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Analyses, Results and Documentation

Kelly A. Burks-Copes and Antisa C. Webb

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Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

Abstract

Over the last century, the Middle Rio Grande was subjected to significant anthropogenic pressures, producing a highly degraded ecosystem that today is poised on the brink of collapse. In 2004, the U.S. Army Corps of Engineers (USACE) (Albuquerque District) initiated a feasibility study of the area and began the preparation of an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the effects of proposed ecosystem restoration alternatives on the watershed's significant resources. As part of the process, a multi-agency, multi-disciplinary evaluation team was established to formulate alternatives that would address two critical problems: 1) hydrological alterations and 2) bosque (riparian) ecosystem degradation. Between 2005 and 2008, this team designed, calibrated, and applied a community-based index model for the bosque (riparian) ecosystem using standard Habitat Evaluation Procedures (HEP) (USFWS 1980a-c). The 17-mile long study area was divided into five separate reaches; within each reach a series of 44 separate measures were formulated and combined to generate no less than 56 potential alternatives for the study (approximately 8 to 13 alternatives per reach were fully formulated and evaluated). The outputs for these alternatives ranged from 3 to 264 Average Annual Habitat Units (AAHUs). The results of these evaluations are provided herein. The intent of this document is to provide details of the HEP application for the Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study (MRGBER). Readers interested in the scientific basis upon which the model was developed should refer to the additional report produced for this study (Burks-Copes and Webb 2009).

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Preface

This report provides the documentation to support a Habitat Evaluation Procedures (HEP) application evaluating proposed ecosystem restoration plans addressing hydrologic and environmental issues along the Middle Rio Grande flowing through Albuquerque, New Mexico.

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

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: Ondrea Hummel, Lynette Giesen, Fritz Blake, Steve Boberg, Alicia Austin-Johnson, Mark Doles (Albuquerque District), Todd Caplan, Chad McKenna, Chas Jones (Parametrix); Jennifer Emerson (Bowhead Information Technology Services); Seth Jones and Andrea Catanzaro (Galveston District), Jeff Lin (ERDC-EL); Stanley Latimer and Dr. Paul Zwick (University of Florida). The authors also wish to thank Andy Casper (ERDC), Kristie Nemec (Kansas City District) and Todd Caplan (Parametrix) for their comprehensive review of the report.

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

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1 Introduction

Background

The desiccated landscape of the Southwest brings to mind tumbleweeds blowing along dusty ground, ancient petroglyphs carved into dark cave and canyon walls, cattle skulls blanching under the merciless sun, and sidewinders slithering between the cacti. Running through these harsh and arid regions, however, are ribbons of lush green narrow corridors where rivers and streams (some ephemeral and 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 only occupying a mere fraction of the land area, these riparian corridors 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). Perhaps one of the more notable riparian ecosystems is found along the Rio Grande (Figure 3).

Figure 2. Riparian corridors immediately adjacent to rivers in the arid Southwest offer lush habitat for fish and wildlife species.[1]

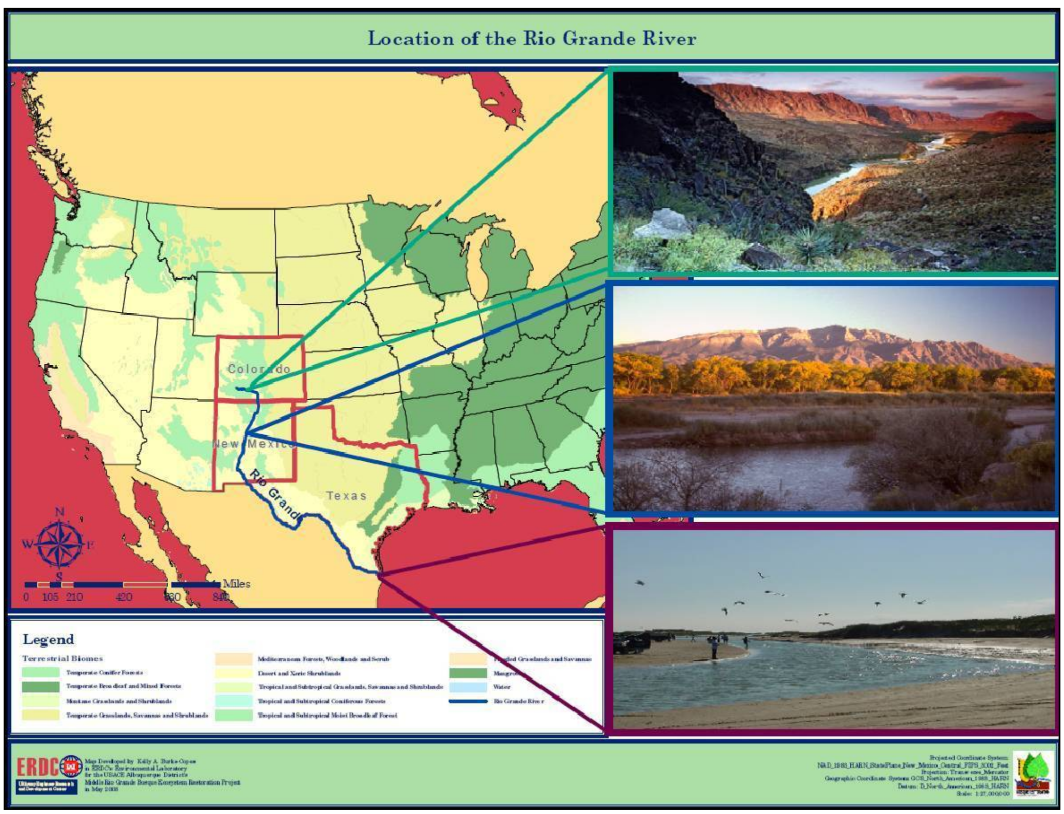

Figure 3. Location of the Rio Grande in the arid Southwest. Images capture the changing characteristics of the river as it flows from Colorado (top), through New Mexico (middle), and down into Texas (bottom) on its way to the Gulf of Mexico.

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[1] Photo take from http://www.domney.com/ (MAY 2008)

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, finally emptying into the Gulf of Mexico. The Middle Rio Grande offers one of the more ecologically complex and culturally significant resources in semi-arid western United States. Historically, the Middle Rio Grande was considered a braided, aggrading stream that meandered freely across a wide floodplain much larger than the current floodway ecosystem. As it meandered through time and space, the Middle Rio Grande created and renewed the unique cottonwood riparian gallery forest communities. "Bosque" was the Spanish word that was used traditionally in the southwest to describe these unique wooded riparian ecosystems (Figure 4).

Figure 4. Cottonwood riparian gallery forests ablaze with fall colors along the Rio Grande.[1]

Today, the bosque is comprised of a dynamic mosaic of cottonwood forests, coyote willow shrublands, wet meadows, wetlands, oxbow ponds, and open water areas with a variety of depths and flows. These wetlands and riparian forests rely entirely upon periodic flooding events to regenerate soils and create new substrates for vegetative colonization. Unlike many upland

[1] Photo taken from http://joemonahansnewmexico.blogspot.com/uploaded_images/New%20Mexico%20-%20Rio%20Grande-794868.jpg MAY 2008)

areas, the primary natural disturbance regime at work in the Middle Rio Grande ecosystem is flooding. As a patchwork of wetlands, open water, wet meadows and woodlands, these riparian areas provide habitat to a greater number of wildlife species than any other ecological community in the region and serve as a critical travel corridor for many species, especially migratory birds moving with the change of seasons.

Yet although these riparian ecosystems are considered to be the most productive and biologically diverse ecosystems in the region, they are now believed to be the most threatened (Johnson and Jones 1977, Johnson et al. 1985, Knopf et al.1988, Ohmart et al. 1988, Johnson 1991, Minckley and Brown 1994). Substantial impacts from human activities, starting about 250 years ago, have resulted in compounding rates of change in structure and vegetation dynamics to the point that the bosque ecosystem is now on the verge of irreversible conversion (Crawford et al. 1996) (Figure 5).

Figure 5. Along the banks of the Middle Rio Grande, anthropogenic pressures have resulted in an extremely degraded bosque community subject to catastrophic fires, exotic species encroachment and a loss of vegetative recruitment in the cottonwood riparian community. In 50 years, the bosque could be completely devoid of floodplain forest without intervention.

In ecological terms, the cumulative effects of these activities have resulted in a disruption of the original hydrologic (hydraulic) regime. This overbank flooding regime is key to the decomposition of leaf litter and dead wood, which are both fire hazards and obstacles to floodplain forest regeneration. With the onset of these periodic flooding events, dissolved salts are flushed from the system, nutrients are cycled into the ecosystem, and soils are renewed. Without flooding, and with the increased demand on water resources in the region, the river banks have destabilized and are now "perched" above the river itself (Figure 6).

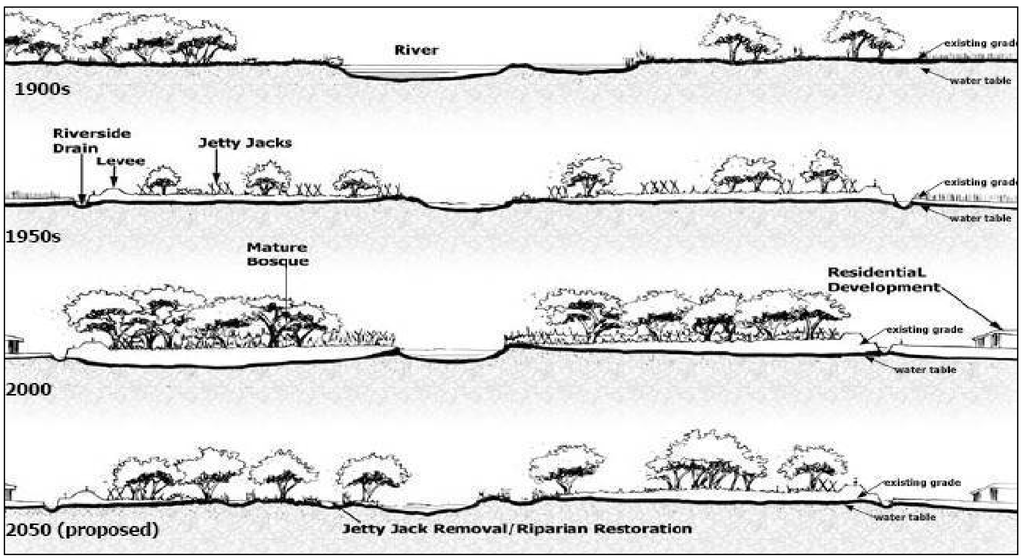

Figure 6. Flood protection projects (e.g., levees, riverside drains and jetty jacks) have reduced the Middle Rio Grande's original floodplain to a fraction of its size in the study area (USACE 2003a).

Ultimately, these conditions have favored the encroachment of exotic species. Salt cedar (*Tamarix chinensis*), Siberian elm (*Ulmus pumila*), Russian olive (*Elaeagnus angustifolia* L.), and tree-of-heaven (*Ailanthus altissima*) have colonized large portions of the bosque, outcompeting and replacing the native species. These exotics do not rely upon the spring flooding regime to reproduce, consume more water than the natives, compound the fire hazards in the area, and fail to provide critical habitat for many key wildlife species. Estimates of riparian habitat loss in the Southwest range from 40% to 90% (Dahl 1990), and desert riparian habitats are considered to be one of this region's most endangered ecosystems (Minckley and Brown 1994, Noss et al. 1995). Decline of natural riparian structure and function of the bosque ecosystem was recognized in the 1980s as a major ecological change in the Middle Rio Grande valley (Hink and Ohmart 1984; Howe and Knopf, 1991) (Figure 7).

Figure 7. Fragmentation, urban encroachment, and exotic species invasions threaten the integrity of the bosque riparian ecosystem situated along Middle Rio Grande.

Study Background

In 2002, the U.S. Army Corps of Engineers (USACE) Albuquerque District was authorized to conduct a Reconnaissance study focused on a 17-mile long stretch of the Middle Rio Grande flowing through the city of Albuquerque, New Mexico (USACE 2002, 2003a, 2007, 2010) (Figure 8).

Figure 8. The Middle Rio Grande flows through the heart of Albuquerque (seen in the background at the base of the mountains) on its way south to the Gulf of Mexico.

The reconnaissance study determined that there was a federal interest in participating in cost-shared feasibility studies to investigate ecosystem restoration, educational/interpretive opportunities and low-impact recreational opportunities for the Middle Rio Grande floodway as it passes through Albuquerque, New Mexico. In 2004, a Feasibility Cost Sharing Agreement was signed between the Middle Rio Grande Conservancy District (MRGCD) as the non-Federal Sponsor, and the USACE subsequently initiated the feasibility phase of the study. The purpose of this feasibility phase study was to determine if there was a Federal (USACE) interest in addressing the water resource problems and opportunities in the Middle Rio Grande area of Bernalillo County, New Mexico.

In 2004, the USACE Albuquerque District contacted the U.S. Army Engineer Research and Development Center's (ERDC) Environmental Laboratory (ERDC-EL) to assist in these endeavors. The Middle Rio Grande study documentation identified and recommended effective, affordable and environmentally sensitive ecosystem restoration features throughout the middle reach of the Rio Grande system (USACE 2002, 2003a, 2007, 2010). The goal was to provide the necessary engineering, economic and environmental plans in a timely manner to establish viable projects that would be acceptable to the public, local sponsors and USACE. The intent of this collaborative effort was to provide a framework for making decisions that would result in the restoration of the bosque ecosystem's structure and function.

The District has prepared an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the benefits of the proposed ecosystem restoration measures in the study area (USACE 2010). As part of the process, a multi-agency evaluation team was established to: (1) identify environmental issues and concerns; (2) evaluate the significance of fish and wildlife resources and select resources; (3) recommend and review environmental alternatives and studies; and (4) evaluate potential benefits of the proposed plans.

USACE headquarters promulgated standard policies and guidance to formulate single-purpose studies under a specific paradigm referred to as the "Six Planning Steps" (Yoe and Orth 1996; USACE 2000). These steps can be outlined as follows:

- Step 1. Identifying Problems and Opportunities. The study team identifies problems and opportunities, objectives and constraints in the study area. The study team also enumerates the resource, legal, and policy constraints in this step as well.
- Step 2. Inventorying and Forecasting Resources. The study team develops qualitative and quantitative descriptions of resources relevant to the problems and opportunities under consideration for the study.
- Step 3. Formulating Alternative Plans. The study team formulates all reasonable alternatives and screens or reduces these to a manageable set of intensively scrutinized potential designs. These alternatives incorporate issues identified in earlier steps, and are bounded by constraints identified during scoping.
- Step 4. Evaluating Alternative Plans. The study team then assesses the effects of the screened alternatives.
- Step 5. Comparing Alternative Plans. All alternatives, including the "No Action Plan," are then compared based on ecological, hydrological, and economic effectiveness and efficiency.
- Step 6. Selecting the Recommended Plan. The study team then selects plans that maximize benefits and minimize costs (consistent with the Federal objective).

Early in the process, an interagency Ecosystem Assessment Team (E-Team) was convened. Representatives from the Albuquerque District, U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service (USFS), Bureau of Reclamation (BOR), Interstate Stream Commission (ISC), New Mexico Department of Game and Fish (NMDGF), New Mexico State Forestry Division (NMSFD), Natural Heritage New Mexico (NHNM), Rocky Mountain Research Station (RMRS), Middle Rio Grande Conservancy District (MRGCD), City of Albuquerque Open Space Division (AOSD), University of New Mexico (UNM), and Parametrix consultants actively participated in the assessment process. Scientists from ERDC-EL facilitated the ecological evaluations undertaken by the E-Team. The planning process is described in great detail in the various Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study (MRGBER) planning and NEPA documents (USACE 2002, 2003a, 2007, 2010). For the purposes of this report, we will focus predominantly on the ecological evaluations supporting these activities.

Coupling Conceptual Modeling and Index Modeling

Conceptual models are proving to be an innovative approach to organizing, communicating, and facilitating analysis of natural resources at the landscape scale (Harwell et al. 1999, Turner et al. 2001, Henderson and O'Neil 2004, 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 in terms of 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 study, 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[1] 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 9).

