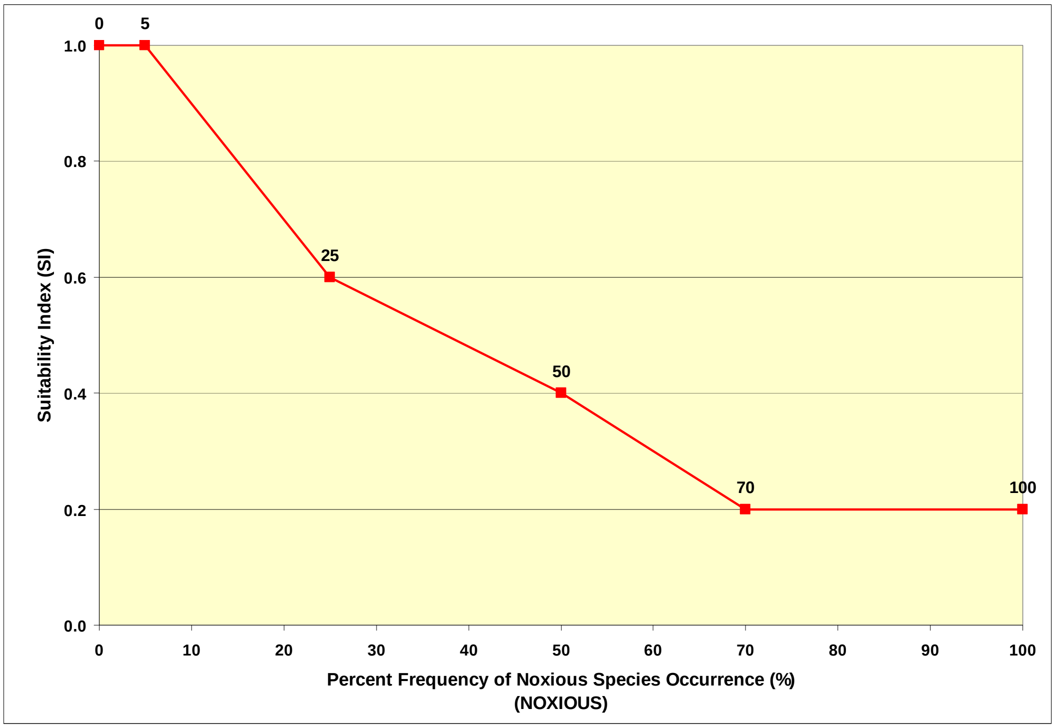
The following curves were developed by the E-Team to measure ecosystem function in the resaca communities found along the Lower Rio Grande running through Brownsville, Texas.[1]

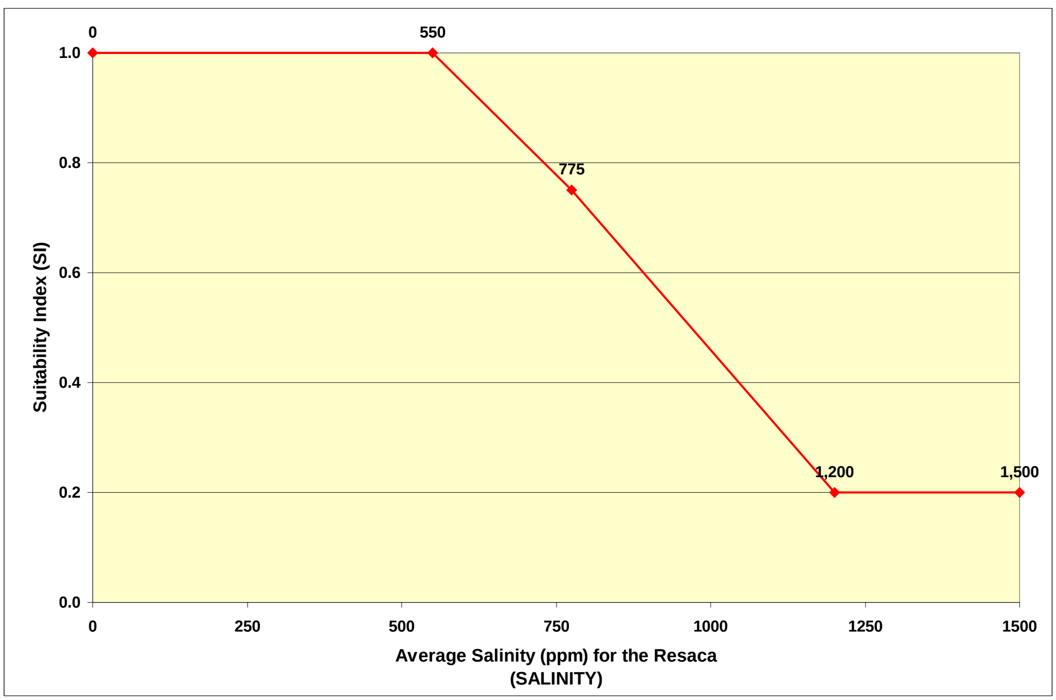


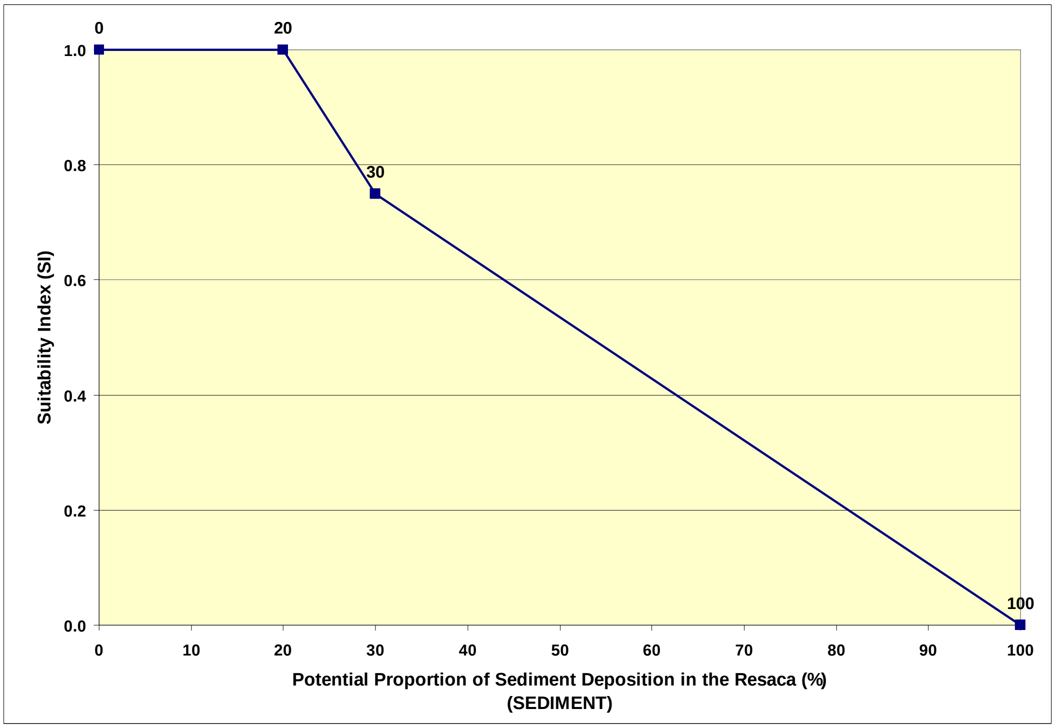
[1] Data are available upon request - contact the District POC (Steve Ireland or Seth Jones, contact information can be found in *Appendix D*).

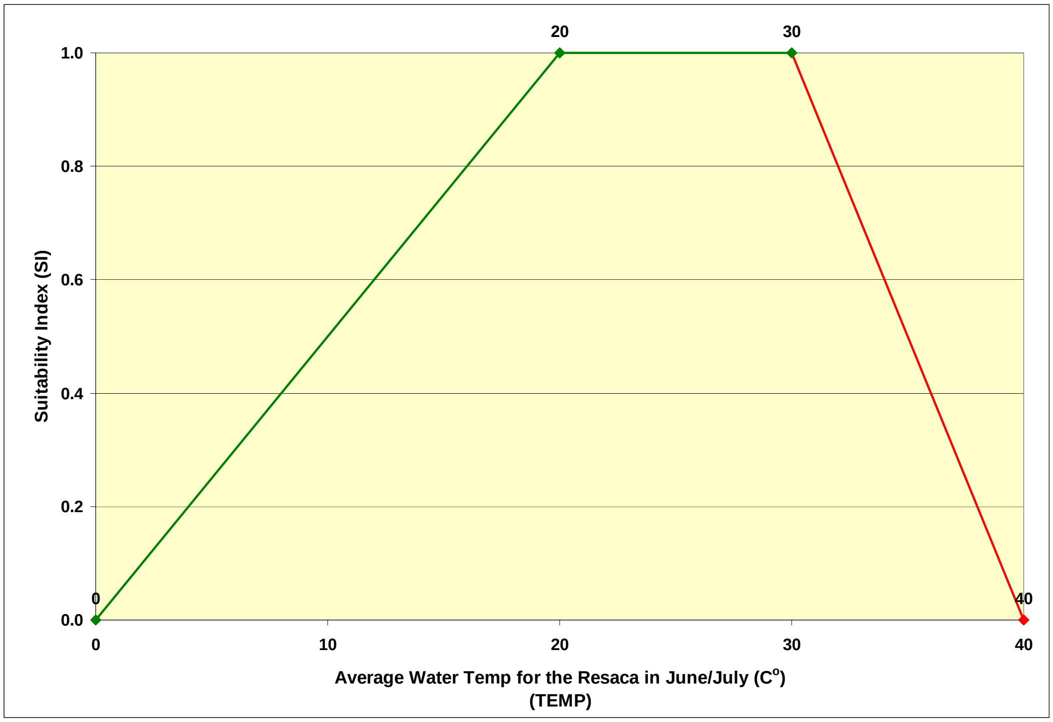

4.0
10.0
1.0
0.8
0.6
0.4
0.2
0.0
0.0
Suitability Index (SI)
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Average Dissolved Oxygen (NTU) for the Resaca in June/July
(DO)

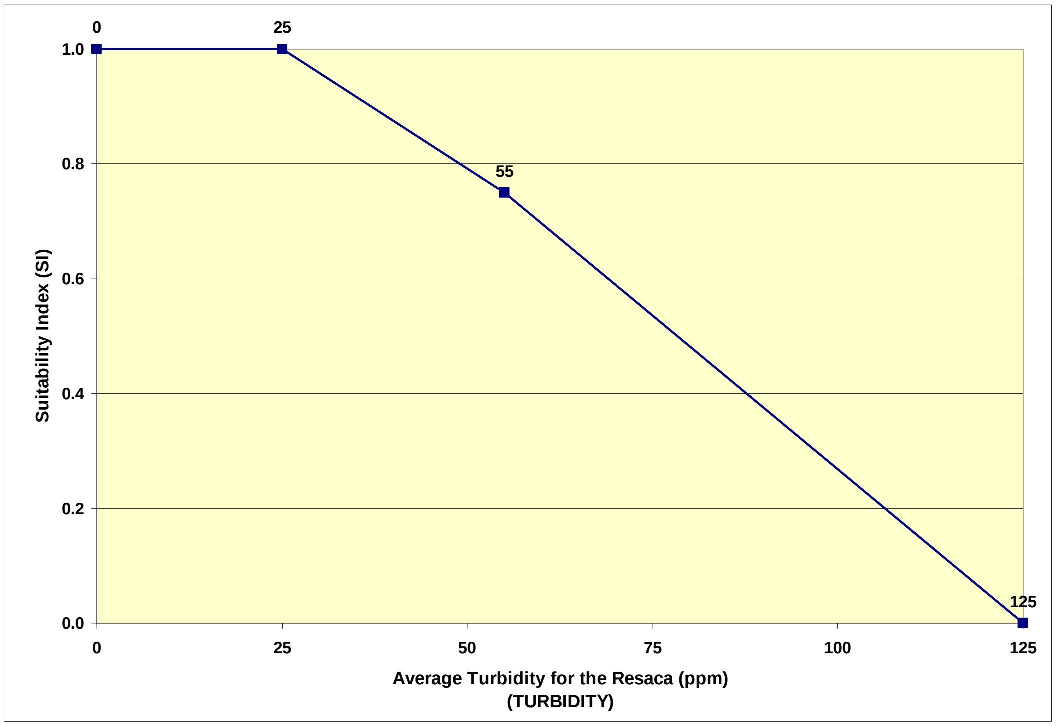

0
10
30
40
100
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0 10 20 30 40 50 60 70 80 90 100
Proportion of the Resaca Study Area that is Impervious to Infiltration (%)
(INFILTRATE)