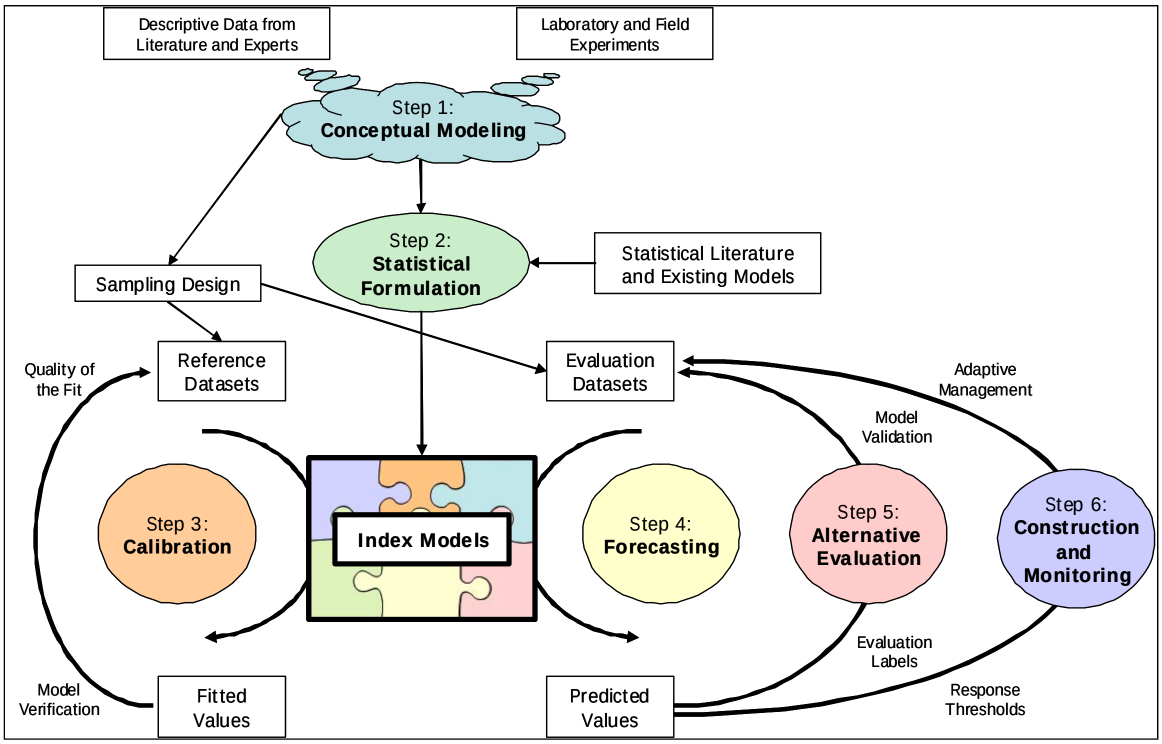

Figure 9. Overview of the successive steps (1-6) of the community-based index model building and application process for ecosystem restoration, where two data sets (one for calibration and one for alternative evaluations) are used (adapted from Guisan and Zimmerman 2000).

Under this MRGBER 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) model. The model was calibrated using reference-based conditions and modified when the application dictated a necessary change. Note that the same model used to evaluate alternatives should be used in the future to monitor the restored ecosystem. The model

[1] We subscribe to the Society of Ecological Restoration's (2004) definition of *ecosystem integrity* here, which has been defined as "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."

should also be used to generate response thresholds to trigger adaptive management under the indicated feedback mechanism.

Several advantages of this approach were readily apparent. First, it provided a logically consistent ordering of relations among planning steps. Second, the relationships among environmental factors were supported by formal logical expressions (mathematical algorithms in the model), couched in terms of ecosystem structure and functions, and quantified in terms of habitat suitability. Key to this approach was the utilization of expert knowledge in a transparent fashion, as well as the characterization of communities across the system in a quantifiable manner with minimal expense and within a limited timeframe.

Using HEP to Assess the Habitat Potential (Suitability)

To evaluate the ecological benefits of proposed ecosystem restoration plans, the District and its stakeholders needed an assessment methodology that could capture the complex ecosystem process and patterns operating at both the local and landscape levels across multiple habitat types (Figure 10).

In 1980, the USFWS published quantifiable procedures to assess planning initiatives as they relate to change of fish and wildlife habitats (USFWS 1980a-c). 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 impact, mitigation, or restoration 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 and others). The MRGBER study team made the decision to assess ecosystem benefits using HEP and a single community-based functional HSI model (Burks-Copes and Webb 2009) therein. Refer to Chapter 2 of this report to review the E-Team's HEP assessment methodology and results.

Figure 10. At stake is the dwindling cottonwood-dominated bosque situated along the Middle Rio Grande.[1]

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 Engineering 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 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*

[1] Photo taken from abqstyle.com/albuquerque_photo/000023.html (MAY 2008).

> *advantage of the opportunities, to evaluate potential effects of alternatives and to support decision-making."*

Clearly, the community-based HSI model developed for the study must be either certified or approved for one-time use. The Albuquerque District initiated this review in 2008 and received a memo from the USACE Eco-PCX granting one-time-use approval in April 2009 (*Appendix C*). Information necessary to facilitate model certification/one-time-use approval is outlined in Table 2 of the EC 1105-2-407 (pages 9-11). To assist the reviewers in the certification effort for the model, the authors have developed an appendix to crosswalk the EC checklist requirements and this report (*Appendix C*).

It is important to note that the model must be formally certified or approved for one-time-use, but 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. 2008) to automate the calculation of habitat units for the MRGBER 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 model, and through their applications in the HEP or the Hydrogeomorphic Wetland Assessment (HGM) processes, calculates 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. The authors used the EXHEP module to calculate outputs for the MRGBER 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 have this tool approved in the next year, barring unforeseen financial and institutional problems. The authors used IWR Planning Suite[1] to complete the cost analyses for the MRGBER study restoration plans. The IWR Planning Suite was certified in 2008.

Report Objectives and Structure

Between 2003 and 2008, the E-Team designed, calibrated, and applied the model using field and spatial data gathered from watershed reference sample sites (Burks-Copes and Webb 2009). Fifty-six potential restoration alternatives were fully formulated and evaluated for this study. The intent of this document is to detail the HEP application and present the findings of that assessment. The objectives of this report are to:

1. briefly characterize the bosque community targeted by the ecosystem restoration plans;
2. describe the method used to assess the proposed National Ecosystem Restoration (NER) Plan;
3. present the results of the ecological evaluations; and
4. present the cost analysis that will facilitate the District's selection of the NER plan.

This report is organized in the following manner. *Chapter 1* provides the background, objectives, and organization of the document. *Chapter 2* is devoted to describing the technical merits and requirements of HEP. A brief characterization of the relevant community is provided, and then a discussion of data-handling techniques, decisions made by the E-Team in the utilization of data in the analysis, and the derivation of baseline outputs (Indices and Habitat Units (HUs)) for the model is presented. *Chapter 3* documents the baseline analyses of the watershed. *Chapter 4* provides details regarding the "No Action" plan, also known as the Without-project (WOP) Condition, and *Chapter 5* documents the outputs of the various alternatives (i.e., the With-project (WP) Condition) and provides the results of both the Cost-Effective Analysis (CEA) and the Incremental Cost Analysis (ICA). *Chapter 6* summarizes the findings of the previous chapters and offers conclusions.

[1] http://www.pmcl.com/iwrplan/ IWR Planning Suite model was certified in 2008.

Appendices A through *C* serve as general information for the reader (e.g., a list of commonly used acronyms in this report, a glossary of terms, and tables of variables associated with the study's community index model). *Appendix D* contains documentation from the USACE Eco-PCX, granting one-time-use approval of the Bosque Riparian Community-based HSI model for the study in April 2009. *Appendix E* has been included to facile-tate review of this document. A separate report has been developed by ERDC-EL documenting the index model (Burks-Copes and Webb 2009) developed for this study. The model's characteristics, limiting factors (i.e., variables and indices), supporting mathematical equations, and significant literature references are documented therein.

2 Methods

The protection and restoration of ecosystems must focus on the preservation and/or recovery of specific system attributes that promote human welfare independent of human use. Such "non-use" benefits can arise from the mere existence and/or maintenance of nationally or regionally rare and unique ecosystems. Indeed, the public is likely to view the protection of endangered species and their associated habitats as an important goal of ecosystem restoration and management. There is no doubt the determination of restoration and management success based on ecosystem processes is complex. Yet, federal law requires that USACE Districts evaluate the effects of proposed ecosystem restoration measures at levels used to justify the project. To facilitate efficiency, evaluation methodologies need be no more elaborate than required to demonstrate that the anticipated ecological benefits are effectively justified. To ensure effectiveness, these methods must include the ecosystem elements necessary for linking benefits to ecosystem integrity response. To guarantee plan completeness, the scope of the method or tool should fit the ecological and social dimensions of environmental problems targeted by ecosystem benefits. To ensure plan acceptance, the model and other decision-support methods have to comply with institutional constraints and influential public opinion (both technically and politically).

Types of Ecosystem Evaluation Methodologies

USACE planning studies depend on non-monetary evaluation methodologies to quantify inherent ecological processes, such as the structure, dynamics and the functions ecosystems carry out in nature. These processes depend on particular attributes that correspond to physical features of an ecological setting (e.g., the density of tree canopy over a section of stream bank, permeability of soils which form the bank, and complexity of surface relief along the bank). It should be noted that these attributes can be measured, counted or described in a standardized way. The attributes of interest in landscape-scale analyses of ecologically important processes typically have an inherent sense of quantity that affects the manner in which they influence the ecosystem. For example, dense tree canopy is indicative of forest age, health, vigor, water availability and nutrient cycling at any given location. Several evaluation techniques have been developed to capture or quantify ecosystem health and function (Stakhiv et al. 2001; Burks-Copes et al. 2008, *Appendix B* and references therein).

The HEP Process

The HEP methodology is an environmental accounting process developed to appraise habitat suitability for fish and wildlife species in response to potential change (USFWS 1980a-c). HEP is an objective, quantifiable, 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. HEP provides an impartial look at environmental effects, and delivers measurable products to the decision-maker for comparative analysis.

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 2005; 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; National Research Council (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. 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).

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, a Habitat Suitability Index (HSI) model is a quantitative estimate of habitat conditions for an evaluation species or community. 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).

Community HSI models in HEP

Existing community-based HSI models offer more promise than species-based HSI models because they are more efficient in capturing those habitat measures necessary for restoring ecosystem integrity and can be compared across a wide range of ecosystems for prioritization purposes (Stakhiv et al. 2001). Community-based HSI models indicate relative ecosystem value more inclusively than species-based models because they link habitat more broadly to ecosystem components or functions. Community-based HSI models can also be deployed in the traditional HEP methodology. The community-based HSI models rely on field-measured habitat parameters (just as the species-based HSI models do). These parameters are integrated into a series of predictive suitability indices – quantifying the suitability of the community in terms of physical, chemical and biological processes relative to other communities from a regional perspective within a reference domain. Community-based HSI models are, by definition, scaled from zero to one. An index of "1" indicates that a community is operating at the highest sustainable level, the level equivalent to a community under reference standard conditions in a reference domain. An index of "0" indicates the community does not operate at a measurable level and will not recover the capacity to operate through natural processes. Community models can often be broken into specific components, such as biota (diversity and structure), water and landscapes. Some examples of variables within these components include presence/absence of canopy architecture, species richness, flooding frequency, flooding duration, patchiness, corridor widths and lengths. The results of the index-based assessments are multiplied by the affected area (in acres) to calculate HUs. 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, which have similar habitat requirements). Most of these species can 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 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.

Most communities are examined inaccurately with the single formula approach described above. 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 HSI formulas are often necessary to calculate the habitat suitability of these comprehensive HSI models. This 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. As such, communities are likely to require more extensive multi-formula 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 and/or global dimensions). Several agencies and organizations have adapted the basic HEP methodology for their specific needs in this 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 derived with the following equation: HU = HSI x Area (acres). Under the HEP methodology, one HU is equivalent to one 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 measurement used in HEP that allow users to anticipate and identify 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 at least a TY = 1 and a TY = X2. TY1 is the first year land- and water-use conditions are expected to deviate from baseline conditions. TYX2 designates the ending target year or the span of the project's life. 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 long-term effects, HUs generated for indicator species/communities are estimated for several TYs to reflect the life of the project (aka period of analysis). In such analyses, future habitat conditions are estimated for both 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.

Applying HEP to the MRGBER Study: 11 Steps

Eleven steps were completed in the assessment of the study's proposed ecosystem restoration designs using HEP. Briefly, they included:

1. Building a multi-disciplinary evaluation team
2. Defining the project
3. Mapping the site's Cover Types (CTs)
4. Selecting, modifying and/or developing index model(s)

5. Collect data
6. Performing data management and statistical analyses
7. Calculating baseline conditions
8. Setting goals and objectives, and defining project life (aka period of analysis) and Target Years (TYs)
9. Generating Without-project (WOP) conditions and calculating outputs
10. Generating With-project (WP) conditions and calculating outputs
11. Reporting the results of the analyses

The following sections provide the details of the MRGBER application plan formulation process and the application of the HEP techniques to the study's plans.

Step 1: The MRGBER ecosystem evaluation team

In HEP, an interagency interdisciplinary team is formed to lead both the model selection/development phase of the project and to establish the baseline and future conditions of the site(s). Participants often include representatives from USACE, U.S. Environmental Protection Agency (USEPA), USFWS, Natural Resources Conservation Service (NRCS), state fish and game offices, and other federal, state, local, and tribal government organizations as deemed necessary. The technical expertise necessary to support planning efforts should include — but is not restricted to — representatives from botany, soils, hydrology, and wildlife ecology disciplines. The E-Team should also include individuals who were responsible for project design and management (i.e., engineers, project managers, NEPA consultants, cost-share sponsors, university professors, etc.).

The MRGBER multidisciplinary ecosystem evaluation team (E-Team) was convened in 2004 to develop the index model and conduct the HEP evaluations for the study. The multi-disciplinary, multi-agency team included various interests and technical expertise. For a complete list, see Table 1.

It is important to note that attrition and turnover over the course of the study led to many changes in this original roster. The authors have attempted to include the names of original participants, any replacements, and any additions.

Table 1. The MRGBER study's E-Team members.

E-Team Members	Agency	Phone	Email Address
Abeyta, Cyndie	USFWS	(505) 761-4738	cyndie_abeyta@fws.gov
Anderson, Steve	NMDGF	(505) 841-8881	scanderson@state.nm.us
Austin-Johnson, Alicia	USACE	(505) 342-3635	Alicia.M.AustinJohnson@usace.army.mil
Blake, Fritz	USACE	(505) 342-3202	Fritz.J.Blake@usace.army.mil
Boberg, Steve	USACE	(505) 342-3336	Steve.A.Boberg@usace.army.mil
Branstetter, John	USFWS	(505) 761-4753	John_Branstetter@fws.gov
Buntjer, Mike	USFWS	(505) 761-4733	Mike_Buntjer@fws.gov
Caplan, Todd	Parametrix	(505) 323-0050	tcaplan@parametrix.com
Coonrod, Julie	UNM	(505) 277-3233	jcoonrod@unm.edu
Crawford, Cliff	UNM	(505) 242-7081	ccbosque@juno.com
DelloRusso, Gina	USFWS	(505) 835-1828	Gina_DelloRusso@fws.gov
Doles, Mark	USACE	(505) 342-3364	Mark.W.Doles@usace.army.mil
Finch, Debbie	USFS, RMRS	(505) 856-0153	dfinch@fs.fed.us
Giesen, Lynette	USACE	(505) 342-3322	Lynette.M.Giesen@usace.army.mil
Gonzales, Santiago	USFWS	(505) 761-4720	Santiago_Gonzales@fws.gov
Grogan, Sterling	MRGCD	(505) 247-0235	grogan@mrgcd.com
Hummel, Ondrea	USACE	(505) 342-3375	Ondrea.C.Linderoth-Hummel@usace.army.mil
Jones, Seth	USACE - Galveston District (Remote Team Member)	(409) 766-3068	Seth.W.Jones@usace.army.mil
Najmi, Yasmeen	MRGCD	(505) 247-0234	yasmeen@mrgcd.dst.nm.us
E-Team Members	Agency	Phone	Email Address
Pegram, Page	ISC	(505) 764-3890	ppegram@ose.state.nm.us
Schmader, Matt	City of Albuquerque Open Space Division	(505) 452-5200	Mschmader@cabq.gov
Stretch, Doug	MRGCD	(505) 247-0234	doug@mrgcd.us
Umbreit, Nancy	BOR	(505) 462-3599	numbreit@uc.usbr.gov
Wicklund, Charles	NMSFD	(505) 865-2776	cwicklund@state.nm.us

Step 2: Defining the MRGBER Project

The following sections (*Lead District*, *Project Location*, etc.) were developed by the District and used to define the overall project. For further details regarding this information, refer to the study's planning and NEPA reports (USACE 2002, 2003a, 2007, 2010)

Lead district

The MRGBER study falls under the purview of the U.S. Army Corps of Engineers, Albuquerque District[1], Albuquerque, NM (Figure 11) in the South Pacific Division.[2]

Figure 11. Albuquerque District boundaries.

Established in 1888, the South Pacific Division is one of the Corps' eight regions nationwide. Four operating districts, headquartered in Albuquerque, Los Angeles, Sacramento, and San Francisco, provide federal

[1] http://www.spa.usace.army.mil/ (MAY 2008).

[2] http://www.spd.usace.army.mil/ (MAY 2008).

and military engineering support in California, Arizona, Nevada, Utah, New Mexico and in parts of Colorado, Oregon, Idaho, Wyoming and Texas. The civil works program is oriented around major watersheds in the region and leverages federal resources for navigation, flood damage reduction and ecosystem restoration. Fifteen of the fastest-growing metropolitan areas in the United States are in this diverse region where water resources are a key limiting factor. Much of the region gets less than 20 inches of precipitation a year; however, when it rains it rains heavily. Major floods are a threat to life and property. The USACE uses a watershed approach to flood damage reduction that takes into account issues such as water supply and ecosystem restoration. Major river basins include the Sacramento, San Joaquin, Santa Ana, Colorado and Rio Grande, which are governed by complex water rights. Water resources are vital to agriculture, urban development, natural ecosystems, and Tribal interests. There are more than 300 threatened and endangered species in the region. USACE issues regulatory permits under the Clean Water Act for development occurring in the nation's waters and wetlands, balancing environmental stewardship with the need for economic and urban growth. The project manager for the MRGBER study is currently Ms. Alicia Austin-Johnson (CESPA-PM-C); the lead planner is currently Mr. Mark Doles (CESPA-PM-LP); the lead hydrologist is currently Mr. Steve Boberg (CESPA-PM-LH); and the lead biologist is currently Ms. Ondrea Hummel (CESPA-PM-LE). Mr. Seth Jones actively participated in the plan formulation of the study and served as a remote team member from the Galveston District (CESWG-PE-PR).

Project location

The MRGBER study area is located in the middle reach of the Rio Grande, in the vicinity of the City of Albuquerque, New Mexico traversing Bernalillo and Sandoval counties (Figure 12).

The study area is approximately 17 miles in length along the river and roughly 5,300 acres in size. The outflow of the city's North Diversion Channel forms the north boundary of the Study Area, while the southern boundary is formed by the northern limits of the Pueblo of Isleta. The area is defined on the east and west by the flood control levees, although the areas adjacent to the levees within the original floodplain have also been considered in the determinations of this report. The study area roughly corresponds with the *Rio Grande Valley State Park*, which runs through the heart of Albuquerque and the County of Bernalillo. The park was dedicated for public uses and conservation purposes, and is one of the last intact

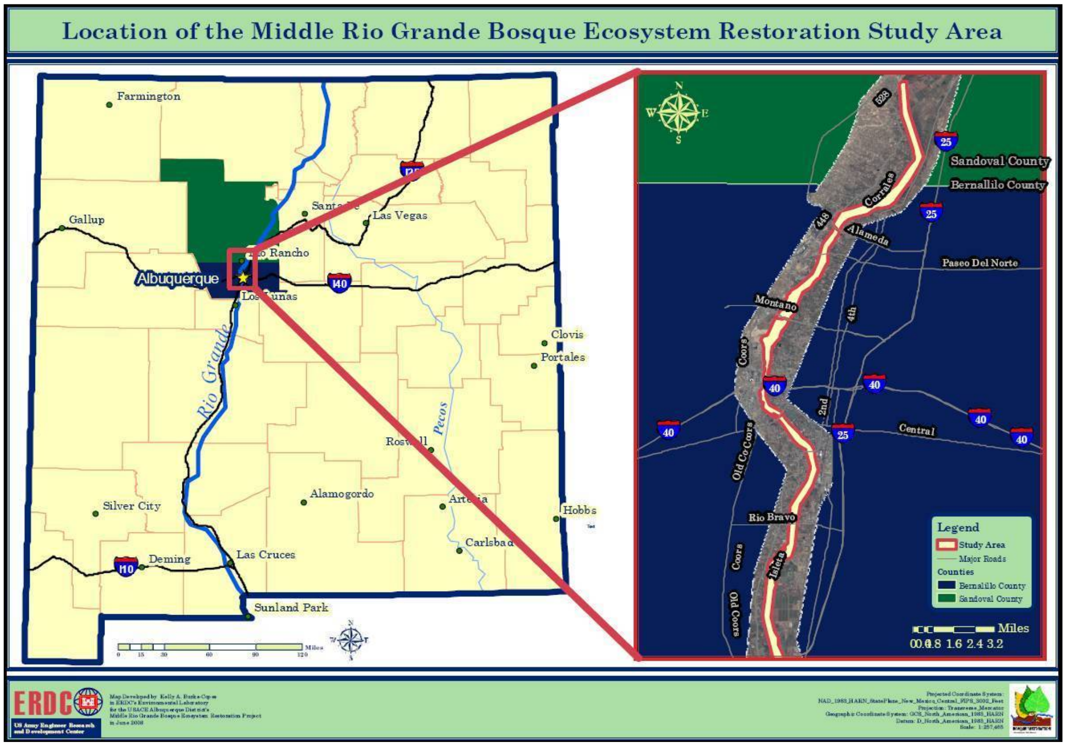

Figure 12. MRGBER study area location.

cottonwood gallery forests along the Middle Rio Grande. The bosque forest therein is one of the most biologically rich areas in the state and arguably one of the largest cottonwood riparian galleries in the southwestern United States (USACE 2002, 2003a, 2007, 2010).

The area is maintained as a part of the Middle Rio Grande Flood Control Acts of 1948 and 1950 and is within the Facilities of the *Middle Rio Grande Project* (USACE 2002, 2003a, 2007, 2010). The bosque area within Albuquerque was designated as the *Rio Grande Valley State Park* through the Park Act of 1983 and is cooperatively managed by the City of Albuquerque Open Space Division and the MRGCD (Figure 13).

The bosque within Corrales is designated as the *Corrales Bosque Preserve* and is cooperatively managed by the Village of Corrales and the Corrales Bosque Commission through an agreement with the MRGCD. *Sandia Pueblo* lands are managed by the Pueblo.

Because the system was so large, and the relative effects of proposed designs were localized to some degree, the project area was divided into five reaches on the basis of stakeholder interests, infrastructure (particularly bridges), hydrologic input, vegetative community makeup, and geographic location (Figure 14).

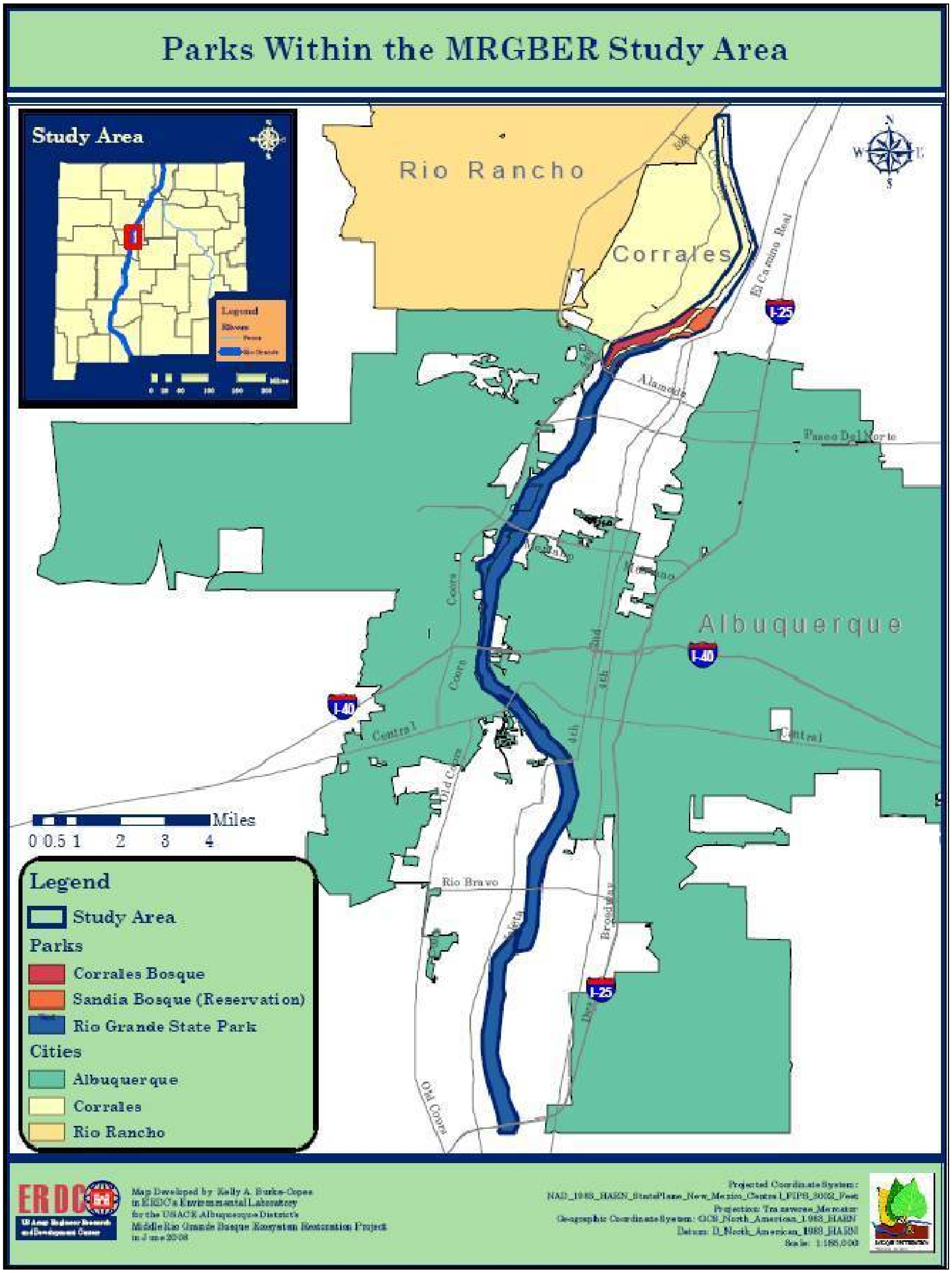

Figure 13. Parks maintained inside the MRGBER Study Area.

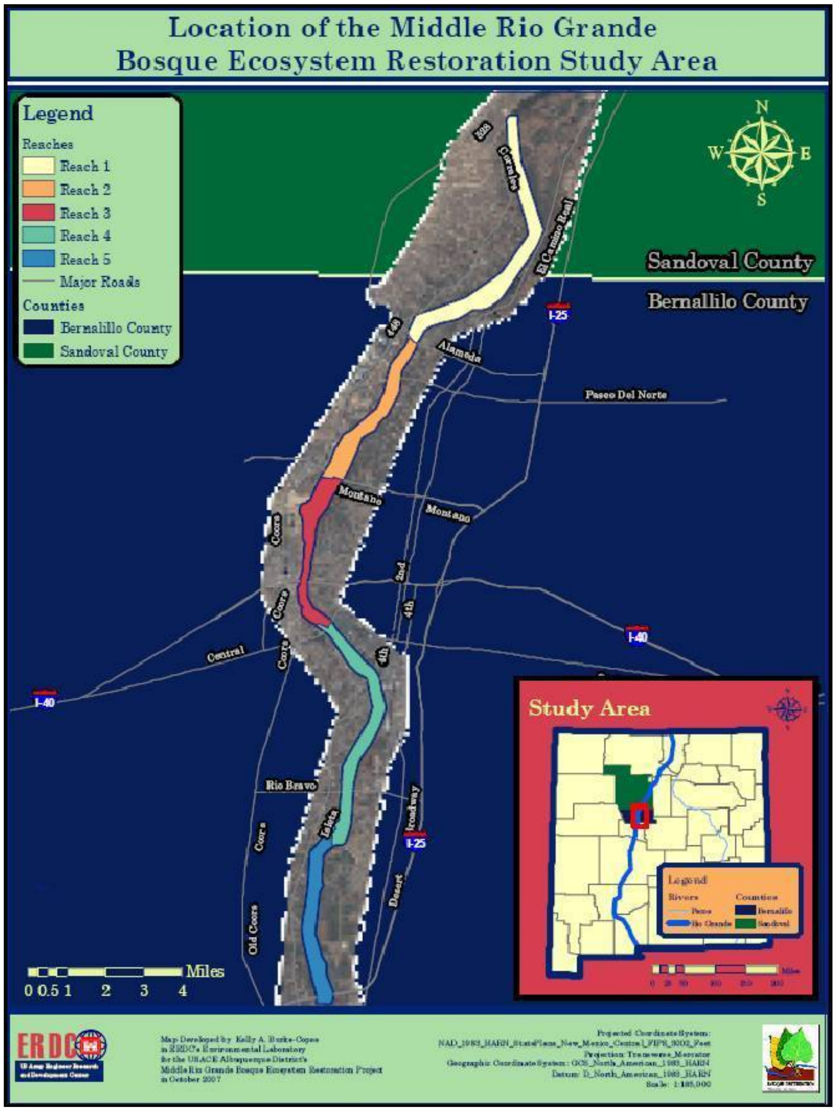

Figure 14. Reaches delineated for the baseline assessment of the MRGBER study.

Physical environment

The proposed project is located in the middle of the Rio Grande Valley, often characterized as a "wide floodplain of fertile bottomland" (USACE 2002, 2003a, 2007, 2010 and references therein). These fertile soils and shallow water tables support vegetation as well as a variety of resident and migratory wildlife. The Rio Grande valley is a productive agricultural area that contributes to the quality of life and economies of the urban areas of Albuquerque, Corrales, and Bernalillo, New Mexico, as well as several other smaller communities. The Rio Grande follows a well-defined geologic feature called the Rio Grande graben. The Rio Grande graben contains several thousand feet of poorly consolidated sediment of the Santa Fe Group of middle Miocene to Pleistocene age. The terrain in the area is characterized by gently sloping plains from the east to the Rio Grande on the west, ranging from about 4,860 feet to 4,875 feet in elevation. (Figure 15).

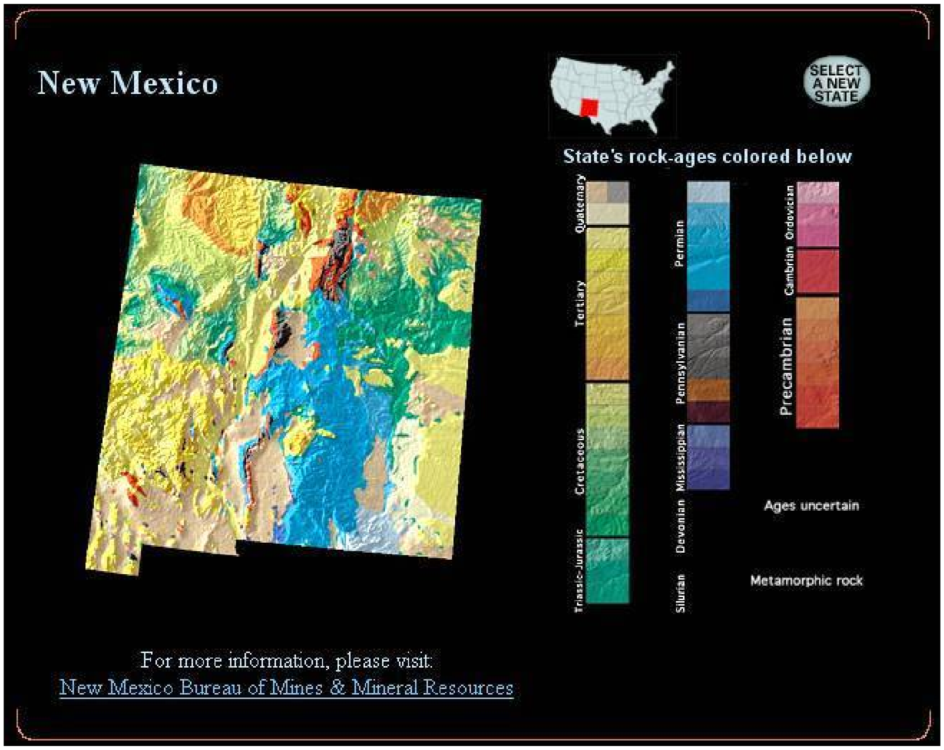

Figure 15. Topography and underlying geology for the state of New Mexico.[1]

The general soil conditions are deep, nearly level, and well-drained that formed in recent alluvium, on floodplains of the Rio Grande. Water tables in the study area are typically four to five feet in depth and permeability is moderate (USACE 2002, 2003a, 2007, 2010 and references therein), but on approximately two percent of the acreage it is between depths of 45 and 60 inches and the soil is moderately saline (Figure 16).