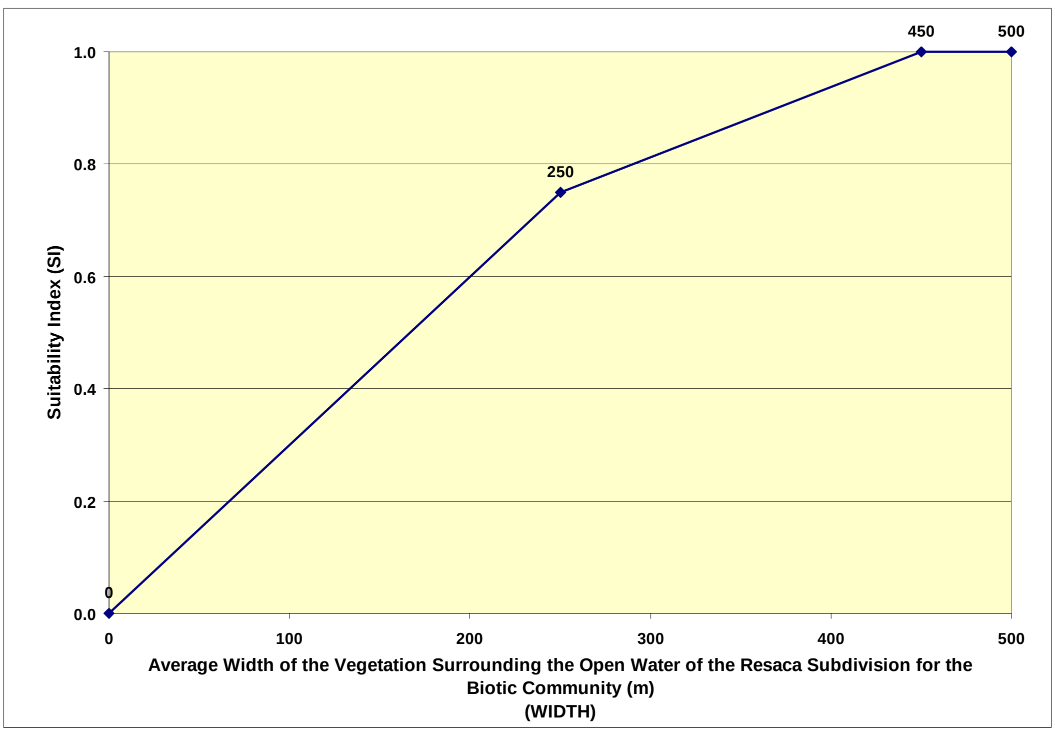

Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
25
50
70
100
0
10
20
30
40
50
60
70
80
90
100
Percent Frequency of Noxious Species Occurrence (%)
(NOXIOUS)

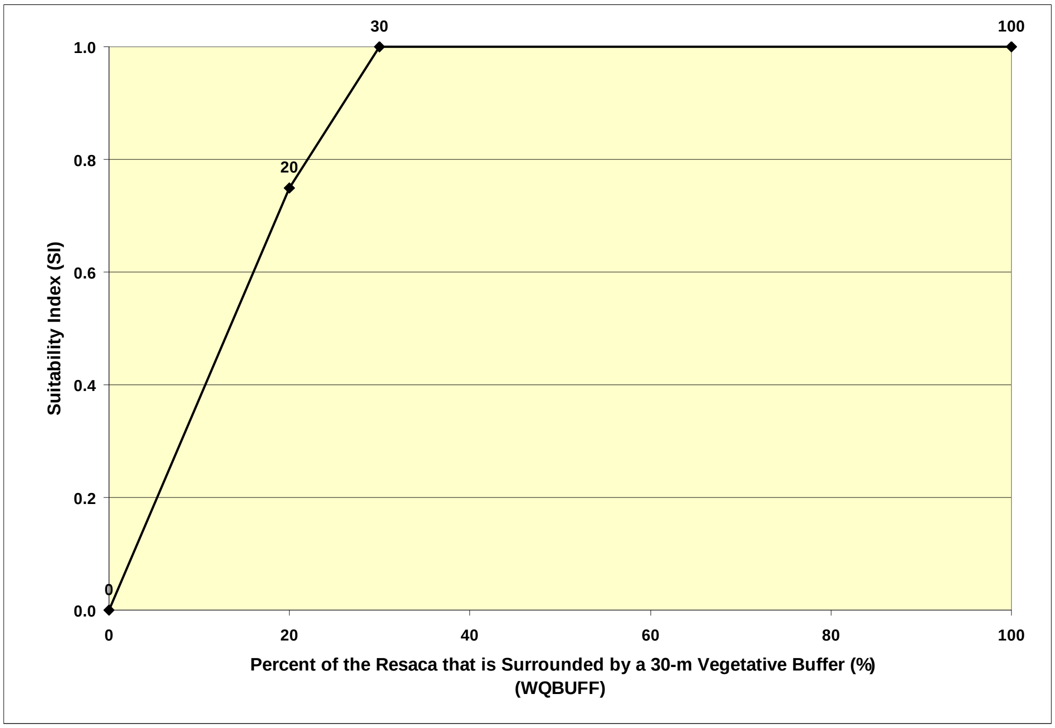

Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
550
775
1,200
1,500
0
250
500
750
1000
1250
1500
Average Salinity (ppm) for the Resaca
(SALINITY)


0
20
30
100
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
10
20
30
40
50
60
70
80
90
100
Potential Proportion of Sediment Deposition in the Resaca (%)
(SEDIMENT)

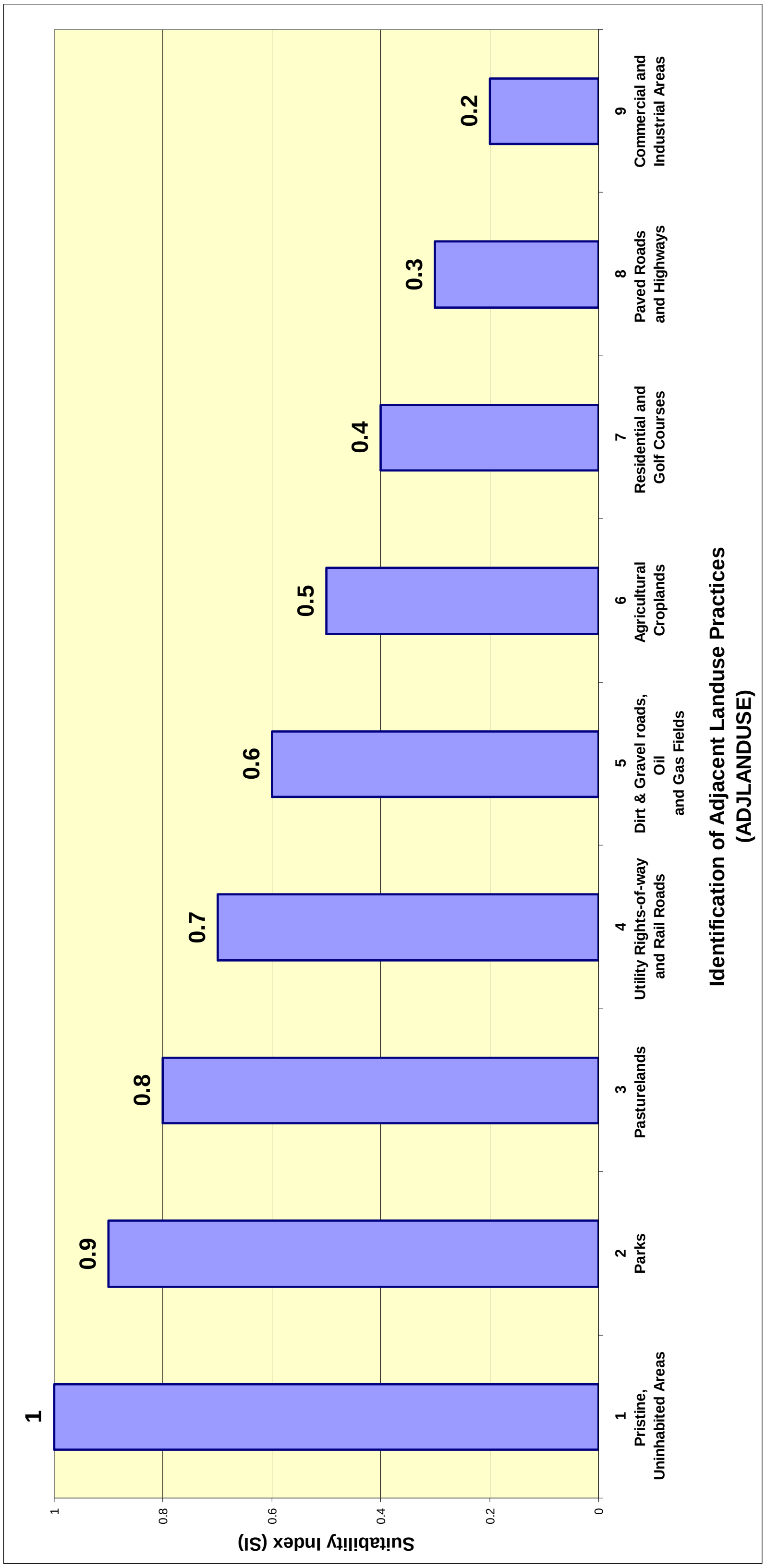

20
30
0
40
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
10
20
30
40
Average Water Temp for the Resaca in June/July (C°)
(TEMP)