A myriad of land covers/land uses have been identified within the study area (Figure 17).

Adjacent to the project area (outside of the levees), farming is still a major land use. Small truck farms grow chile, corn, squash, tomatoes and fruit. Alfalfa is a main crop. Dairies and feedlots are also present. There is limited grazing, which is usually confined to families raising cattle for their own use.

[1] Image taken from http://tapestry.usgs.gov/states/newmexico.html (JUNE 2008).

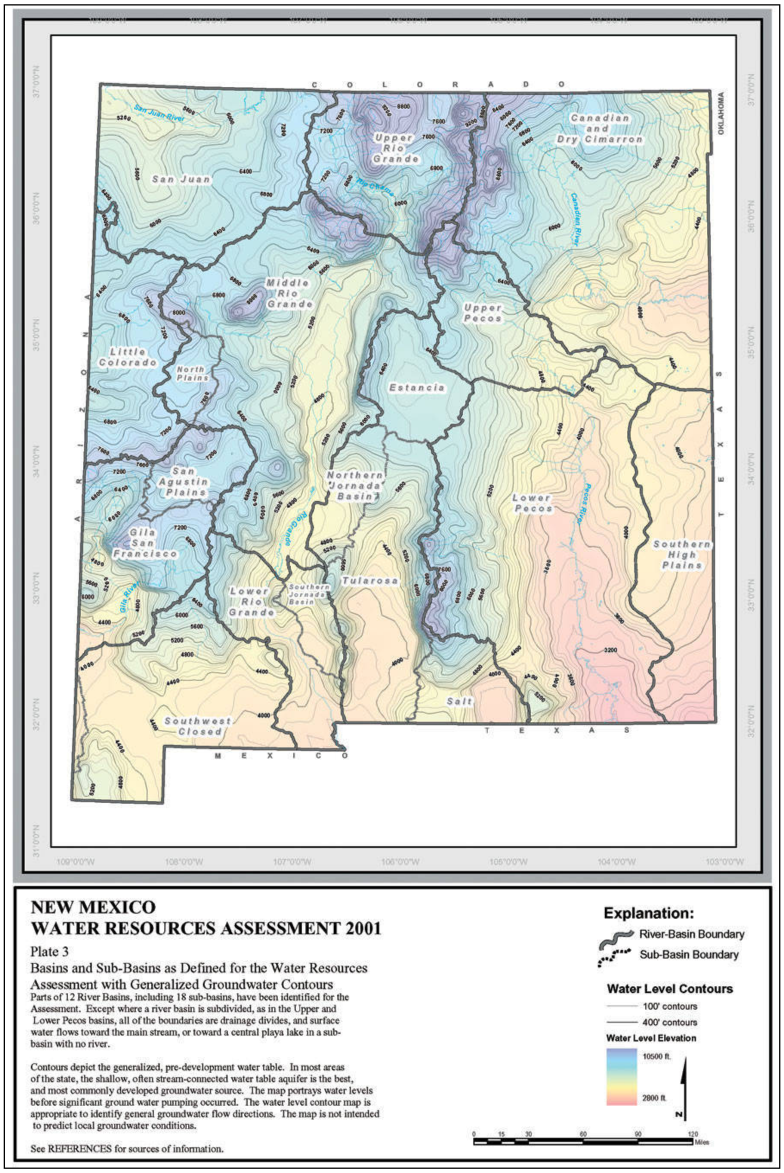

Figure 16. Groundwater elevations for the state of New Mexico.[1]

Socioeconomic environment

Socioeconomic resources include population and economic activity, as reflected by personal income, employment distribution, and unemployment (USACE 2002, 2003a, 2007, 2010). Bernalillo and Sandoval Counties serve as the Region of Influence in which most impacts can be expected to occur, and the state and region serve as regions of comparison. Specific information for recreation in the local area and Region of Influence are relevant and presented here.

[1] Map taken from http://www.esri.com/mapmuseum/mapbook_gallery/state1/nm1.html (JUNE 2008).

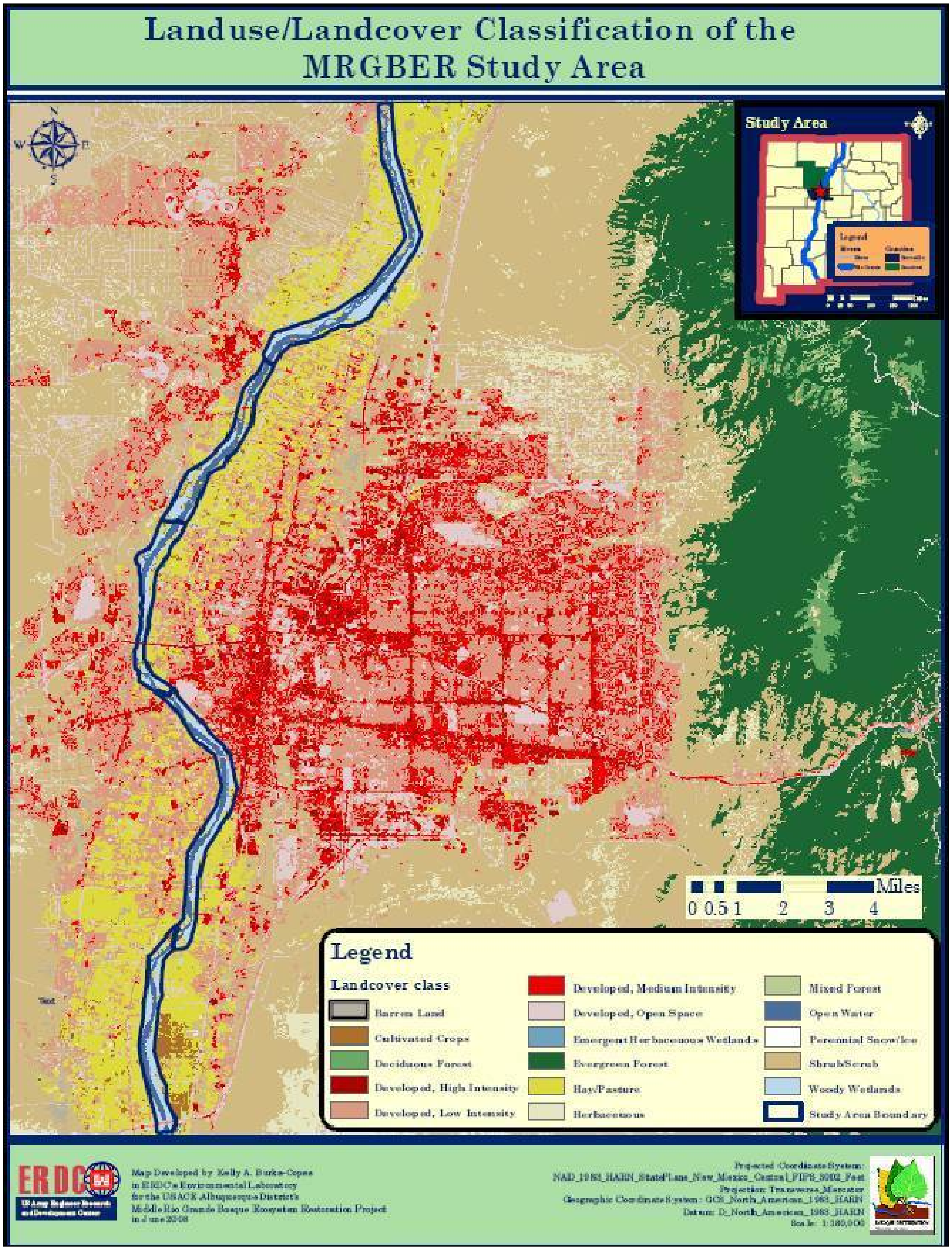

Figure 17. Landuse/landcover (LULC) classes present in the MRGBER study area.[1]

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[1] This information was extracted from the National Land Cover Data website: (http://www.mrlc.gov/multizone_download.php?zone=5 and http://www.mrlc.gov/multizone_download.php?zone=7 (MAY 2008).

The population in Bernalillo County was estimated at 573,675 in 2002 (USACE 2002, 2003a, 2007, 2010 and references therein). It is approximately 1,166 square miles with 477 persons per square mile, and is generally urban in character. Sandoval County is roughly 3,709 square miles, with approximately 24.2 persons per square mile (Figure 18).

The total population of Sandoval County in 2000 was 89,908 (USACE 2002, 2003a, 2007, 2010 and references therein), and it can be considered generally rural in character.

The Town of Bernalillo and City of Rio Rancho had populations of 6,611 and 51,765, respectively, in 2000. In 1999, Bernalillo County had a per capita personal income (PCPI) of $20,790. In 2000, Sandoval County had a PCPI of $22,247. This PCPI ranked 5th in the State of New Mexico, and was 101 percent of the State of New Mexico average, $21,931, and was 75% of the national average, $29,469. The average annual growth rate of PCPI over the past 10 years was 4.7 percent for Sandoval County. The average annual growth rate for the State of New Mexico was 3.9 percent, and for the nation was 4.2 percent (U.S. Census Bureau 2001a-b). In 2003, the median income of households in Albuquerque was $40,061. For more details on the economic status of the region, refer to the District's reports (USACE 2002, 2003a, 2007, 2010).

Opportunities to experience the bosque within the MRGBER study area

In the southern reaches (*Rio Grande Valley State Park*), trails within the bosque exist on both sides of the river and are either paved, or in most cases dirt (though in some cases a formalized crusher fine trail has been constructed) (Figure 19).

Various levels of recreation take place on the paved trail including jogging, bicycling, roller blading and walking. On the natural surface trails jogging and walking take place but mountain biking and horseback riding are also favorite uses. No motorized vehicles, except for maintenance and emergency vehicles, are allowed per City of Albuquerque and Bernalillo County ordinances (USACE 2002, 2003a, 2007, 2010). In the *Corrales Bosque Preserve*, a natural surface trail allows limited access (for those capable of navigating a natural surface trail) for jogging, walking, horseback riding, and bicycling. No motorized vehicles are allowed, except for maintenance and emergency vehicles, per Village ordinance. Within the Sandia Pueblo, a formalized trail system does not exist but varying levels of recreation take

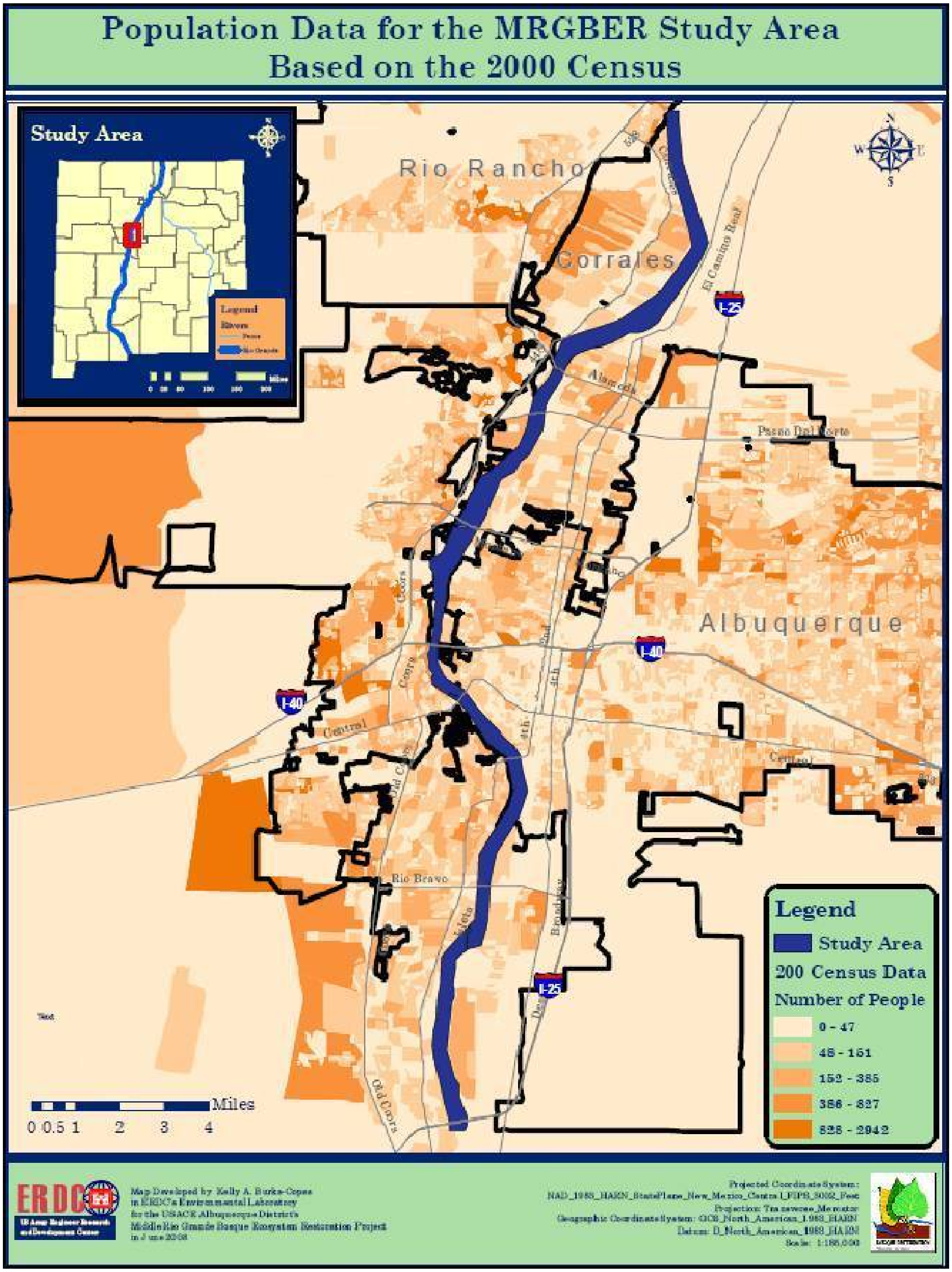

Figure 18. Population data derived from the 2000 Census for Bernalillo and Sandoval Counties.

Figure 19. Opportunities to access and experience the bosque first-hand are critical to establishing the cultural connection between the public and this rare and unique ecosystem.

place on the levee and inside the bosque. Another recreational activity that takes place in all locations is fishing. Sandia Pueblo has a formal fishing area called Sandia Lakes. In Corrales, fishing takes place along the drains. Within the *Rio Grande Valley State Park*, there are various fishing locations. Tingley Ponds is the main fishing location, with two large fishing ponds and a children's fishing pond (see Figure 20).

Figure 20. Opportunities abound to introduce the region's next generation to the bosque – The Children's Pond at Tingle offers this experience to kids ages 12 and younger.[1]

Other areas remaining open to anglers include the Rio Bravo Picnic Area fishing pier, which is over the drain at the northeast corner of Rio Bravo and the river. Other fishing takes place on the drain at Paseo del Norte on the east side of the river and various other locations, though these are not formalized.

Vegetative communities of concern

Watershed 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

[1] Photos taken from http://www.cabq.gov/biopark/tingley/fishing.html (JUNE 2008).

vegetation to these factors, the watershed vegetation has been a changing mosaic of different types. For details regarding the historical conditions of the study, refer to the District's documents (USACE 2002, 2003a, 2007, 2010).