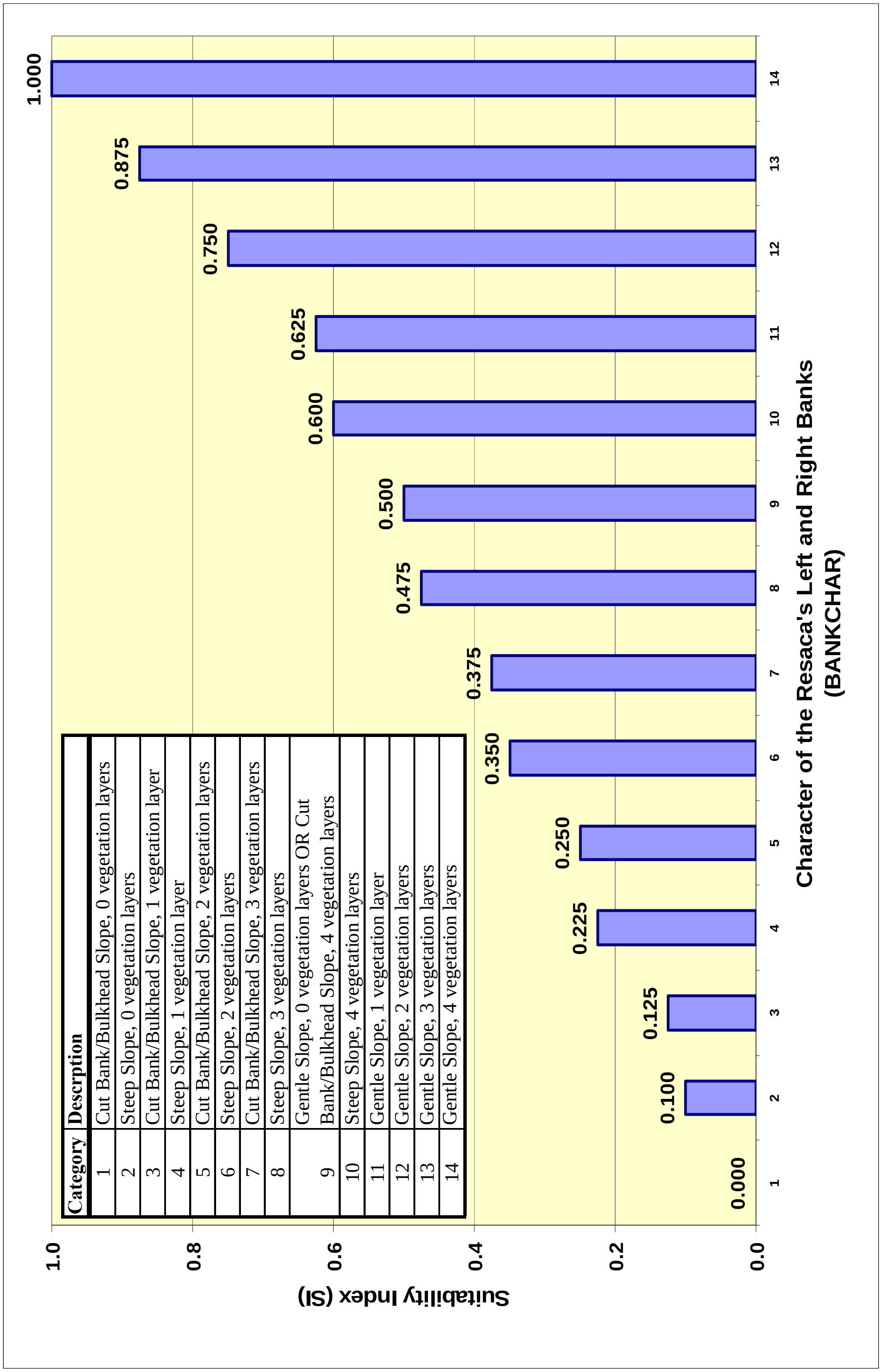

0
25
55
125
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
25
50
75
100
125
Average Turbidity for the Resaca (ppm)
(TURBIDITY)


450
500
250
0
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
100
200
300
400
500
Average Width of the Vegetation Surrounding the Open Water of the Resaca Subdivision for the Biotic Community (m)
(WIDTH)



30
100
1.0
0.8
20
0.6
0.4
0.2
0
0.0
0
20
40
60
80
100
Suitability Index (SI)
Percent of the Resaca that is Surrounded by a 30-m Vegetative Buffer (%)
(WQBUFF)


Suitability Index (SI)
0
0.2
0.4
0.6
0.8
1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1 Pristine, Uninhabited Areas
2 Parks
3 Pasturelands
4 Utility Rights-of-way and Rail Roads
5 Dirt & Gravel roads, Oil and Gas Fields
6 Agricultural Croplands
7 Residential and Golf Courses
8 Paved Roads and Highways
9 Commercial and Industrial Areas
Identification of Adjacent Landuse Practices (ADJLANDUSE)


Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
Character of the Resaca's Left and Right Banks
(BANKCHAR)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0.000
0.100
0.125
0.225
0.250
0.350
0.375
0.475
0.500
0.600
0.625
0.750
0.875
1.000
Category Descrption
1 Cut Bank/Bulkhead Slope, 0 vegetation layers
2 Steep Slope, 0 vegetation layers
3 Cut Bank/Bulkhead Slope, 1 vegetation layer
4 Steep Slope, 1 vegetation layer
5 Cut Bank/Bulkhead Slope, 2 vegetation layers
6 Steep Slope, 2 vegetation layers
7 Cut Bank/Bulkhead Slope, 3 vegetation layers
8 Steep Slope, 3 vegetation layers
9 Gentle Slope, 0 vegetation layers OR Cut Bank/Bulkhead Slope, 4 vegetation layers
10 Steep Slope, 4 vegetation layers
11 Gentle Slope, 1 vegetation layer
12 Gentle Slope, 2 vegetation layers
13 Gentle Slope, 3 vegetation layers
14 Gentle Slope, 4 vegetation layers

Appendix F: Proof of Concept Exploration – Hypothetical Model Application

Purpose

The information herein is offered as a "proof of concept" that tests the Resaca model's capability to inform planning decisions using a "mock" plan formulation experiment. The plans herein were not formulated with input from the E-Team, and as such, they should be considered "hypothetical" in nature. All forecasts were derived in a March 2011 brainstorming session with the District's POC (Andrea Catanzaro), and only the differences in model outputs (i.e., qualities, quantities, and units derived via the HEP process) are presented herein as evidence that the model is performing correctly. In other words, the USACE planning process employs a wide variety of tools and methodologies to distinguish among plans (including cost analyses) that **have not** been employed in this test.

The impetus driving this "proof of concept" testing stems from peer reviews the model has received thus far. One requirement of the reviewers was to demonstrate the capabilities of the model by determining whether it could meet three specific criteria, namely whether its outputs could:

1. Distinguish among plans,
2. Adequately capture the ecosystem responses at an appropriate scale, and
3. Be used to establish performance measures.[1]

The five hypothetical plans formulated for this demonstration are described, along with the assumptions underlying both the without-project and with-project conditions that resulted in the forecasts employed in the assessment. This appendix concludes by demonstrating to the satisfaction of the reviewers that the model has met the three mandatory criteria above.

[1] Personal Communications. Scott Estergard, U.S. Army Engineer District, Los Angeles and Ondrea Hummel, Ecologist, U.S. Army Engineer District, Albuquerque.

Subdivision focus area and plan formulation approach

In order to test the model, the focus was solely on applying the tool to plans formulated within the Resaca del Rancho Viejo – specifically subdivision #1 (Figure F1).

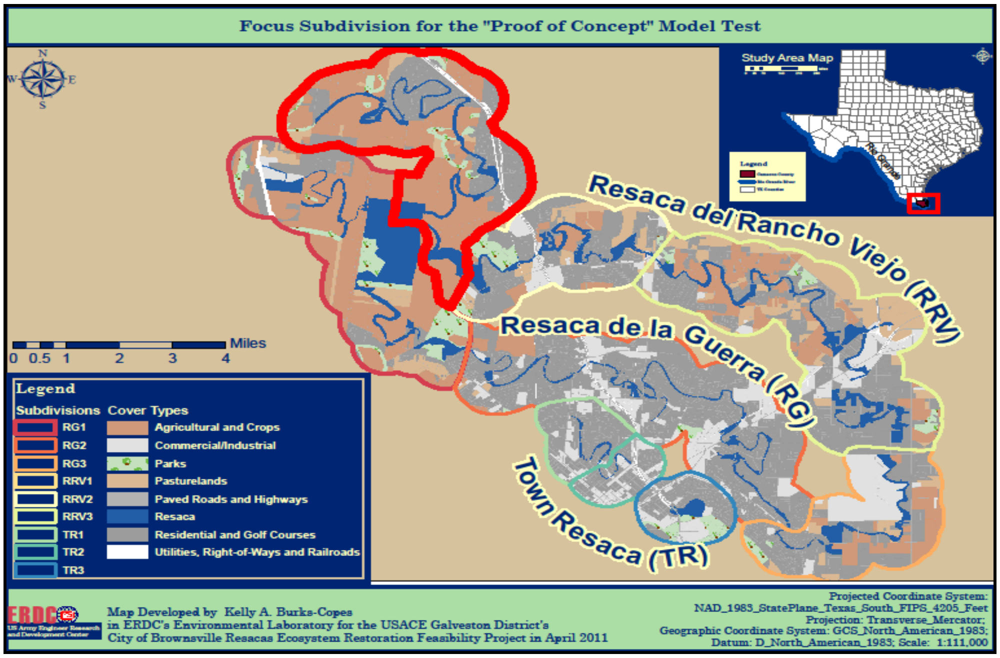


Figure F1. Location of focus area for the “proof of concept” test of the Resaca model: Resaca del Rancho Viejo, Subdivision #1 (indicated in red).

The test site (RRV1) is 8,174 acres in size, with the majority of this acreage held in Agricultural Croplands (50%) and Residential/Golf Course land uses (Figure F2). At present, 898 acres of this subdivision can be classified as Resaca habitat.

With the sole intent of developing straightforward alternatives that could be easily used to test the model, the District formulated plans based on the concepts of comparing/contrasting passive vs. active restoration activities across a variety of footprint sizes. In other words, the final array of alternative designs spans the gamut of possibilities – some are small, concise, and extremely focused combinations of measures that address a specific restoration goal or objective (i.e., improvement of water quality, return of the historic hydrology, control of invasive species, conservation easements, etc.), while others seek to employ the “kitchen sink” approach where all possible measures are combined to fully engage the restoration opportunities (i.e., earth movement, pump installations, land purchases, intensive plantings with high-levels of O&M requirements, etc.).

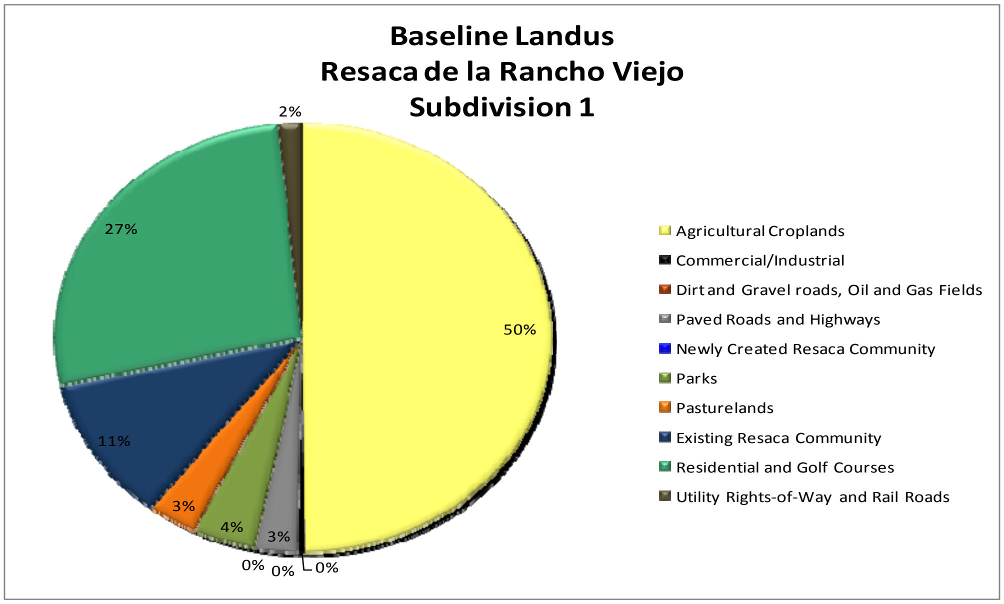


Figure F2. Location of focus area for the “proof of concept” test of the Resaca model: Resaca del Rancho Viejo, Subdivision #1 (indicated in red).

Costs were not considered in this “mock” formulation exercise, but in general, one can infer that larger footprints are likely to require additional resources to implement. In that same vein, passive preservation-based initiatives are likely to cost less than more aggressive rehabilitative efforts. As will be discussed in the next section, the area is under intense urban pressures, and as such, all plans were formulated under the assumption that these disturbances would continue. However, with extensive measures (purchases of significant footprints that allowed for buffering), the disturbance and fragmentation stemming from urban growth and subsequent impacts to water quality and biodiversity in the surrounding areas could be partially alleviated.