Of concern for this analysis, is the state of the vegetative communities within the study area today. To fully quantify the habitat conditions for this study, it is useful to divide the project into manageable sections and quantify these in terms of acres per habitat type. This process, referred to as "cover typing," allows the user to define the differences between vegetative covers (e.g., forest, shrublands, wet/dry meadows, etc.), hydrology and soils characteristics, and clearly delineate these distinctions on a map. The final classification system, based primarily upon dominant vegetation cover, captures "natural" settings and common landuse practices in a specific and orderly fashion that accommodates USACE's plan formulation process. The "Middle Rio Grande Biological Survey" completed by Hink and Ohmart in 1984 described the plant communities within the study area's riparian zone and provided detailed information on species composition and the structure of cover types. Six general plant vegetation categories were developed by Hink and Ohmart (1984), based on the height of the vegetation and the make up of the understory or lower layers:[1]

- **Type I: Mature Riparian Forests** (Figure 21) with tall trees ranging from 50 to 60 feet in height, closed canopies, and well-established (relatively dense) understories composed of saplings and shrubs
- **Type II: Mature Riparian Forests** (Figure 22) with tall trees exceeding 40 feet in height and nearly closed canopies, but limited sapling and shrub understories
- **Type III: Intermediate-aged Riparian Woodlands** (Figure 23) characterized by mid-sized trees less than 30 feet in height, but with closed canopies and dense understories
- **Type IV: Intermediate-aged Riparian Woodland/Savannahs** (Figure 24) characterized by open stands of mid-sized trees with widely scattered shrubs and sparse herbaceous growth underneath

[1] In actuality, the Hink and Omart classification requires field biologists to identify vegetation at the species level, and has generated a unique naming convention based on these characterizations. Those familiar with the Hink and Omart system should refer to Appendix H in Burks-Copes and Webb 2009 to see a crosswalk for cover types used in this assessment and the detailed Hink and Omart classification.

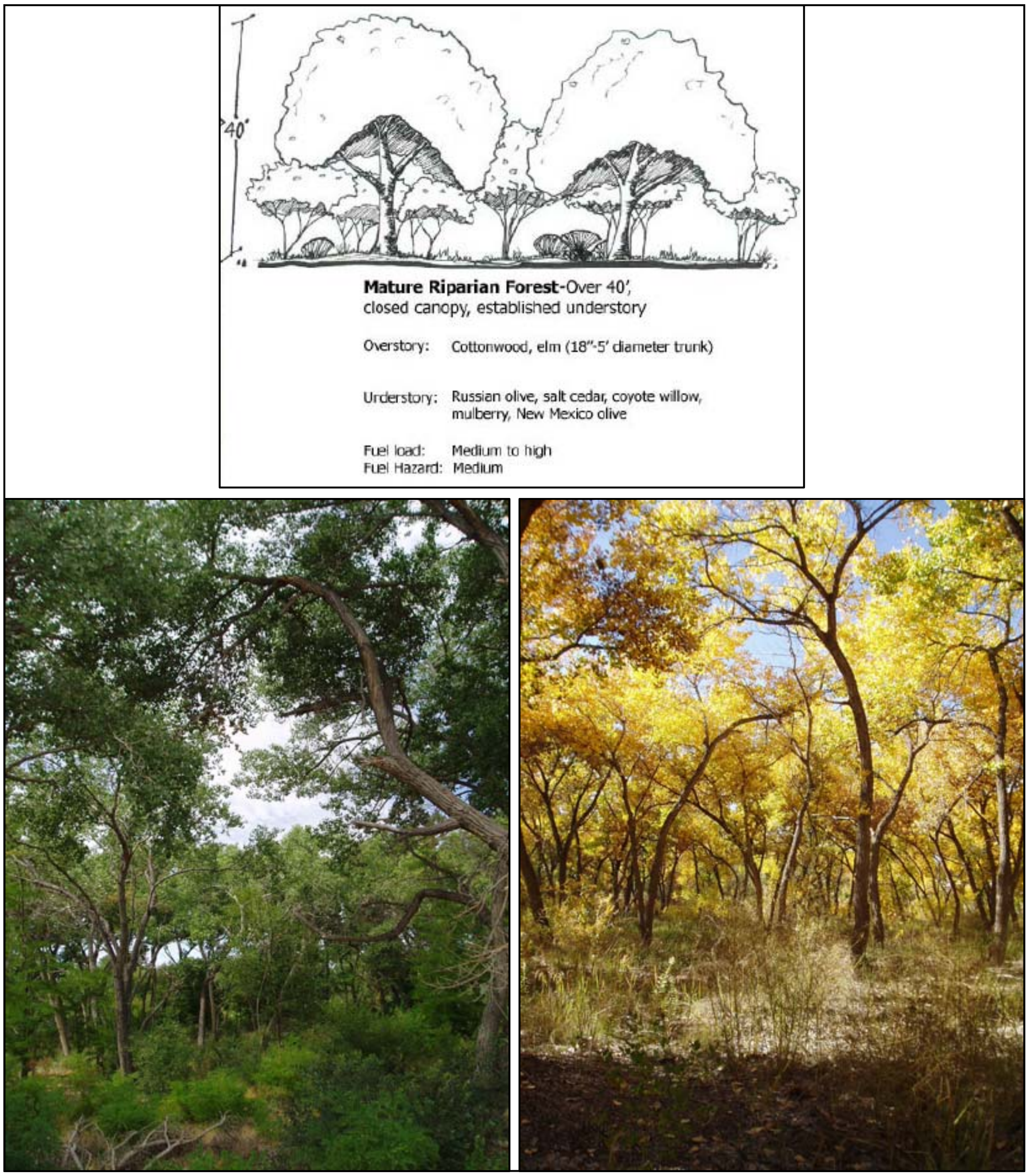

Figure 21. Classic examples of Type I (Mature Riparian Forests) vegetation in the study area.

- **Type V: Riparian Shrubs** (Figure 25) are characterized by dense vegetation (shrubs and saplings) up to 15 ft in height, but lacking tall tree species, and often having dense herbaceous growth underneath
- **Type VI: Dry Grass Meadows and Wet Marshes** (Figure 26) are characterized by scattered plant growth composed of short shrubs (less than 5 feet in height), seedlings, and grasses. This category includes both dry meadows and the rare marshes found in the oxbow of the Middle Rio Grande River that are vegetated with cattail, bullrush, sedges, watercress and algae.

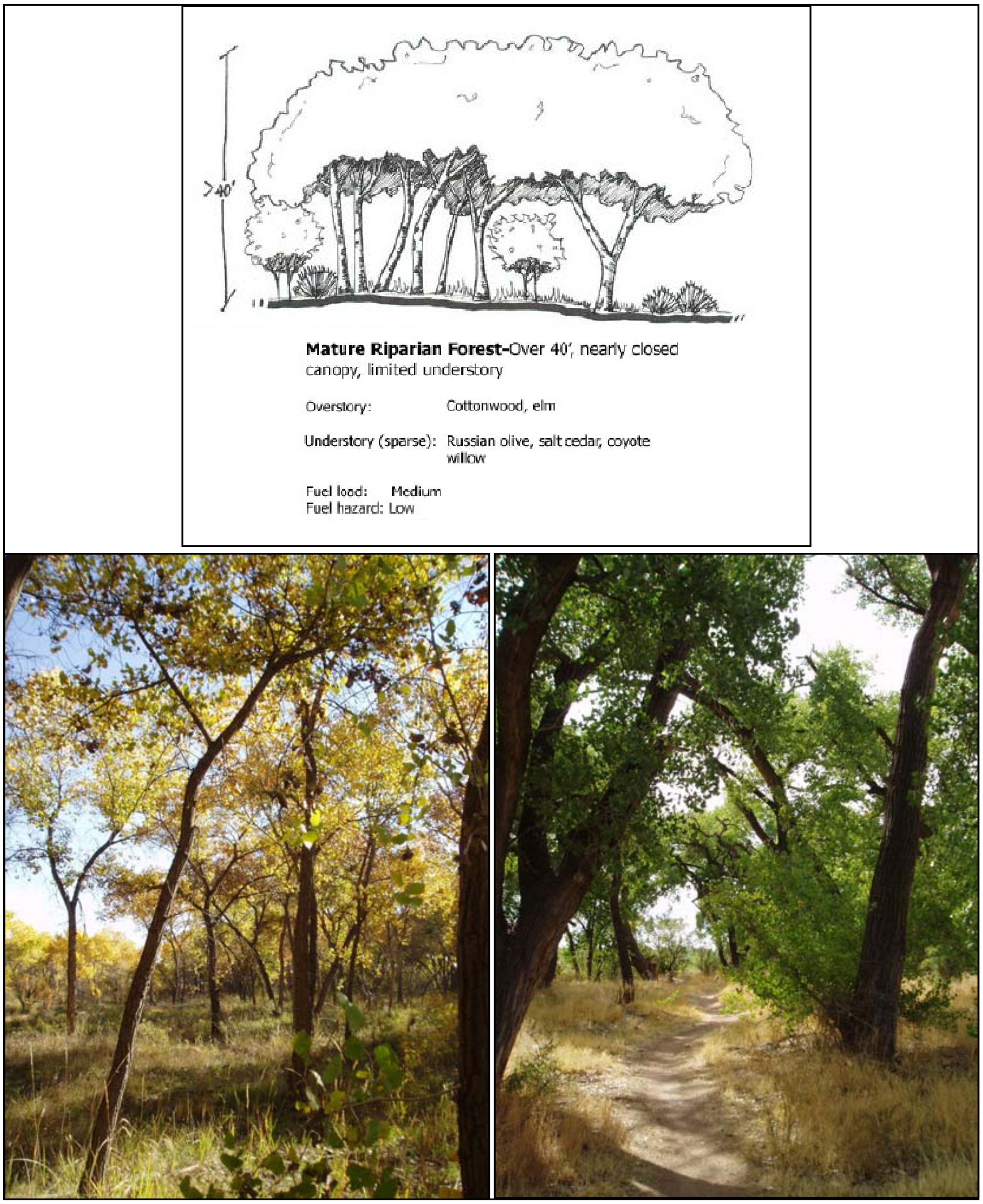

Figure 22. Classic examples of Type II (Mature Riparian Forests) vegetation in the study area.

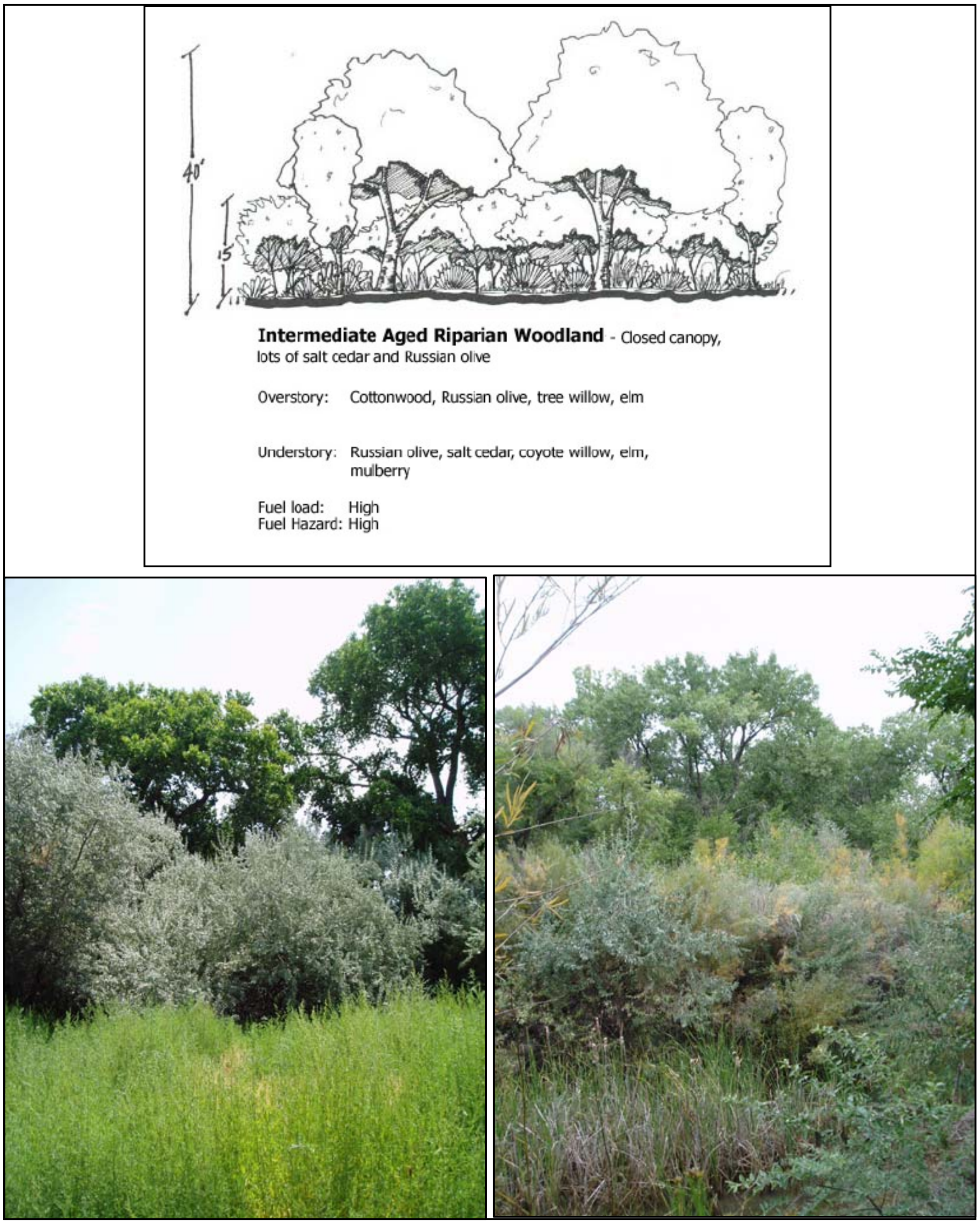

Figure 23. Classic examples of Type III (Intermediate-aged Riparian Woodlands) vegetation in the study area.

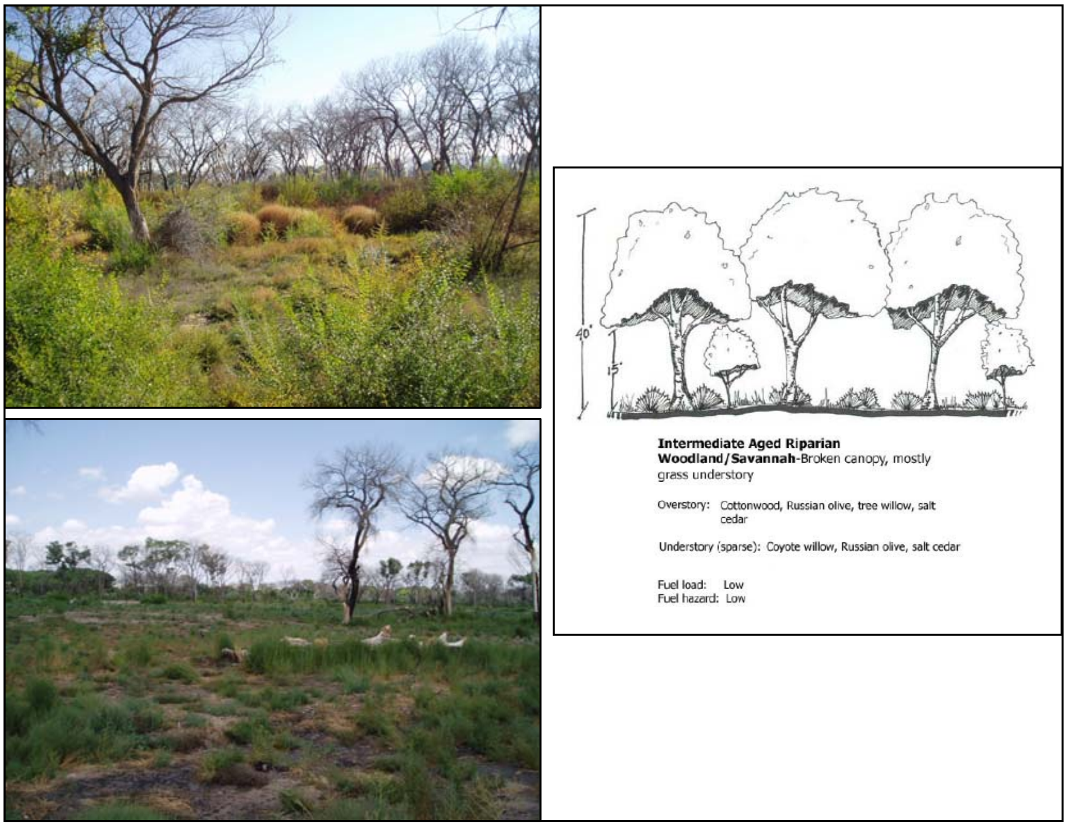

Figure 24. Classic examples of Type IV (Intermediate-aged Riparian Woodland/Savannahs) vegetation in the study area.