All told, five plans were developed for the test (Table F1). These have been numbered 1 through 5, and have been arrayed in increasing number of size (i.e., construction footprint). Maps were created to capture the construction footprints (Figures F3 through F7).

Acreage and variable projections

In an effort to capture these significant land use changes for the test, projection tables were developed for both acreages (Tables F2 through F6) and variables (Tables F7 through F12).

Table F1. Alternative matrix for the “proof of concept” test in RRV1.

Plan Number	Construction Footprint (ac)	Applicable Resaca Habitat (TY51) (ac)	Description
No Action Plan	NA	416 Existing	It was assumed that the future without-project conditions of the study area were certain to reflect losses in wetland presence (i.e., quantity) and habitat suitability (i.e., quality) when faced with the pressures of increasing population growth and increases in water demand in the city. Given the study’s location and the projected growth trends for the area, forecasting suggests initial development would focus on privately held vacant and agricultural parcels. Agricultural lands toward the center of each resaca division are thought to be especially vulnerable to residential conversion over the next 50 years. As privately held lands are converted to commercial and industrial park uses, adjacent publicly-owned areas (currently considered prime candidates for preservation, creation, and restoration activities) would come under increased development pressure. In general under the No Action Plan, as the loss of potential wetland acreage accelerates with urban encroachment, associated environmental value (e.g., habitat suitability and community function) was assumed to decline as well. As a direct result of growth, impervious ground cover would increase, thereby reducing both available land for native habitat and infiltration of runoff. All existing native riparian vegetation within the study area is completely dependent on the availability of water. Without this source, the vegetation would gradually give way to xeric species more suited to desert upland settings. With the disappearance of the riparian vegetation, goes all water-dependent species of wildlife. Water quality (temperature, dissolved oxygen, turbidity and salinity) too would degrade significantly, and the resacas will likely fill with sediment. Noxious species would likely be introduced and proliferate rapidly into homogenous stands of undesirable vegetation choking out the native fringe and submerged communities. As the stabilizing function of native plants, especially trees, is lost (and as further development occurs), channel banks must be armored to control erosion. Without native vegetation to provide resistance to erosion, the unprotected banks would become more mobile and unpredictable. Urban development would occur right up to the edge of the resaca shorelines, and bulwarks would likely be deployed to maintain shoreline stability. People would likely remove scrubby woody vegetation in favor of planting Bermuda grass to water’s edge. Buffers would be lost entirely, and any remaining habitat will be highly fragmented.
Plan 1	184	416 Existing 48 New	Alternative Plan 1 would establish a 30-m-wide buffer strip to control erosion within newly created resaca habitat. Within this buffer, cover types such as agriculture/crops, pasture and park would be converted to create new resaca habitat (48 acres); existing resaca cover type would not be included (although some acreage would

Plan Number	Construction Footprint (ac)	Applicable Resaca Habitat (TY51) (ac)	Description
			remain without federal protection/restoration) (416 acres). The alternative assumes some manipulation (e.g. clearing, grading, planting, etc.) of land will be necessary. In addition, restrictions on building and construction within the buffer would be established to include no new bulkheads, or extensions of existing bulkheads along the shorelines, no new structures or facilities within the buffer, and no new structures (e.g. piers, walkways, etc.) extending over the water surface of the resaca. Within the buffer, earthwork would also be prohibited in and adjacent to the resacas. New resacas created from converting other cover types would be planted with suitable species of native vegetation based on elevation. Techniques such as cutting and treating plants with herbicide would be employed annually through the 50-year period of analysis to control invasive plant species like Brazilian pepper that are present within the buffer.
Plan 2	727	592 Existing 0 New	Alternative Plan 2 would establish a 30-m-wide buffer strip around the existing resacas habitat to control erosion. Within this buffer, existing resaca cover type is preserved (592 acres); land-use practices within other cover types such as agriculture/crops, pasture and park are restricted, but these cover types would not be converted to new Resaca (0 acres). The alternative assumes no manipulation (e.g. clearing, grading, planting, etc.) of land is necessary. Land use restrictions would include restrictions on building and construction within the buffer to include no new bulkheads, or extensions of existing bulkheads along the shorelines, no new structures or facilities within the buffer, and no new structures (e.g. piers, walkways, etc.) extending over the water surface of the resaca. Within the buffer, earthwork would also be prohibited in and adjacent to the resacas. Techniques such as cutting and treating plants with herbicide would be employed annually through the 50-year period of analysis to control invasive plant species like Brazilian pepper that are present within the buffer. Spatial integrity baseline conditions are maintained for all cover type acreages occurring within the footprint of the alternative.
Plan 3	727	592 Existing 48 New	Alternative Plan 3 would establish a 30-m-wide buffer strip around the existing and new resaca habitat to control erosion. Within this buffer, existing resaca cover type is preserved (592 acres) and other cover types such as agriculture/crops, pasture and park are converted to create new resaca habitat (48 acres). The alternative assumes some manipulation (e.g. clearing, grading, planting, etc.) of land will be necessary. In addition, restrictions on building and construction within the buffer would be established to include no new bulkheads, or extensions of existing bulkheads along the shorelines, no new structures or facilities within the

Plan Number	Construction Footprint (ac)	Applicable Resaca Habitat (TY51) (ac)	Description
			buffer, and no new structures (e.g. piers, walkways, etc.) extending over the water surface of the resaca. Within the buffer, earthwork would also be prohibited in and adjacent to the resacas. New resacas created from converting other cover types would be planted with suitable species of native vegetation based on elevation. Techniques such as cutting and treating plants with herbicide would be employed annually through the 50-year period of analysis to control invasive plant species like Brazilian pepper that are present within the buffer. Baseline conditions would be maintained for the resaca cover type acreage within the footprint of the alternative.
Plan 4	898	898 Existing 0 New	Alternative Plan 4 would preserve 898 acres of existing resaca habitat in its entirety to prevent destruction of habitat area as well as reduced habitat quality resulting from future development pressures. The alternative assumes no manipulation (e.g. clearing, grading, planting, etc.) of land will be necessary, although techniques such as cutting and treating plants with herbicide would be employed annually through the 50-year period of analysis to control invasive plant species like Brazilian pepper that are present within the area being preserved.
Plan 5	906	898 Existing 976 New	Alternative Plan 5 involves preserving 898 acres of existing resaca habitat in its entirety to prevent destruction of habitat area as well as reduced habitat quality resulting from future development pressures. Patch connectivity within the resaca would be expanded by restoring habitat corridors and/or hydrologic connections through the conversion of other land uses such as agriculture/crops, pasture and park to create 1,325 acres of new resaca habitat between patches of vegetation within the resaca cover type. In addition, isolated resaca ponds that once had hydrologic connections to RRV1, or areas of marginal connection, would be reconnected hydrologically where it is still possible to do so. This alternative assumes extensive manipulation (e.g. clearing, grading, excavating, planting, etc.) of land will be necessary to reestablish connectivity. In addition, techniques such as cutting and treating plants with herbicide would be employed annually through the 50-year period of analysis to control invasive plant species like Brazilian pepper that are present within the area being preserved.

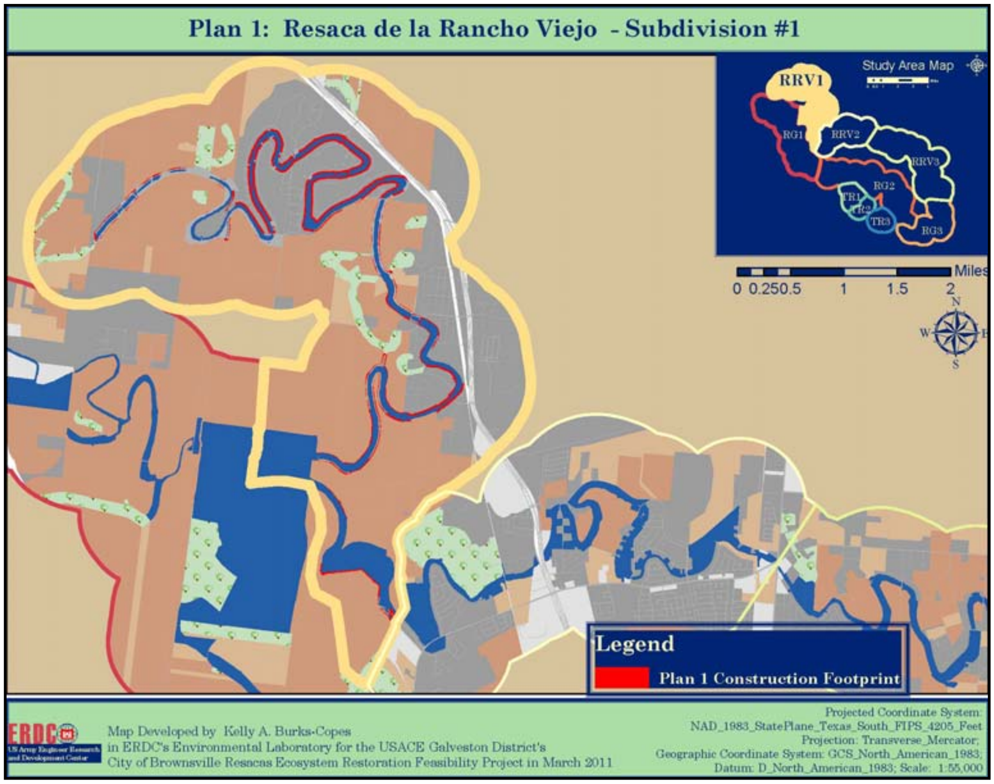


Figure F3. Plan 1 alternative design (construction footprint in red).

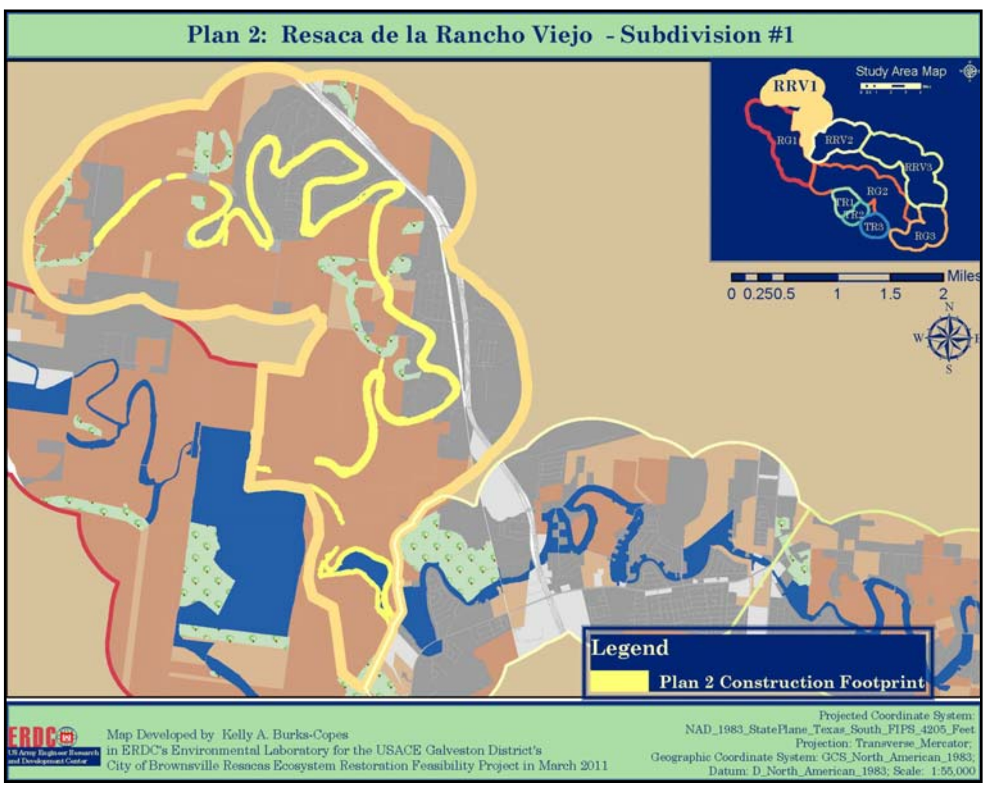


Figure F4. Plan 2 alternative design (construction footprint in yellow).

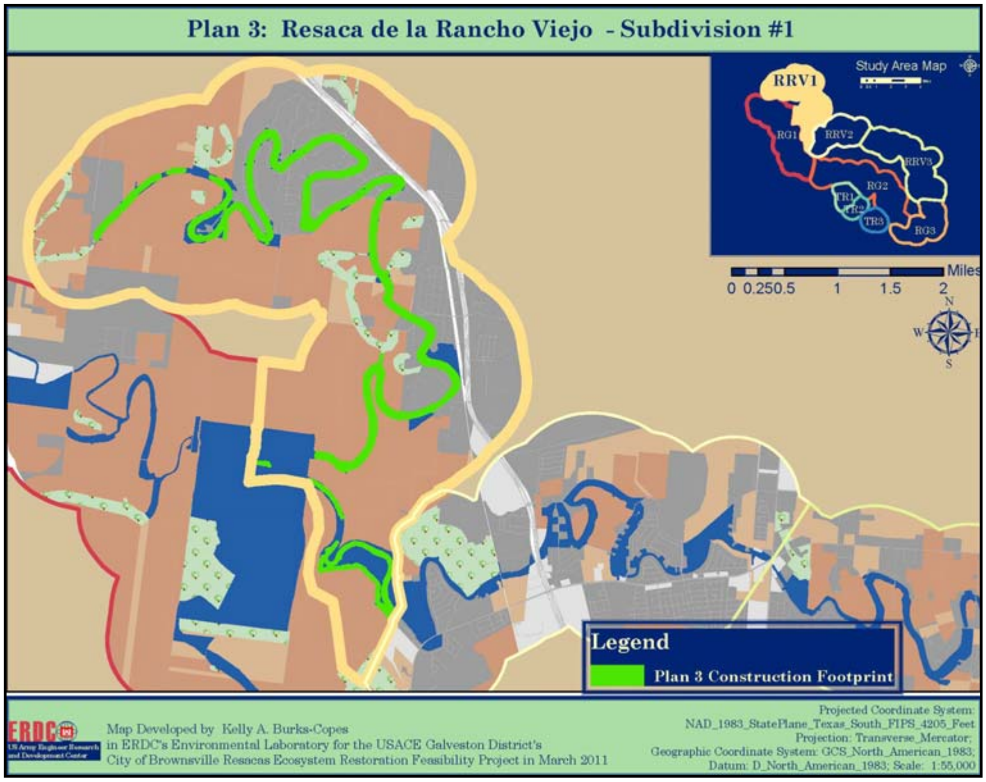


Figure F5. Plan 3 alternative design (construction footprint in green).

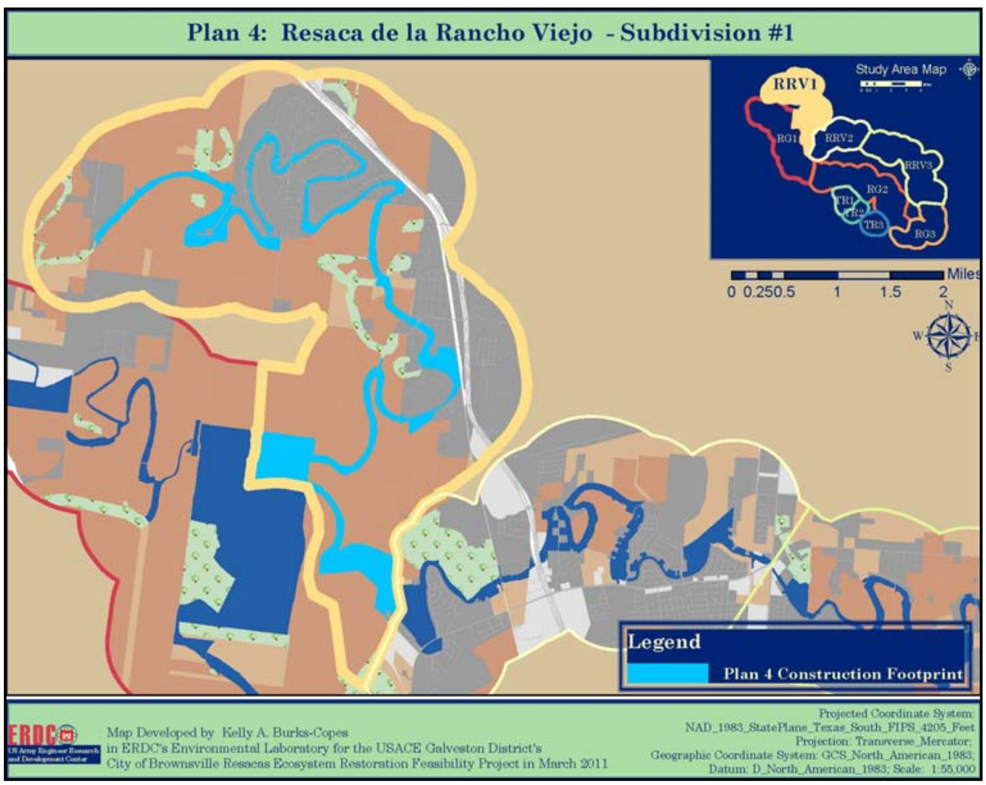


Figure F6. Plan 4 alternative design (construction footprint in blue).

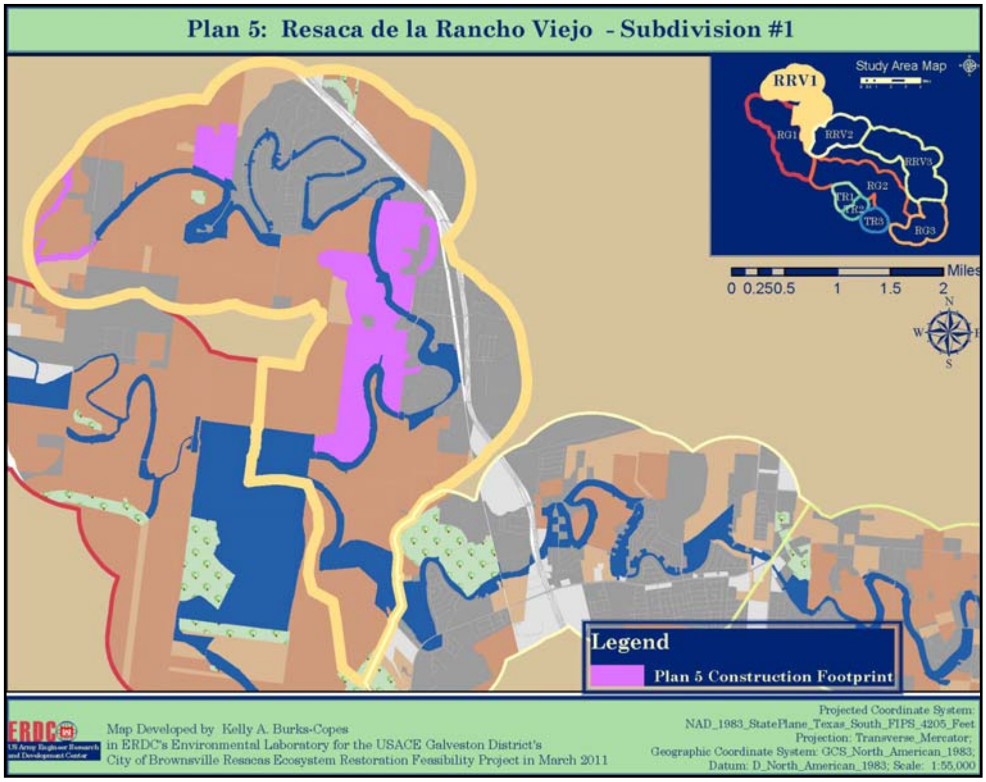


Figure F7. Plan 5 alternative design (construction footprint in purple).

Proof of concept HEP results

The changes predicted above under the hypothetical plans resulted in the following quantifiable benefits for the resacas community within the Resaca del Rancho Viejo Subdivision #1 (Table F13, Figure F8, and Figure F9).

As evidenced by these results, the Resacas model is capable of distinguishing between plans to a significant extent. Only two plans overlap slightly (Plan 2 and Plan 3). It should be noted that Plans 2 and 3 were intentionally formulated to be similar to test the veracity of the model - their construction footprints are identical, they are both intent on preserving 592 acres of existing habitat, and the only distinction between plans is whether new Resaca habitat is created or not. These new habitat acres are developed only in small amounts in Plan 3 (48 acres, which is equivalent to 7.5% of the total Resaca community when complete). All other plans formulated under this exercise are unique in their outcomes, thereby supporting the conclusion that the model meet two of the three requirements to assume model robustness; namely, that when applied under these conditions, the model can distinguish among plans and can adequately capture the ecosystem responses at an appropriate scale (namely, the subdivision level).

Table F2. Acreage projections for Plan 1 (including without-project conditions).

Plan 1			Without Project					With Project				
			Target Year					Target Year				
			2004	2013	2016	2026	2063	2004	2013	2016	2026	2063
No.	Code	Description	TY0	TY1	TY4	TY11	TY51	TY0	TY1	TY4	TY11	TY51
1	AGCROP	Agricultural Croplands	4,074	3,843	3,376	1,327	1	4,074	3,795	3,328	1,279	0
2	COMMERCIAL	Commercial/Industrial	36	298	391	801	1,113	36	298	391	801	1,113
3	DIRTROADS	Dirt and Gravel Roads, Oil and Gas Fields	0	0	0	0	0	0	0	0	0	0
4	HIGHWAYS	Paved Roads and Highways	231	362	409	614	770	231	362	409	614	770
5	NEWRESACA	Newly Created Resaca Community	0	0	0	0	0	0	48	48	48	48
6	PARKS	Parks	332	0	0	0	0	332	0	0	0	0
7	PASTURE	Pasturelands	267	0	0	0	0	267	0	0	0	0
8	RESACA	Existing Resaca Community	898	416	416	416	416	898	416	416	416	416
9	RESIDENTL	Residential and Golf Courses	2,206	3,059	3,363	4,695	5,475	2,206	3,059	3,363	4,695	5,428
10	RIGHTOFWAY	Utility Rights-of-Way and Railroads	130	196	219	321	399	130	196	219	321	399
		TOTALS:	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174

Table F3. Acreage projections for Plan 2 (including without-project conditions).

Plan 2			Without Project					With Project				
			Target Year					Target Year				
			2004	2013	2016	2026	2063	2004	2013	2016	2026	2063
No.	Code	Description	TY0	TY1	TY4	TY11	TY51	TY0	TY1	TY4	TY11	TY51
1	AGCROP	Agricultural Croplands	4,074	3,843	3,376	1,327	1	4,074	3,667	3,200	1,151	1
2	COMMERCIAL	Commercial/Industrial	36	298	391	801	1,113	36	298	391	801	1,113
3	DIRTROADS	Dirt and Gravel Roads, Oil and Gas Fields	0	0	0	0	0	0	0	0	0	0
4	HIGHWAYS	Paved Roads and Highways	231	362	409	614	770	231	362	409	614	770
5	NEWRESACA	Newly Created Resaca Community	0	0	0	0	0	0	0	0	0	0
6	PARKS	Parks	332	0	0	0	0	332	0	0	0	0
7	PASTURE	Pasturelands	267	0	0	0	0	267	0	0	0	0
8	RESACA	Existing Resaca Community	898	416	416	416	416	898	592	592	592	592
9	RESIDENTL	Residential and Golf Courses	2,206	3,059	3,363	4,695	5,475	2,206	3,059	3,363	4,695	5,299
10	RIGHTOFWAY	Utility Rights-of-Way and Railroads	130	196	219	321	399	130	196	219	321	399
		TOTALS:	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174

Table F4. Acreage projections for Plan 3 (including without-project conditions).