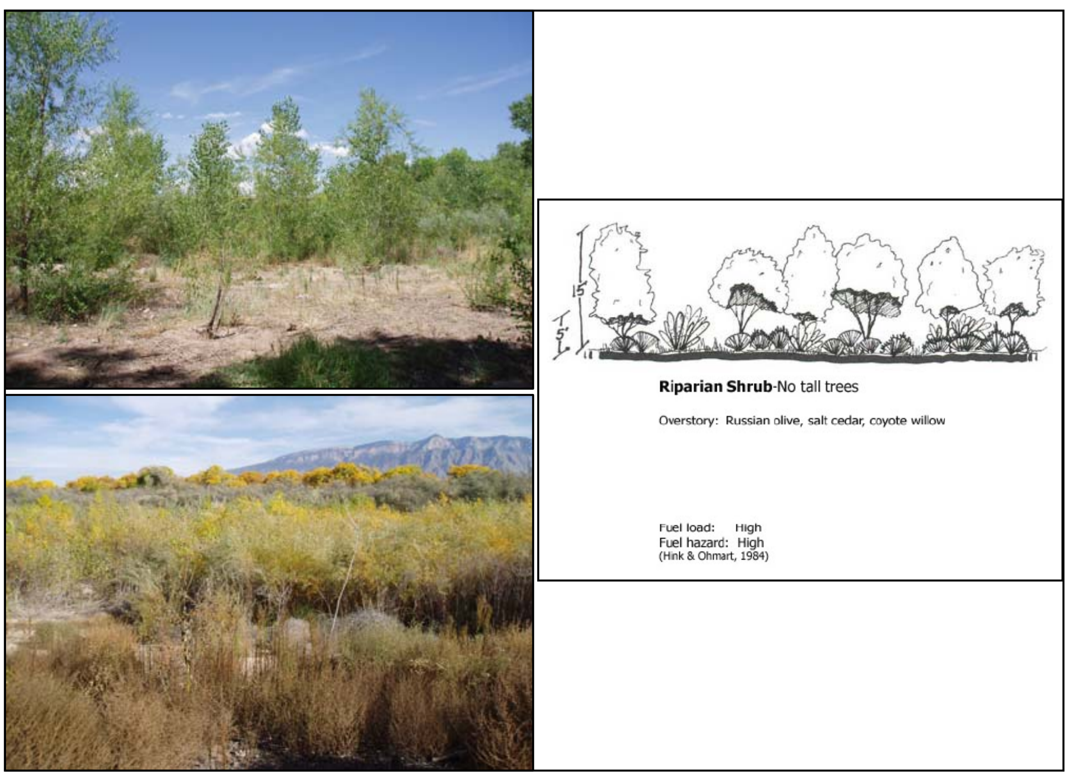

Figure 25. Classic examples of Type V (Riparian Shrubs) vegetation in the study area.

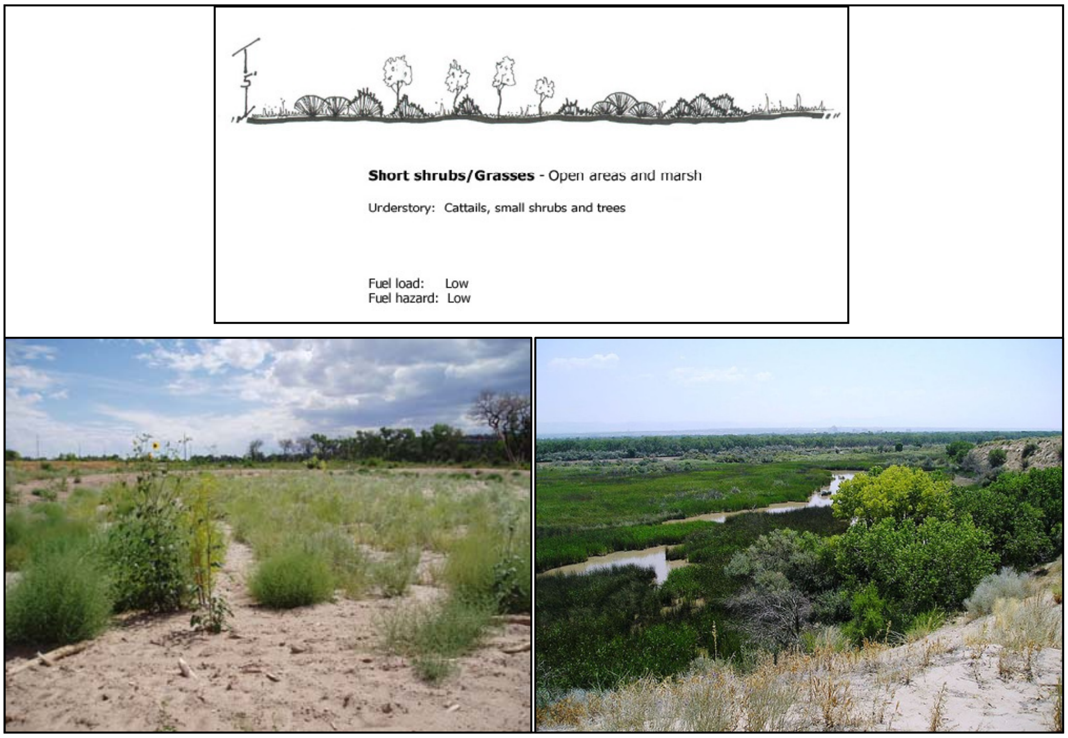

Figure 26. Classic examples of Type IV (Dry Grass Meadows and Wet Marshes) vegetation in the study area.

For purposes of the study, these six cover types were subsequently divided into "Treated" and "Untreated" categories indicating the condition of "fire management" within their boundaries (Figure 27).

Figure 27. Untreated forests (left) carry extensive fuel loads susceptible to catastrophic fires. The District and stakeholders actively reduce fuel loads to reduce the risk (right). These areas have reduced functionality (lower habitat suitability).

Since the fires that took place in June 2003 burning 253 acres (Figure 28), the City of Albuquerque Open Space Division (AOSD) has initiated an extensive thinning project in order to prevent fires in the Albuquerque area.

Figure 28. Location of 2003 bosque fires (map taken from USACE 2007).

Unfortunately, two more fires occurred in 2004 - one between Rio Bravo and Interstate-25 (I-25) on both sides of the river burning approximately 63 acres and the other south of Bridge Blvd. on the east side of the river, burning approximately 18 acres (USACE 2007). Prior to these recent fires and in between them, the City has been thinning most areas within the Rio *Grande Valley State Park*. To date, approximately 2,300 of the 3,000 bosque acres in the park have been “treated” in some way by the AOSD, Ciudad Soil and Water Conservation District (SWCD), the Corps (through the Bosque Wildfire Project) and other agencies and private organizations. Some areas were lightly thinned while other areas were cleared of all non-native vegetation and dead material, depending on the level of fuel reduction required for the site. Clearing activities have greatly reduced the acreage of Type I, III, and V woodlands. Recently-created Type II stands are largely devoid of understory vegetation. However, Russian olive and salt cedar have begun sprouting from the root crowns of cut trees in treated stands. Open areas not associated with the model have been mapped, and offer potential areas of restoration and rehabilitation within the study area. To complete the characterization, a series of “Newly Developed” coverages were created as placeholders for conversion of the open areas and existing degraded areas into newly restored wetland (riparian) habitats.

Step 3: Mapping the applicable cover types

To quantify the community’s habitat conditions, the HEP process requires the study area be divided into manageable sections and quantified in terms of acres. This process, referred to as “cover typing,” allows the user to define the differences between vegetative covers (e.g., meadow, forest, marsh, etc.) hydrology and soils characteristics, and clearly delineate these distinctions on a map. The final classification system, based primarily upon dominant vegetation cover, captures “natural” settings as well as common land-use practices in a specific and orderly fashion that accommodates the USACE plan formulation process.

In the MRGBER study, twenty-four unique habitat types were (i.e., cover types or CTs) were identified and mapped across the entire project study area (Table 2).[1]

Cover types identified as “NEW” refer to newly developed areas proposed in conjunction with construction of proposed alternatives. The existing cover types were subsequently mapped using a Geographic Information System (GIS) (and ground-truthed during the 2005 field season) (Figure 29). For details regarding the total baseline acreages and quality of these CTs, refer to *Chapter 3* of this report.

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[1] Because the Albuquerque District knew that the fires and treatments had caused significant changes to the existing vegetation in the study area, an effort was undertaken to ground-truth and remap the reach in 2005 (again using the Hink and Ohmart 1984 methodology and classification scheme). Details of this effort are described in USACE 2007. The 2005 updated mapping was used for this assessment.

Table 2. Cover types identified and mapped for the MRGBER study area.

No.	Code	Cover Type (and Land Use) Description
1	TYPE_1	Hink and Ohmart (1984) vegetation Study.. Class I not treated - MATURE RIPARIAN FOREST (Over 40' – closed canopy, established understory).
2	TYPE_2T	H&O Class II treated - MATURE RIPARIAN FOREST (Over 40' – nearly closed canopy, limited understory).
3	TYPE_2U	H&O Class II not treated - MATURE RIPARIAN FOREST (Over 40' – nearly closed canopy, limited understory).
4	TYPE_3	H&O Class III not treated - INTERMEDIATE AGED RIPARIAN WOODLAND (Closed canopy, lots of salt cedar and Russian olive).
5	TYPE_4T	H&O Class IV treated - INTERMEDIATE AGED RIPARIAN WOODLAND/SAVANNAH (Broken canopy, mostly grass understory).
6	TYPE_4U	H&O Class IV not treated - INTERMEDIATE AGED RIPARIAN WOODLAND/SAVANNAH (Broken canopy, mostly grass understory).
7	TYPE_5	H&O Class V Shrublands not treated - RIPARIAN SHRUB (no tall trees).
8	TYPE_6T	H&O Class VI dry (grass) meadow treated - SHORT SHRUBS/GRASSES – Open areas.
9	TYPE_6U	H&O Class VI dry (grass) meadow not treated - SHORT SHRUBS/GRASSES – Open areas.
10	TYPE_6W	H&O Class VI wet meadow not treated - SHORT SHRUBS/GRASSES – Open areas and Marsh.
11	OPENLAND	Open Areas
12	OPENWATER	Open Water
13	NEWTYPE_1	Newly Developed Type 1
14	NEWTYPE_2T	Newly Developed Type 2T
15	NEWTYPE_2U	Newly Developed Type 2U
16	NEWTYPE_3	Newly Developed Type 3
17	NEWTYPE_4T	Newly Developed Type 4T
18	NEWTYPE_4U	Newly Developed Type 4U
19	NEWTYPE_5	Newly Developed Type 5
20	NEWTYPE_6T	Newly Developed Type 6T
21	NEWTYPE_6U	Newly Developed Type 6U
22	NEWTYPE_6W	Newly Developed Type 6W
23	ISLANDS	Islands
24	UTILITY	Utility Areas

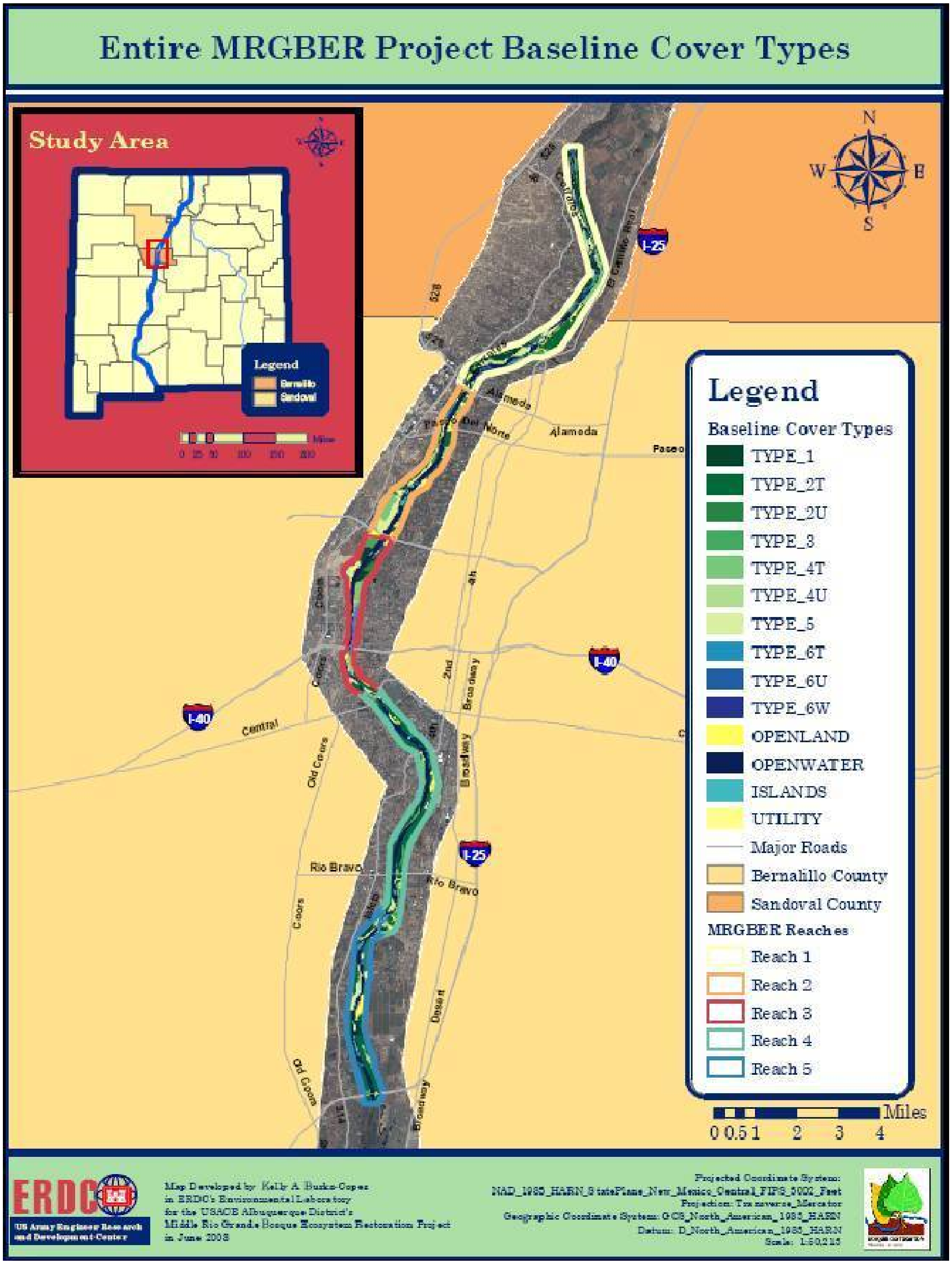

Figure 29. Baseline cover type map for the project study area.

Step 4: Developing a Model for the Study

Community assessment and spatial habitat diversity were identified as priorities for the District's upcoming feasibility study. However, few models were published and available for application. ERDC-EL proposed a strategy to the District to develop a model for the MRGBER 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, etc.) of the system that could be combined in a meaningful manner to "model" the communities. In the workshop(s), 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 system requirements. The outcome of the workshop(s) was a series of mathematical formulas that were identified as functional components (e.g., Hydrology, Vegetative Structure, Diversity, Connectivity, Disturbance, etc.) for the community index model. The model was comprised of variables that were:

    a. biologically, ecologically, socioeconomically, or functionally meaningful for the subject;
    b. easily measured or estimated;
    c. able to have scores assigned for past and future conditions;
    d. related to an action that could be taken or a change expected to occur;
    e. were 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 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 the ERDC-EL/District/E-Team review and then request review from the initial expert panel that participated in the original workshop, as well as solicit review from independent regional experts who were not included in the model development and application process.