Plan 3			Without Project					With Project				
			Target Year					Target Year				
			2004	2013	2016	2026	2063	2004	2013	2016	2026	2063
No.	Code	Description	TY0	TY1	TY4	TY11	TY51	TY0	TY1	TY4	TY11	TY51
1	AGCROP	Agricultural Croplands	4,074	3,843	3,376	1,327	1	4,074	3,619	3,152	1,103	0
2	COMMERCIAL	Commercial/Industrial	36	298	391	801	1,113	36	298	391	801	1,113
3	DIRTROADS	Dirt and Gravel Roads, Oil and Gas Fields	0	0	0	0	0	0	0	0	0	0
4	HIGHWAYS	Paved Roads and Highways	231	362	409	614	770	231	362	409	614	770
5	NEWRESACA	Newly Created Resaca Community	0	0	0	0	0	0	48	48	48	48
6	PARKS	Parks	332	0	0	0	0	332	0	0	0	0
7	PASTURE	Pasturelands	267	0	0	0	0	267	0	0	0	0
8	RESACA	Existing Resaca Community	898	416	416	416	416	898	592	592	592	592
9	RESIDENTL	Residential and Golf Courses	2,206	3,059	3,363	4,695	5,475	2,206	3,059	3,363	4,695	5,252
10	RIGHTOFWAY	Utility Rights-of-Way and Railroads	130	196	219	321	399	130	196	219	321	399
		TOTALS:	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174

Table F5. Acreage projections for Plan 4 (including without-project conditions).

Plan 4			Without Project					With Project				
			Target Year					Target Year				
			2004	2013	2016	2026	2063	2004	2013	2016	2026	2063
No.	Code	Description	TY0	TY1	TY4	TY11	TY51	TY0	TY1	TY4	TY11	TY51
1	AGCROP	Agricultural Croplands	4,074	3,843	3,376	1,327	1	4,074	3,361	2,894	845	1
2	COMMERCIAL	Commercial/Industrial	36	298	391	801	1,113	36	298	391	801	1,113
3	DIRTROADS	Dirt and Gravel Roads, Oil and Gas Fields	0	0	0	0	0	0	0	0	0	0
4	HIGHWAYS	Paved Roads and Highways	231	362	409	614	770	231	362	409	614	770
5	NEWRESACA	Newly Created Resaca Community	0	0	0	0	0	0	0	0	0	0
6	PARKS	Parks	332	0	0	0	0	332	0	0	0	0
7	PASTURE	Pasturelands	267	0	0	0	0	267	0	0	0	0
8	RESACA	Existing Resaca Community	898	416	416	416	416	898	898	898	898	898
9	RESIDENTL	Residential and Golf Courses	2,206	3,059	3,363	4,695	5,475	2,206	3,059	3,363	4,695	4,993
10	RIGHTOFWAY	Utility Rights-of-Way and Railroads	130	196	219	321	399	130	196	219	321	399
		TOTALS:	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174

Table F6. Acreage projections for Plan 5 (including without-project conditions).

Plan 5			Without Project					With Project				
			Target Year					Target Year				
			2004	2013	2016	2026	2063	2004	2013	2016	2026	2063
No.	Code	Description	TY0	TY1	TY4	TY11	TY51	TY0	TY1	TY4	TY11	TY51
1	AGCROP	Agricultural Croplands	4,074	3,843	3,376	1,327	1	4,074	2,485	2,018	0	0
2	COMMERCIAL	Commercial/Industrial	36	298	391	801	1,113	36	298	391	801	1,113
3	DIRTROADS	Dirt and Gravel Roads, Oil and Gas Fields	0	0	0	0	0	0	0	0	0	0
4	HIGHWAYS	Paved Roads and Highways	231	362	409	614	770	231	362	409	614	770
5	NEWRESACA	Newly Created Resaca Community	0	0	0	0	0	0	876	876	876	876
6	PARKS	Parks	332	0	0	0	0	332	0	0	0	0
7	PASTURE	Pasturelands	267	0	0	0	0	267	0	0	0	0
8	RESACA	Existing Resaca Community	898	416	416	416	416	898	898	898	898	898
9	RESIDENTL	Residential and Golf Courses	2,206	3,059	3,363	4,695	5,475	2,206	3,059	3,363	4,664	4,118
10	RIGHTOFWAY	Utility Rights-of-Way and Railroads	130	196	219	321	399	130	196	219	321	399
		TOTALS:	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174	8,174

Table F7. Variable projections for the No Action Plan (without-project for all plans).

Without Project (Existing Resacas Only)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	6	0.348	80	7.0	20	10	921	30	32	55	480	68
1	7	0.209	50	3.1	50	40	1,371	50	33	70	125	39
4	7	0.136	40	3.1	45	45	1,371	60	34	90	75	23
14	7	0.136	25	3.1	45	45	1,371	70	35	115	40	10
51	7	0.136	15	3.1	45	45	1,371	80	36	145	0	0

Table F8. Variable projections Plan 1.

Plan 1 (Existing Resacas Only)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	6	0.348	80	7.0	20	10	921	30	32	55	480	68
1	7	0.219	50	3.5	50	40	1,200	45	33	65	125	44
4	7	0.15	40	3.5	45	45	1,250	55	34	85	75	28
14	7	0.157	25	3.5	45	45	1,300	65	35	110	40	15
51	7	0.165	15	3.5	45	45	1,350	75	36	140	30	5
Plan 1 (New Resacas)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	0	0	0	0.0	0	0	0	0	0	0	0	0
1	7	0.219	50	3.5	50	40	1,200	45	33	65	125	44
4	7	0.15	40	3.5	45	45	1,250	55	34	85	75	28
14	7	0.157	25	3.5	45	45	1,300	65	35	110	40	15
51	7	0.165	15	3.5	45	45	1,350	75	36	140	30	5

Table F9. Variable projections Plan 2.

Plan 2 (Existing Resacas Only)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	6	0.348	80	7.0	20	10	921	30	32	55	480	68
1	7	0.251	80	6.951	50	5	921	30	32	55	125	68
4	7	0.195	80	6.951	45	5	921	30	32	55	75	68
14	7	0.235	80	6.5	45	5	950	45	33	65	40	68
51	7	0.281	80	6	45	5	1,000	60	34	70	30	68
Plan 2 (New Resacas)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	0	0	0	0.0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0

Table F10. Variable projections Plan 3.

Plan 3 (Existing Resacas Only)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	6	0.348	80	7.0	20	10	921	30	32	55	480	68
1	7	0.251	80	7.351	50	5	750	30	32	50	125	68
4	7	0.195	80	7.351	45	5	800	30	32	50	75	68
14	7	0.235	80	6.9	45	5	879	35	33	60	40	68
51	7	0.281	80	6.4	45	5	979	40	34	65	30	68

Plan 3 (New Resacas)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	0	0	0	0.0	0	0	0	0	0	0	0	0
1	7	0.251	80	7.351	50	5	750	30	32	50	125	68
4	7	0.195	80	7.351	45	5	800	30	32	50	75	68
14	7	0.235	80	6.9	45	5	879	35	33	60	40	68
51	7	0.281	80	6.4	45	5	979	40	34	65	30	68

Table F11. Variable projections Plan 4.

Plan 4 (Existing Resacas Only)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	6	0.348	80	7.0	20	10	921	30	32	55	480	68
1	7	0.348	80	6.951	50	10	921	30	32	55	480	68
4	7	0.348	80	6.951	45	10	921	30	32	55	480	68
14	7	0.348	80	6.951	45	10	921	30	32	55	480	68
51	7	0.348	80	6.951	45	10	921	30	32	55	480	68
Plan 4 (New Resacas)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	0	0	0	0.0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0

Table F12. Variable projections Plan 5.

Plan 5 (Existing Resacas Only)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	6	0.348	80	7.0	20	10	921	30	32	55	480	68
1	7	0.6	80	6.951	23	5	650	30	31	50	600	70
4	7	0.6	80	6.951	26	5	675	30	30	50	600	70
14	7	0.6	80	6.951	30	5	700	35	31	60	600	70
51	7	0.6	80	6.951	35	5	725	40	32	65	600	70
Plan 5 (New Resacas)												
TY	ADJLANDUSE	BANKCHAR	CONTIG	DO	INFILTRATE	NOXIOUS	SALINITY	SEDIMENT	TEMP	TURBIDITY	WIDTH	WQBUFF
0	0	0	0	0.0	0	0	0	0	0	0	0	0
1	7	0.6	80	6.951	23	5	650	30	31	50	600	70
4	7	0.6	80	6.951	26	5	675	30	30	50	600	70
14	7	0.6	80	6.951	30	5	700	35	31	60	600	70
51	7	0.6	80	6.951	35	5	725	40	32	65	600	70

Table F13. Final results for the “proof of concept” hypothetical plans. Sensitivity (i.e., Best vs. Worst Case scenarios are based on the sensitivity analysis reported in *Chapter 4* of the main report for the RRV1 site).

Reach Name	**Site Name**	**AAHUs**	**Best Case (16% higher)**	**Worst Case (21% lower)**
Resaca del Rancho Viejo Sub Division #1	Plan 1	21	25	17
	Plan 2	165	191	130
	Plan 3	191	221	151
	Plan 4	382	443	302
	Plan 5	1,035	1,201	818

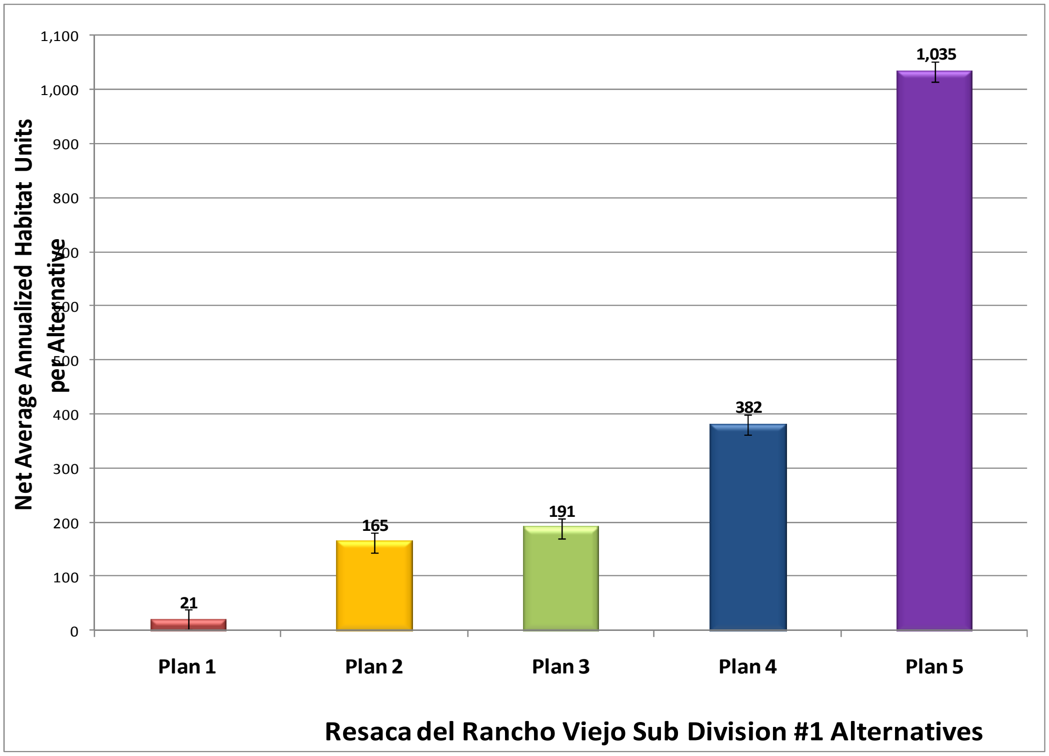


Figure F8. Alternative results presented with error bars extrapolated from the sensitivity analyses performed earlier in the report (*Chapter 4*).