A series of ten workshops were held over the course of three years (2005-2008) to develop a model, characterize baseline conditions of the study area, then formulate plans and assess alternatives for the ecosystem restoration study. 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. 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 four categories: 1) hydrologic alteration, 2) geomorphic and topographic alteration, 3) urban encroachment and agricultural use, and 4) exotic species introductions. Each stressor altered ecosystem integrity within a water, soils, habitat and/or landscape context. For example, hydrologic alterations to the channel have caused changes not only in flooding frequency and duration, but have altered ecosystem function and structure across the basin. Urban encroachment has exacerbated these problems by reducing infiltration, increasing storm water 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 alternations are as obvious as they are numerous – flooding, erosion, fragmentation, and loss of biodiversity.

As a first step in the index model development process, ERDC-EL developed a conceptual model to illustrate the relationships between these system-wide drivers and stressors and tried to highlight the ecosystem responses to these pressures across the entire Middle Rio Grande-Albuquerque watershed (Figure 30).

Conceptually speaking, the "Significant Ecosystem Components" (water, soils, habitat, and landscape) were characterized by parameters responsive to project design. These parameters or variables (hydroperiod, vegetative

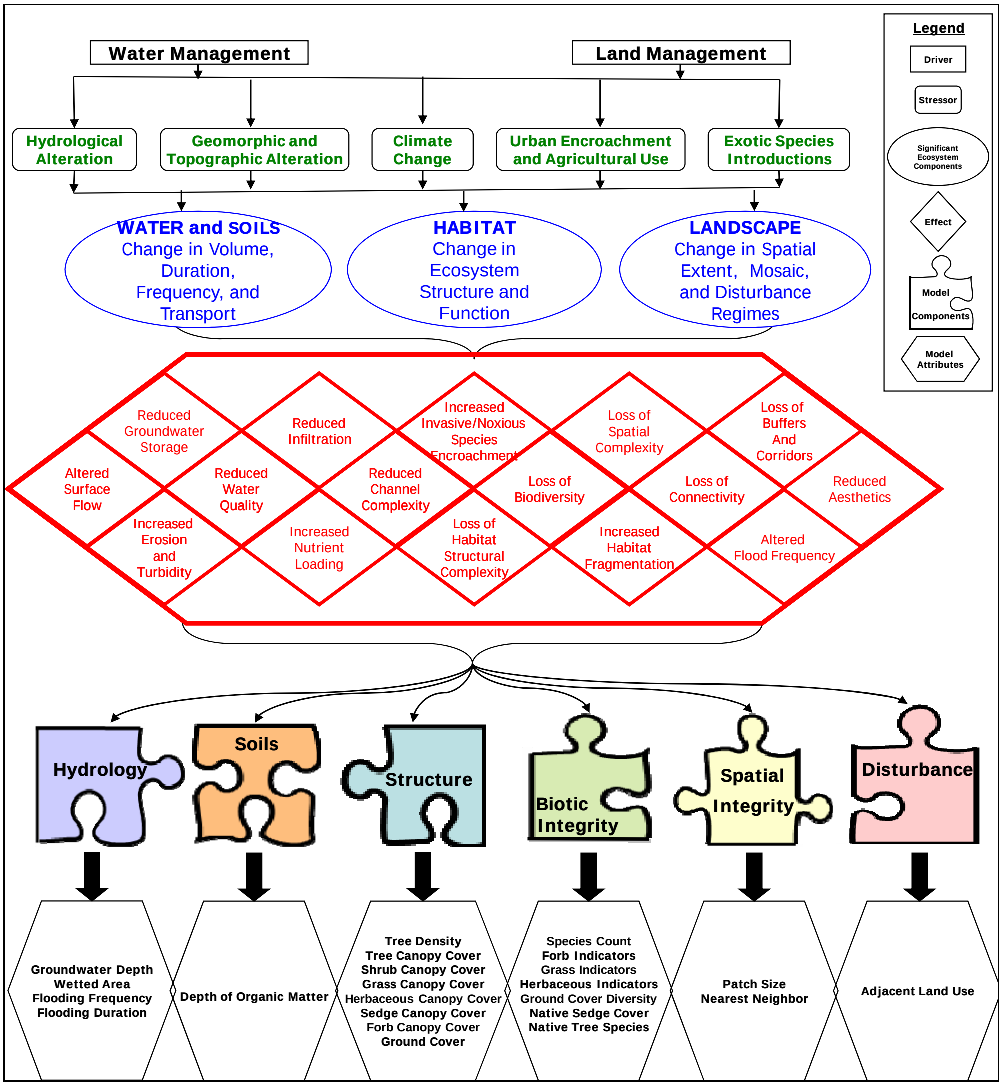

Figure 30. A conceptual model for the MRGBER.

cover, disturbance, etc.) were grouped in a meaningful manner to quantify the functionality of the community in the face of change. The effort to combine the variables in mathematical algorithms could then be viewed as community modeling. 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 31).

A single community-based index model (**Bosque Riparian Community**) was developed under this paradigm. We summarize the model below, but for readers interested in the details of these metrics, look to the model documentation (Burks-Copes and Webb 2009).

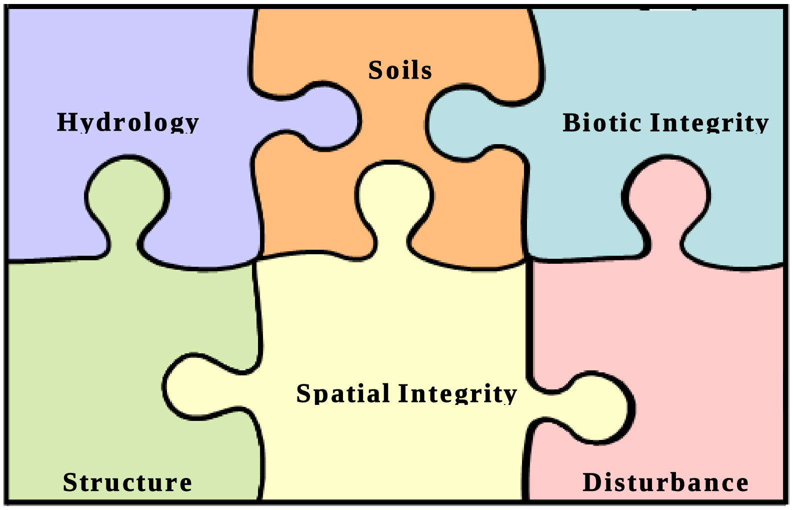

Figure 31. Within the conceptual modeling building framework, the various model components (color-coded for organization purposes) are pieced together to capture the essence of community functionality using the ecosystem puzzle analogy.

Habitat Potential – Bosque (Riparian) Community Index Model

For the Bosque Riparian Community Index Model three categories: 1) Hydrology; 2) Structure/Soils/Biotic Integrity; and 3) Spatial Integrity and Disturbance were identified as the key functional components necessary to model the ecosystem integrity of MRGBER's bosque community. Flow diagrams best illustrate the model's component relationships (Figure 32).

The E-Team developed mathematical algorithms to relate the various components to the ecosystem processes occurring throughout the watershed in this community. To test these concepts, a series of reference sites[1] were used to provide relevant feedback and verification of the model's conceptual architecture (Figure 33).

Reference sites in this instance refer to multiple sites in the defined geographic area (the reference domain) that were selected to represent a specific type of ecosystem (i.e., arid riparian forests and wetlands or bosques). Reference sites are most commonly described as natural settings – with minimal human disturbances (Hughes 1994, Bailey et al. 2004a, Chessman and Royal 2004, Intergovernmental Task Force on Monitoring

[1] ERDC-EL assisted the Albuquerque District in locating a series of 27 sample sites across the entire study area that were considered both reference standard (optimal) or sub-optimal and representing the range of conditions existing within the reference domain.

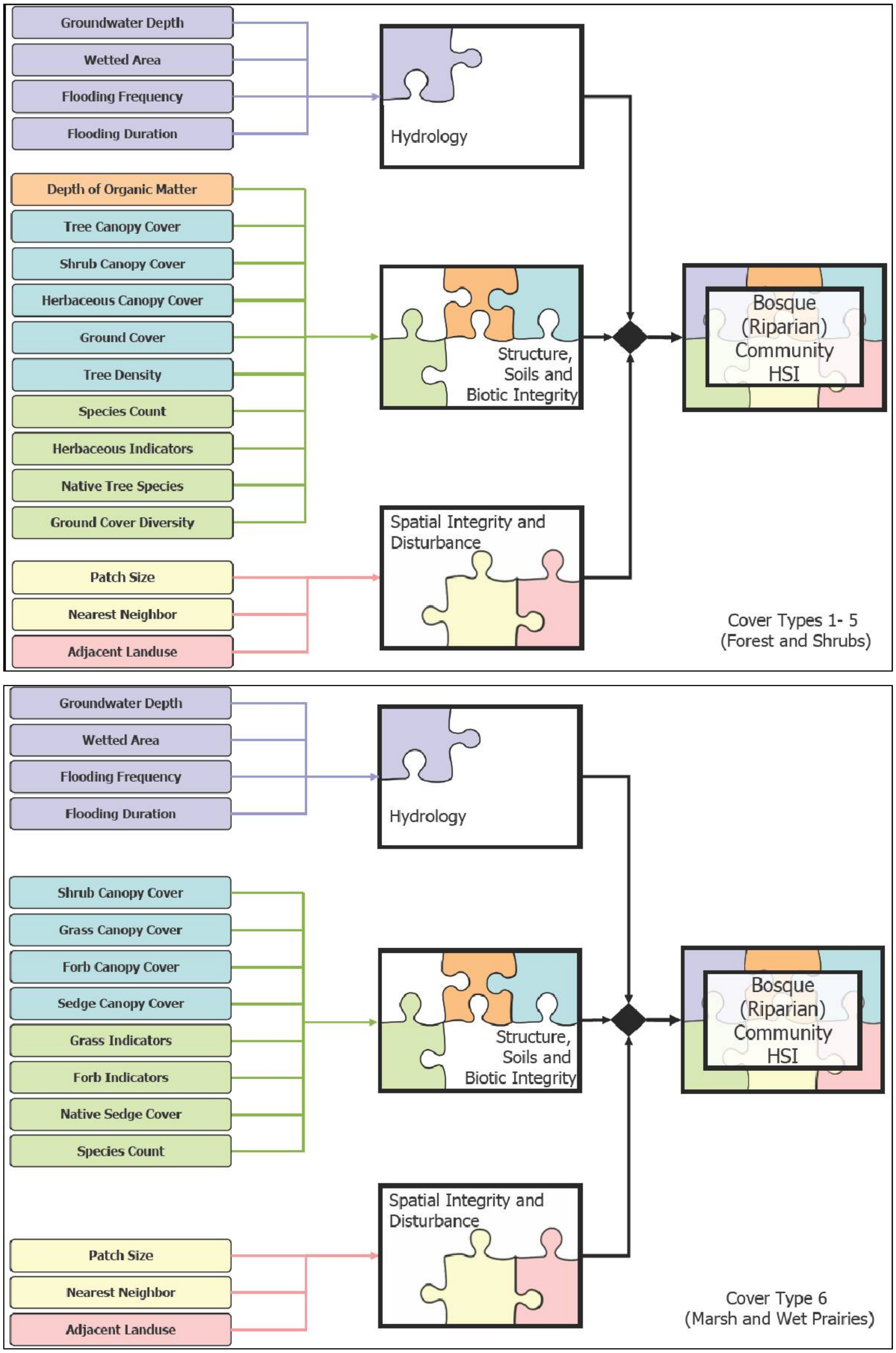

Figure 32. Flow diagram depicting combinations of model components and variables to form the Bosque community index model in the MRGBER study. There are two versions of the model depending on the cover types being evaluated. Types I-V use the upper diagram, and Type VI uses the lower diagram.

Figure 33. Bosque reference sites in the MRGBER study area used to calibrate the Bosque community index model.

Water Quality 2005). Reference-based conditions are therefore the range of physical, chemical, and biological values exhibited within the reference sites. When reference sites are characterized as undisturbed ecosystems, reference conditions exhibit a range of values that reflect the spatial and temporal variability that commonly occur in natural ecosystems (Swanson et al. 1993; Morgan et al. 1994; White and Walker 1997; Landres et al. 1999). When reference sites include altered or disturbed ecosystems (as is the case in most urban-based ecosystem restoration efforts such as the MRGBER), the reference conditions exhibit a wider range of values that reflect both natural variability and variability due to human activities. In these instances, optimal conditions or "virtual" references can be established using a variety of techniques including literature values, historical data, paleoecological data, and expert opinion (Society for Ecological Restoration International 2004; Ecological Restoration Institute 2008). Regardless of how reference conditions are established, ecosystem restoration evaluations can use the reference-based approach as a template for model development, restoration planning, and alternative analysis.

In the case of the MRGBER project, a reference-based approach used "reference ecosystems" to establish optimal conditions (HSI = 1.0) that served as benchmarks or standards of comparison for the assessment. 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 1998). Reference-based approaches have also been used to evaluate ecosystems in a landscape or watershed context (Warne et al. 2000, Rheindardt et al. 2007, Wardrop et al. 2007, Whigham et al. 2007, Smith 2008).

With the reference-based information in hand, ERDC-EL (with review and oversight from the E-Team) used a systematic, scientifically-based, statistical protocol to calibrate the community index model. Modifications to the original algorithms were incorporated into the system as indicated, and the final formulas were made ready for the MRGBER application (Table 3). Further descriptions of the community-based index model and its development/verification can be found in Burks-Copes and Webb (2009). A general list and description of the model components and its associated variables have been included in *Appendix C*.

Step 5: Data collection

Baseline inventory of the ecological, economic, and social characteristics of the MRGBER study area necessitated the collection of hydrologic, floristic, and spatially-explicit data system-wide. Site- and landscape-level data

Table 3. Index formulas for the MRGBER Bosque community model.

Model Component	Variable Code	CT Code	Formulas
Structure, Soils, and Biotic Integrity (RIP-BIOINTEG)	CANTREE CANSHRUB CANHERB DISTBIGTR NATIVETREE INDICATHB SPPCOUNT COVGRND CTGRNDCOV DEPTHOM	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5	$\frac{\left\{3 \times \left[\left(\frac{\left(\left(V_{CANTREE} \times V_{NATIVETREE}\right) \times V_{DISTBIGTR}\right)^{1/2} + V_{CANSHRUB}}{2}\right) \times V_{SPPCOUNT}\right]^{1/2}\right\} + \left(V_{CANHERB} \times V_{INDICATHB}\right) + V_{DEPTHOM} + \left[\left(V_{COVGRND} \times V_{CTGRNDCOV}\right)^{1/2}\right]}{6}$
	CANSHRUB CANGRASS CANFORB CANSEDGE INDICATGR INDICATFB NATIVESDG SPPCOUNT	TYPE_6T TYPE_6U TYPE_6W	$\frac{\left(V_{CANSHRUB} \times V_{SPPCOUNT}\right) + \left(V_{CANGRASS} \times V_{INDICATGR}\right) + \left(V_{CANFORB} \times V_{INDICATFB}\right) + \left(V_{CANSEDGE} \times V_{NATIVESDG}\right)}{4}$
Hydrology (RIP-HYDRO)	DEPTHGW WETTEDAREA FLOODFREQ DURATION	ALL	$\frac{\left(V_{FLOODFREQ} \times V_{DURATION}\right)^{1/2} + V_{DEPTHGW} + V_{WETTEDAREA}}{3}$
Spatial Integrity and Disturbance (RIP-SPATIAL)	PATCHSIZE TYPDISTURB DISTPATCH	ALL	$\frac{\left[2 \times \left(V_{PATCHSIZE} \times V_{DISTPATCH}\right)^{1/2}\right] + V_{TYPDISTURB}}{3}$
Overall Habitat Suitability Index (HSI):			$\frac{V_{BBIOTA} + V_{BWATER} + V_{BLANDSCPAPE}}{3}$

were collected between spring of 2003 and the winter of 2007.[1] To the greatest extent possible, underlying stressors in the region were also identified. In particular, land-use activities, physical habitat alterations, and indicator species (both natives and exotics) were described in detail. Some of this information was geographically-based and was assessed using documented protocols in a GIS environment. This information was stored in a personal geodatabase to assure portability and ready access.[2] 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. Refer to Burks-Copes and Webb (2009) for details on sampling protocols used in this effort.