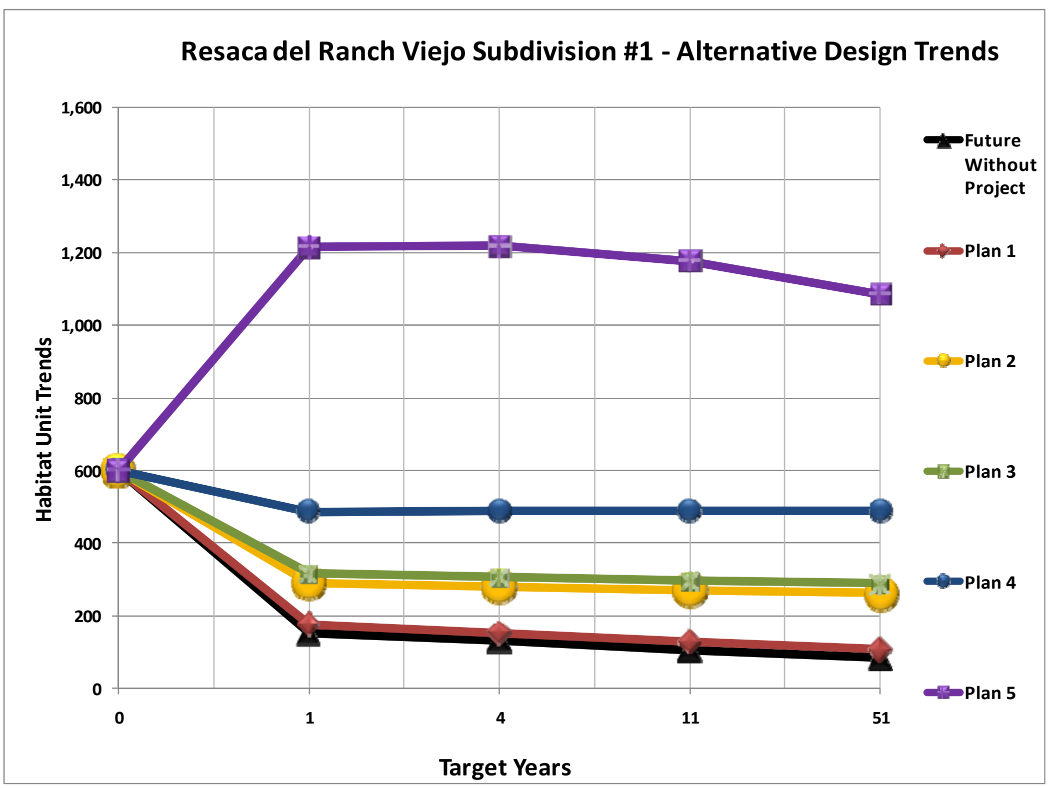


Figure F9. Comparison of trends over the 50-year period of analysis illustrating the span of potential outcomes given the five hypothetical alternative designs.

In order to meet the final requirement (that of using the model to establish performance measures), one simply needs to tailor the goals and objectives to address the parameters therein. In other words, objectives could be verbalized in the following manner to measure restoration success:

1. Assume that the resacas habitat is under threat (as evidenced by the without-project results of the model), and sustainable, resilient restoration can be achieved if baseline conditions are either maintained or improved. Given this assumption, only one of the five plans (namely Plan 5) meets the objective of maintaining baseline conditions (i.e., it's the only one that does not fall below ~600 HUs, which is the baseline condition).
2. If a different goal is targeted, say attaining 15% of maximum possible restoration using a "virtual" reference (i.e., one in which the components of the HSI Resaca model are optimized at 1.0 HSI by the first year of evaluation, and the maximum number of acres are restored in the subdivision), then we can establish a target of 250 AAHUs (maximum possible = 1,655 AAHUs) (Table F14). Under this performance measure, Plans 4 and 5 meet the objective.

Table F14. Comparison of possible restoration initiatives with respect to gains beyond the No Action Plan, as well as comparisons to a "virtual" reference condition, and thresholds of HSI productivity.

Reach Name	Site Name	AAHUs	Percent Optimum Obtained	Improvement Over the No Action Plan
Resaca del Rancho Viejo Sub Division #1	Plan 1	21	1%	13%
	Plan 2	165	10%	27%
	Plan 3	191	12%	30%
	Plan 4	382	23%	49%
	Plan 5	1,035	63%	114%

3. Alternatively, one could consider measuring functional lift (above the baseline condition) and setting targets such as 50%. In this instance, Plan 4 almost meets the objective, and Plan 5 greatly exceeds the target.
4. Another option is to focus on the detailed outputs of the model, namely the final HSIs or the Individual Component indices (i.e., LRSIs), and set targets. If sustainable restoration is equated with functional scores in excess of 0.5, then plans can be compared across HSIs or the LRSIs to determine objective attainment (Tables F15 and F16). In these instances, Plans 4 and 5 meet the success critieria when considering HSIs alone. However, Plan 4 does not meet the criteria across all LRSIs. In fact, possible improvements on Plan 4 should focus on improving parameters characterizing

disturbance (i.e., adjacent land use practices) and hydrology (i.e., dissolved oxygen, water temperature, sedimentation, salinity, turbidity) and improving buffers/land use conditions (i.e., adding water quality buffers and removing conditions that restrict infiltration). Plan 5 meets the objective in two of three instances – it is deficient in the DISTURB component (i.e., the surrounding area is predominantly disturbed). Improvements on this plan must focus on conservation easements and other buffering mechanisms to reduce the human influence on the resacas community.

Table F15. Comparison of possible restoration initiatives with respect to gains beyond the No Action Plan, as well as comparisons to a "virtual" reference condition, and thresholds of HSI productivity.

Reach Name	Site Name	TY 0	TY 1	TY 4	TY 11	TY51
Resaca del Ranch Viejo Sub Division #1	Plan 1	0.669	0.381	0.328	0.275	0.230
	Plan 2	0.669	0.489	0.474	0.454	0.442
	Plan 3	0.669	0.496	0.479	0.461	0.450
	Plan 4	0.669	0.540	0.543	0.543	0.543
	Plan 5	0.669	0.685	0.687	0.664	0.612

Table F16. Comparison of possible restoration initiatives with respect to gains beyond the No Action Plan, as well as comparisons to a "virtual" reference condition, and thresholds of HSI productivity.

Reach Name	Site Name	LRSI	TY 0	TY 1	TY 4	TY 11	TY51
Resaca del Ranch Viejo Sub Division #1	Plan 1	HYDRO	0.758	0.356	0.287	0.186	0.080
		STRUCT	0.749	0.386	0.298	0.238	0.209
		DISTURB	0.500	0.400	0.400	0.400	0.400
	Plan 2	HYDRO	0.758	0.472	0.478	0.436	0.395
		STRUCT	0.749	0.594	0.543	0.526	0.530
		DISTURB	0.500	0.400	0.400	0.400	0.400
	Plan 3	HYDRO	0.758	0.493	0.495	0.457	0.420
		STRUCT	0.749	0.594	0.543	0.526	0.530
		DISTURB	0.500	0.400	0.400	0.400	0.400
	Plan 4	HYDRO	0.758	0.472	0.478	0.478	0.478
		STRUCT	0.749	0.749	0.749	0.749	0.749
		DISTURB	0.500	0.400	0.400	0.400	0.400
	Plan 5	HYDRO	0.758	0.818	0.823	0.753	0.600
		STRUCT	0.749	0.837	0.837	0.837	0.837
		DISTURB	0.500	0.400	0.400	0.400	0.400

What do the results of this hypothetical exercise offer to District decision makers and their stakeholders in formulating alternatives and searching for a recommended plan? Conclusions can be drawn easily enough. Overall, the exercise has proven that the Resaca model is capable of distinguishing among plans, that it operates well at the subdivision level, and that it can be used alone or in combination with other techniques (e.g., incremental cost analysis) to establish performance measures for a study that can quantify successful restoration attainment with respect to quantifiable goals and objectives.

Appendix G: Model Review Forms and Comments

ERDC-EL used technical experts both within the laboratory itself, and outside the facility (but still within the USACE planning community) to review both the model development process and the model itself. To assure fair and impartial review of the products, members of the Laboratory-based Technical Review Team (LTRT) were chosen on the basis of expertise, seniority in the laboratory chain of command, and USACE planning experience.

The following were members of the LTRT:

1. Dr. Andrew Casper (ERDC-EL) – technical (peer) reviewer,
2. Marie Perkins (ERDC-EL) – technical (peer) reviewer,
3. Janean Shirley – editorial review (Technical Editor),
4. Antisa Webb - management review (Branch Chief),
5. Dr. Edmond J. Russo – management review (Division Chief),
6. Dr. Steve Ashby – program review (System-Wide Water Resources Research Program, Program Manager),
7. Dr. Al Cofrancesco – program review (Technical Director), and
8. Dr. Mike Passmore – executive office review (Environmental Laboratory Deputy Director).

No peer review members of the LTRT were directly associated with the development or application of the model(s) for this study, thus assuring <u>independent</u> technical peer review.[1] Referred to as the in-house Laboratory-based Technical Review (LTR), these experts were asked to consider the following issues when reviewing this document:

1. Whether the concepts, assumptions, features, methods, analyses, and details were appropriate and fully coordinated;
2. Whether the analytic methods used were environmentally sound, appropriate, reasonable, fell within policy guidelines, and yielded reliable results;

[1] Resumes for Dr. Casper and Ms. Perkins (i.e., the technical peer reviewers) can be found immediately following the comment/response tables at the end of this appendix.

3. Whether any deviations from USACE policy and guidance were identified, documented, and approved;
4. Whether the products met the Environmental Laboratory's standards based on format and presentation; and
5. Whether the products met the customer's needs and expectations.

LTRT review comments and responses

Review comments were submitted to the Laboratory-based Project Delivery Team (LPDT) in written format and the LPDT responded in kind. In the EL Electronic Manuscript Review System (ELEMRS) 2.0, both reviewers indicated that the document was "Acceptable" with grammatical/formatting modifications needed, and when asked to offer their opinion as to the production of the report they stated that it was a, "quality study, well designed and presented [with] important new information."[1]

[1] Details regarding specific comments proffered by these reviewers (and the issue resolutions) can be obtained through written request to the authors.

LTRT Technical Reviewer Curriculum Vitae

US Army Corps of Engineers

ERDC

U.S. ARMY

Professional Experience

Research Biologist, Aquatic Ecology and Invasive Species Branch, Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS., 2006 to present.

- Specializing in large river science, engineering and ecology spanning the continent from Gulf Coast rivers and estuaries to the Ohio and Mississippi River Valley's to the arctic Mackenzie River Delta and Beaufort Sea in Canada
- Development of conceptual, physical habitat, and watershed models
- Modeling climate change and land use impacts/responses
- Assessment of dam removal and ecological restoration
- Food web and community ecology techniques for fish and invertebrates in large navigable rivers and flood plains
- GIS-based, 2-D water quality mapping in tidal creeks/coastal rivers

Dr. Andrew F. Casper

Research Biologist - ERDC, Environmental Laboratory
3909 Halls Ferry Rd., Vicksburg, MS 39180
601-634-4681
Andrew.F.Casper@usace.army.mil

Education

- **Ph.D.** Océanography, 2005, Université Laval, Québec City, QC.
- **M.S.** Biological Sciences,1993 Southern Illinois University Carbondale.
- **B.S.** Natural Sciences, 1990 Southern Illinois University Carbondale

Research & Teaching

- A.F. Casper and C. Fischenich. Framework and Integration of Conceptual Models in the CoE Planning Process (System Wide Water Resource Program Environmental Benefits Analysis Program, USACE HQ).
- Brasfield, S., A.F. Casper and B. S. Payne. Potential Contribution of Climate Change to the Bioassessment of Contaminants on Military Installations: Additive, Synergistic or Antagonistic? (USACE ERDC Basic Research Program).
- K. J. Killgore, J. J. Hoover, D. R. Johnson, and A. F. Casper. Envirofish: A HEC compatible floodplain habitat model for evaluating mitigation scenarios (reimbursable project for D. R. Johnson, Mississippi Valley District).

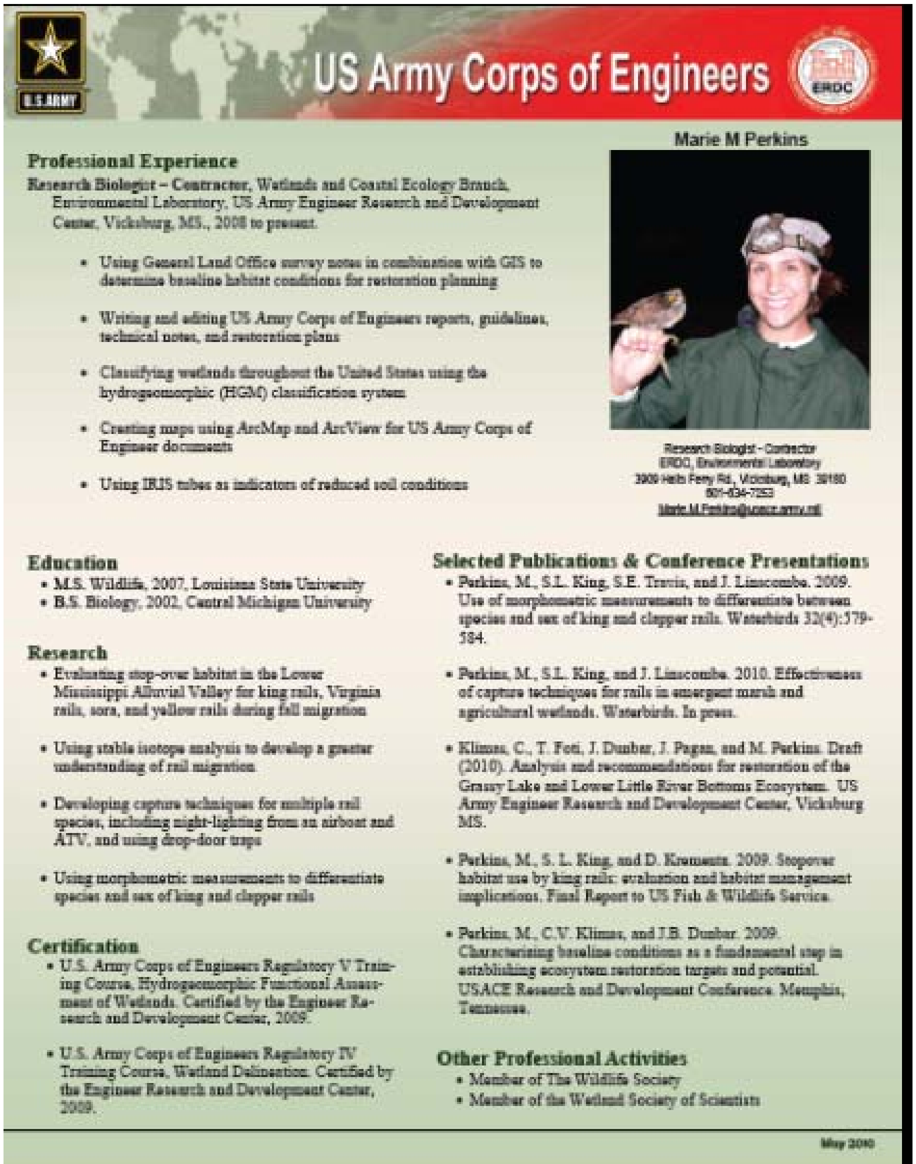
Other Professional Activities

- Ecosystem restoration/mitigation
- Sensitivity analysis and incorporation of risk/ uncertainty
- Forecasting effects of scenarios and plan formulations
- Project/Watershed cumulative impacts assessments
- Coordinate field collections, management, analysis and reporting for river ecology
- SOW proposal and budget writing for multi-year research projects (NSF, EPA, USACE)

Selected Publications & Conference Presentations

- Casper, R. A. Efoymson, S. M. Davis, G. Steyer, and B. Zettle. 2009. Improving Conceptual Model Development: Avoiding Underperformance Due to Project. U.S. Army Engineer Reseawrch and Development Center, Vicksburg, MS.
- Casper A. F., and J. H. Thorp. 2007. Diel and lateral patterns of zooplankton distribution in the St. Lawrence River. Rivers Research and Application 23(1):73-85.
- Casper, A. F., J. H. Thorp, S. P. Davies, and D. L. Courtemanch. 2006. Ecological responses of large river benthos to the removal of the Edwards Dam on Kennebec River, Maine (USA). Archiv fur Hydrobiologie 16(4):541-555 (Large River Supplement 115).
- June 2008 – A surrogate model for future regional climate change: The current affects of the Atlantic Multidecadal Oscillation and its influence on the ecohydrology of Great Lakes and New England rivers. 56th Annual North American Benthological Society International Conference, Salt Lake City, Utah.
- July 2007 - Linking ecological responses to hydrologic characteristics of rivers: Examples from studies of dam removals and PHABSIM modeling for minimum flow standards. US Army Corps of Engineers Waterways Experiment Station. Vicksburg MS.
- A. F. Casper, B. Dixon, E. Steimle, J. Gore, P. Coble, and R. Conmy. Water quality sampling strategies for monitoring coastal rivers & estuaries: Applying technological innovations to Tampa Bay tributaries. Awarded by USEPA (Oct 2006 - Dec 2007).
- Carrabetta, M., A. F. Casper, B. Chernoff, and M. Daniels. The ecological and physical effects of removal of two low-head dams on Eight Mile Creek, a tributary of the Connecticut River. Awarded by TNC/NOAA Community Restoration Program (2005-07).

September 2009



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Marie M Perkins

Research Biologist - Contractor
ERDC, Environmental Laboratory
3909 Halls Ferry Rd., Vicksburg, MS 39180
601-634-7253
Marie.M.Perkins@usace.army.mil

Professional Experience

Research Biologist – Contractor, Wetlands and Coastal Ecology Branch, Environmental Laboratory, US Army Engineer Research and Development Center, Vicksburg, MS., 2008 to present.

- Using General Land Office survey notes in combination with GIS to determine baseline habitat conditions for restoration planning
- Writing and editing US Army Corps of Engineers reports, guidelines, technical notes, and restoration plans
- Classifying wetlands throughout the United States using the hydrogeomorphic (HGM) classification system
- Creating maps using ArcMap and ArcView for US Army Corps of Engineer documents
- Using IRIS tubes as indicators of reduced soil conditions

Education

- M.S. Wildlife, 2007, Louisiana State University
- B.S. Biology, 2002, Central Michigan University

Research

- Evaluating stop-over habitat in the Lower Mississippi Alluvial Valley for king rails, Virginia rails, sora, and yellow rails during fall migration
- Using stable isotope analysis to develop a greater understanding of rail migration
- Developing capture techniques for multiple rail species, including night-lighting from an airboat and ATV, and using drop-door traps
- Using morphometric measurements to differentiate species and sex of king and clapper rails

Certification

- U.S. Army Corps of Engineers Regulatory V Training Course, Hydrogeomorphic Functional Assessment of Wetlands. Certified by the Engineer Research and Development Center, 2009.
- U.S. Army Corps of Engineers Regulatory IV Training Course, Wetland Delineation. Certified by the Engineer Research and Development Center, 2009.

Selected Publications & Conference Presentations

- Perkins, M., S.L. King, S.E. Travis, and J. Linscombe. 2009. Use of morphometric measurements to differentiate between species and sex of king and clapper rails. Waterbirds 32(4):579-584.
- Perkins, M., S.L. King, and J. Linscombe. 2010. Effectiveness of capture techniques for rails in emergent marsh and agricultural wetlands. Waterbirds. In press.
- Klimas, C., T. Foti, J. Dunbar, J. Pagan, and M. Perkins. Draft (2010). Analysis and recommendations for restoration of the Grassy Lake and Lower Little River Bottoms Ecosystem. US Army Engineer Research and Development Center, Vicksburg MS.
- Perkins, M., S. L. King, and D. Kremantz. 2009. Stopover habitat use by king rails: evaluation and habitat management implications. Final Report to US Fish & Wildlife Service.
- Perkins, M., C.V. Klimas, and J.B. Dunbar. 2009. Characterizing baseline conditions as a fundamental step in establishing ecosystem restoration targets and potential. USACE Research and Development Conference. Memphis, Tennessee.

Other Professional Activities

- Member of The Wildlife Society
- Member of the Wetland Society of Scientists

May 2010

Administrative review status and technology transfer forms

Two technology transfer forms will be completed when the document has been reviewed/approved by both the senior staff and the program managers (Tables G1 and G2).

Table G1. Internal ERDC-EL Technology Transfer Review Form.

TECHNOLOGY TRANSFER STATUS SHEET

INSTRUCTIONS
The author(s) of a document based on ERDC-EL research and written for publication or presentation should attach one copy of this sheet to the document when the first draft is prepared. Documents include reports, abstracts, journal articles, and selected proposals and progress reports. The sheet will remain with the most recent draft of the document.

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12. GROUP/DIVISION CHIEF	13. DATE

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c. ____________________ ______________________ _________________ ___________________
DATE TO REVIEWER DATE RETURN REQUESTED DATE RETURNED TECHNICAL REVIEWER

____ ACCEPTABLE W/MINOR REVISIONS ____ ACCEPTABLE W/MAJOR REVISIONS ____ UNACCEPTABLE

NOTE: RETURN TO AUTHOR WHEN TECHNICAL REVIEW IS COMPELTED.

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Table G2. Security Clearance Form for ERDC-EL reports.

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REPORT DOCUMENTATION PAGE

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14. ABSTRACT
Over the last century, the Lower Rio Grande running through Brownsville, Texas has experienced significant anthropogenic pressures that, when combined with severe droughts of the last decade, have produced a highly degraded ecosystem that today is poised on the brink of collapse. In 1999, the U.S. Army Corps of Engineers (USACE) (Galveston District) was authorized to study the feasibility of providing improvements to the resacas (Spanish for oxbow lakes) near Brownsville, Texas in the interest of flood control, watershed management, environmental restoration and protection, and water quality. The District has been preparing an Environmental Assessment (EA) to evaluate the environmental benefits to ecosystem restoration efforts in the area. A multi-agency, multi-disciplinary evaluation team was convened to formulate alternatives that would improve, restore, and expand sustainable terrestrial and aquatic habitats in and around the existing Brownsville resacas ecosystems. Between 2004 and 2009, this team designed, calibrated, and applied a community-based index model for the Brownsville resaca ecosystems using field and spatial data gathered from 111 reference sample sites scattered across the watershed. This unique community was modeled by combining 13 individual variables into numerous predictive community functional components capable of capturing the changes to ecosystem integrity in response to changes in land and water management activities. This document provides the scientific basis upon which the model was developed, and describes the 6-year process the team undertook to complete this effort. Application of this model to the City of Brownsville Resacas Ecosystem Restoration project is discussed in a second report (Burks-Copes and Webb, in preparation).

15. SUBJECT TERMS		
	Lower Rio Grande	Resacas
Environmental restoration	Habitat Evaluation and Assessment Tools (HEAT)	Watershed management
Flood control	Habitat Evaluation Procedures (HEP)	

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