Step 6: Data management and statistical analysis

Baseline data were subject to straightforward statistical analysis. Means, modes and standard deviations were derived for the variables sampled in the field and generated through the GIS exercises. Some limits to the assessment's data should be acknowledged. In some instances, variables were sampled incorrectly, recorded incorrectly or not measured in certain settings, and the data was either discarded or corrections were made several weeks after sampling was concluded. Where parameters were discarded or absent, extrapolations were made from regional means. When data management problems arose, ERDC-EL consulted with the E-Team prior to data handling, and solutions were devised with their full knowledge and consent. Detailed notes and minutes were taken during these meetings and phone conversations to provide documentation for the assessment.[3]

Step 7: Calculate Baseline Conditions

Once the baseline inventory was completed, the indices and the acreages were calculated for each applicable metric. The baseline conditions in terms of units (HUs) were generated by multiplication for the community model. The details of all calculations are presented below.

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[1] The GIS information (e.g., vegetative cover, access points along the river, bike trails, kiosks, etc.) was collected from various sources including the District itself, Bernalillo County, New Mexico Resource Geographic Information System (http://rgis.unm.edu/) and the U.S. Census Bureau (http://www.census.gov/) between 2005 and 2008 (JUNE 2008).

[2] Contact Ondrea Hummel (Table 1) in the USACE Albuquerque District Office to obtain copies of the geodatabase.

[3] For transcripts of these meetings, contact Ms. Ondrea Hummel at the District office (Table 1).

Calculating Baseline for the Bosque Community HSI Model

The means/mode values for each variable were applied to the SI graphs as dictated by the model's documentation (Burks-Copes and Webb 2009). A new graph was developed for each variable based on reference standards and reference site findings. The mean for each variable was then "scored" on index graphs, while providing a comparison of the baseline conditions to that of reference optimum. The basic mathematical premise is fairly straightforward and easy to complete. For example, if the average core size is 15 acres, the value "15" was entered into the "X-axis" on the SI curve below, and the resultant SI score (Y-axis) was determined (SI = 0.75) (Figure 34).

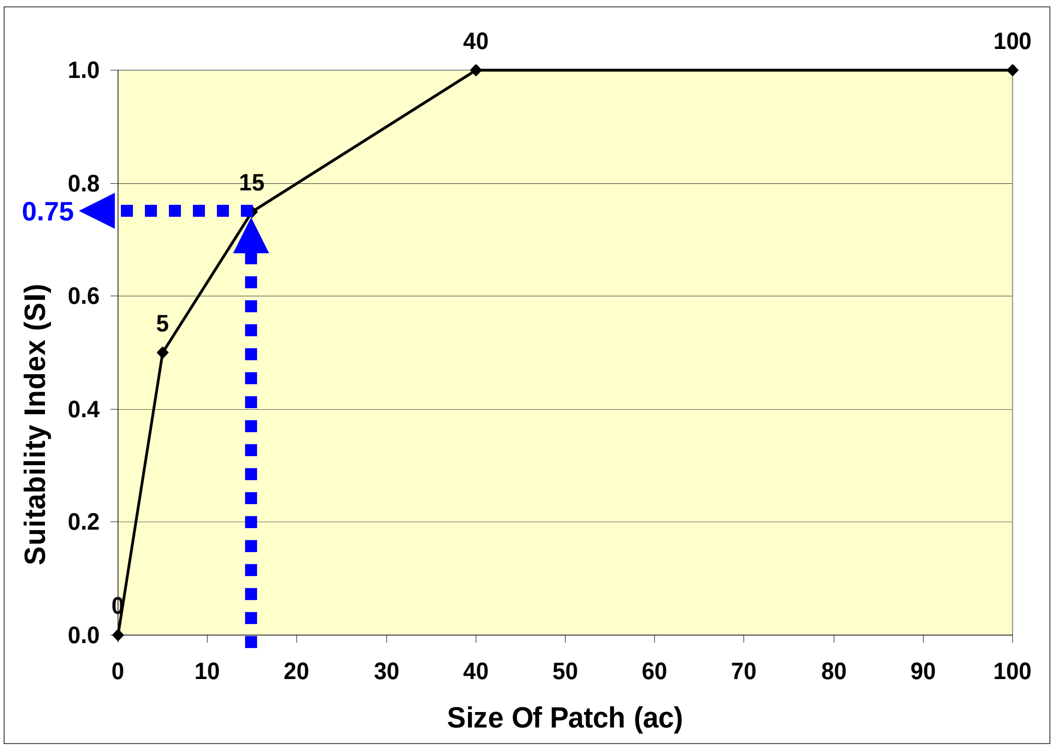

Figure 34. Example Suitability Index (SI) curve.

The process was repeated for every variable in each applicable cover type. The individual Life Requisite Suitability Index (LRSI) scores were entered into the HSI formulas (Table 3 above) on a CT-by-CT basis, and individual CT HSIs were generated.

The Relative Area (RA) of the CT was applied to each answer (CT HSI) from the previous step and then combined with the answers from the remaining associated CTs in an additive fashion. The model HSI formulas were considered to be the sum of the CT HSIs with RAs applied, or arithmetically speaking:

$$\mathbf{HSI_{Model}} = \sum (\mathbf{CT\ HSI\ x\ RA})_X$$

where

CT HIS = Results of the CT HSI calculation,
X = Number of CTs associated with the model, and
RA = Relative area of each CT.

The final step was to multiply the HSI results against the habitat acres (i.e., CT acres associated with the model). The final results, referred to as HUs, quantified the quality and quantity of the baseline ecosystem conditions per community.

Step 8: MRGBER’s Goals, Objectives, Period of Analysis, and Target Years

In an attempt to generate quantifiable objectives for the study, the District began the process of establishing specific ecosystem restoration goals, and developed a series of performance measures to assess the success of the restoration designs. The process is ongoing and iterative, and is subject to change as lessons from the review process are incorporated into the overriding planning process.

Project goals

The primary goal of the study was to provide the necessary engineering, economic and environmental plans in a timely manner to establish viable ecosystem restoration projects that would restore the structure and function of the bosque, and be acceptable to the public, local sponsors and USACE (USACE 2002, 2003a, 2007, 2010). The MRGBER study’s objectives included:

1. Restore the native bosque communities while creating greater stand diversity in terms of stand age, size and composition within the bosque. This will be achieved by removing nonnative dominant stands and nonnative understory plants, and replanting with native plants. Likewise, replanting highly disturbed areas (burn sites, dumps) can provide additional bosque communities.
2. Promote bosque habitat heterogeneity by recreating pockets of new cottonwood and willow where root zones reach the shallow water table

3. Implement measures to reestablish fluvial processes in the bosque, including removal of non-functional jetty jacks, bank improvements, promote overbank flooding and low-flow / side channel creation
4. Create new wetland habitat while extending and enhancing quality aquatic habitat in existing wetlands
5. Prevent catastrophic fires in the bosque through the reduction of fuel loads identified as hazardous
6. Recreate hydraulic connections between the bosque and the river consistent with operational constraints
7. Protect and restore areas of potential habitat for listed species within the existing bosque
8. Develop and implement a long-term operations and maintenance plan, which incorporates long-term monitoring of proposed restoration features
9. Coordinate and integrate project implementation and monitoring with other, ongoing restoration and research efforts in the bosque;
10. Create opportunities for educational or interpretive features, while integrating recreational features that are compatible with ecosystem integrity
11. Engage the public in the restoration of the bosque ecosystem by encouraging input and involvement

The general approach to accomplish these goals was to formulate alternatives that offered the most ecosystem restoration for the least cost. The proposed restoration efforts would be designed to mimic historic, natural conditions that harvested water, trapped sediments, facilitated water absorption, and provided water to vegetation. Existing vegetation communities would be improved with supplemental plantings, invasive species control, and other best management practices and strategies (aka restoration/rehabilitation). With the restoration of the vegetation communities, habitat structure should be improved and there should be an increase in the number and diversity of wildlife species in the area. This approach to restoration — focused on restoration of community functions and processes via the rehabilitation of habitat and vegetation structure — would eventually lead to a more natural (i.e., sustainable) system.

Selection of the period of analysis and TYs

Given these goals and objectives, the District designated a “Period of Analysis” of 50 years for the MRGBER study, and asked the E-Team to develop a series of TYs within this 50-year setting to guide the projections of both Without-project and With-project activities. Six TYs were defined by the E-Team:

TY = “**0**” refers to the baseline condition, or the **2005** calendar year
TY = “**1**” refers to the last year of construction and planting activities, or the **2016** calendar year
TY = “**6**” was chosen to capture 5 full years of vegetative growth under the proposed With-project conditions (e.g., the **2021** calendar year)
TY = “**21**” was selected to capture 15 full years of vegetative growth under the With-project conditions (e.g., the **2036** calendar year)
TY = “**31**” was selected to capture 10 full years of vegetative growth under the With-project conditions (e.g., the **2046** calendar year)
TY = “**51**” was selected to capture 20 full years of vegetative growth under the With-project conditions (e.g., the **2066** calendar year)

Step 9: WOP Conditions for the MRGBER Study

To develop plans for a community or region, it becomes necessary to predict both the short-term and long-term future conditions of the environment (USACE 2000). Forecasting is undertaken to identify patterns in natural systems and human behavior, and to discover relationships among variables and systems, so that the timing, nature and magnitude of change in future conditions can be estimated. A judgment-based method, supported by the scientific and professional expertise of the evaluation team, is often relied upon to forecast the impacts and evaluate the effectiveness of proposed restoration plans, rate project performance, and determine many other important aspects of both WOP and WP conditions.

The WOP condition is universally regarded as a vital and important element of the evaluation (USACE 2000). No single element is more critical to the planning process than the prediction of the most likely future conditions anticipated for the study area if no action is taken as a result of the study. It is important to note that by definition the “No Action Alternative” in NEPA is the WOP condition that describes the future that society would have to forego if no action was taken. When formulating plans, NEPA regulations require that the No Action Alternative be considered – this requires that any action taken be more “in the public interest" than doing nothing. The WOP condition becomes the default recommendation.

The WOP descriptions must adequately describe the future (USACE 2000). Significant variables, elements, trends, systems and processes must be sufficiently described to support good decision-making. WOP descriptions must be rational. Forecasts must be based on appropriate methods, and professional standards must be applied to the use of those methods. Accuracy is an important element of a rational scenario. All future scenarios should be based on the assumption of rational behavior by future decision-makers. A good scenario must pass the test of making common sense. WOP conditions are not "before-and-after" comparisons. "Before-and-after" comparisons can overlook the causality that is important to effective plan evaluation. Conditions that concentrate on causality of existing conditions, and focus too narrowly on how existing conditions might change, fail to be future-oriented. WOP conditions are not mere extensions of existing conditions, and should be oriented toward comparing alternative future scenarios. There should never be deliberately misleading information in a scenario, nor should any important information ever be deliberately withheld. An honest scenario would point out weaknesses and soft spots in the analysis, identifying the implications of these "faults." Honesty also implies a sincere effort to convey the full implications of the scenario. Honesty requires that significant differences in the future scenario are completely described as alternate WOP conditions. The WOP condition must be inclusive in the sense that it is subjected to rigorous review and comment as part of the public participation process (and throughout the coordination and review process). Because the WOP condition occupies such a critical role in the planning process, it is essential that it be developed "in the open," and subjected to the scrutiny of all project stakeholders, before the project proceeds too far. In some cases, this will simply mean that data/information receive an unbiased thorough technical review. In other cases, where judgmental or technological changes are being considered, the review and coordination may have a structured part in the public participation process.

Most federal agencies use annualization as a means to display benefits and costs, and ecosystem restoration analyses should provide data that can be directly compared to the traditional benefit:cost analyses typically portrayed in standard evaluations of this nature. Federal projects are evaluated over the period of time that is referred to as the "life of the project" and is defined as that period of time between the times that the project becomes operational and the end of the project life, as dictated by the construction effort or lead agency. However, in many cases, gains or losses in habitat may occur before the project becomes operational and these changes should be considered in the assessment. Examples of such changes include construction impacts, implementation and compensation plans and/or other land-use impacts. Ecosystem restoration analyses incorporate these changes into evaluations by using a "period of analysis" that includes pre-start impacts. However, if no pre-start changes are evident, then the "life of the project" and the "period of analysis" are the same.

In HEP, HUs are annualized by summing HUs across all years in the period of analysis and dividing the total (cumulative HUs) by the number of years in the life of the project.[1] In this manner, pre-start changes can be considered in the analysis. The results of this calculation are referred to as Average Annual Habitat Units (AAHUs), and can be expressed mathematically in the following fashion:

Annualized Units =

$$\sum \text{Cumulative Units} \div \text{Number of years in the life of the project}$$

where:

$$Cumulative\ Units = \sum (T_2 - T_1)\left[\frac{(A_1 I_1 + A_2 I_2)}{3} + \frac{(A_2 I_1 + A_1 I_2)}{6}\right]$$

and where:

T_1 = First Target Year time interval
T_2 = Second Target Year time interval
A_1 = Ecosystem area at beginning of T_1
A_2 = Ecosystem area at end of T_2
I_1 = Index score at beginning of T_1
I_2 = Index score at end of T_2

[1] This same approach was used to annualize the outputs from the habitat diversity analysis – in that instance Average Annual Habitat Diversity Units or AAHDUs were calculated.

For those interested in the derivation of the annualization formula, cumulative units are computed by summing the area under a plot of units versus time [pers. comm., Adrian Farmer, U.S. Geological Survey (USGS), June 18, 2007]. This is equivalent to mathematical integration of the unit relationship over time, or

$$Cumulative\_Units = \int_0^T U\ dt$$

But U = A x I
where:

A = Area
I = Quality index.

Also, over any time interval of length T (= $T_2 - T_1$) within which A and I either change linearly or not at all, the values of A and I are given by:

$$A = A_1 + m_1 t$$

$$I = I_1 + m_2 t$$

where :

t = time
A_1 = the area at the beginning of the time interval
I_1 = the quality index at the beginning of the time interval
m_1 = the rate of change of area with time
m_2 = the rate of change of quality with time

Thus,

$$\int_0^T U\ dt \equiv \int_0^T (A_1 + m_1 t)(I_1 + m_2 t)dt$$
$$\equiv \int_0^T A_1 I_1\ dt + \int_0^T m_1 I_1 t\ dt + \int_0^T m_2 A_1 t\ dt + \int_0^T m_1 m_2 t^2\ dt$$
$$\equiv A_1 I_1 T + \frac{m_1 I_1 T^2}{2} + \frac{m_2 A_1 T^2}{2} + \frac{m_1 m_2 T^3}{3}$$

Substitute the following equations for the slopes, m_1 and m_2

$$m_1 = \frac{A_2 - A_1}{T}$$
$$m_2 = \frac{I_2 - I_1}{T}$$

into the above formula to generate the following:

$$\int_0^T U\ dt \equiv A_1 I_1 T + \frac{(A_2 - A_1) I_1 T}{2} + \frac{(I_2 - I_1) A_1 T}{2} + \frac{(A_2 - A_1)(I_2 - I_2) T}{3}$$

Collecting terms, substituting (T_2 –T_1) for T, and simplifying yields:

$$\int_0^T U\ dt \equiv (T_2 - T_1)\left[\left(\frac{A_1 I_1 + A_2 I_2}{3}\right) + \left(\frac{A_2 I_1 + A_1 I_2}{6}\right)\right]$$

This formula is applied to the time intervals between TYs. The formula was developed to calculate cumulative HUs when either HSIs or areas (or both) change over a time interval. The rate of change of HUs may be linear (either HSIs or areas change over the time interval) – the formula will work in either case. The shaded area in the curve below represents the cumulative HUs for all years in the period of analysis, and is calculated by summing the products of HSIs and areas of available communities for all years in the period of analysis (Figure 35).

The assumptions that went into the projection of future conditions at the MRGBER study under the "No Action Alternatives" for the proposed pilot studies are reported in *Chapter 4* of this report. Results, in terms of annualized units as well as expectations of change in terms of qualities and acres for the study, are fully documented therein.

Step 10: WP Conditions for the MRGBER study

Between 2008 and the present, the E-Team participated in several workshops to present and modify alternatives designs developed by the District for the NER plan. The District (with assistance from ERDC-EL) was responsible for developing draft alternative matrices, generating acreage and quality trends (by variable and cover type) for the affected ecosystems and developing documentation (maps and narrative descriptions) for the

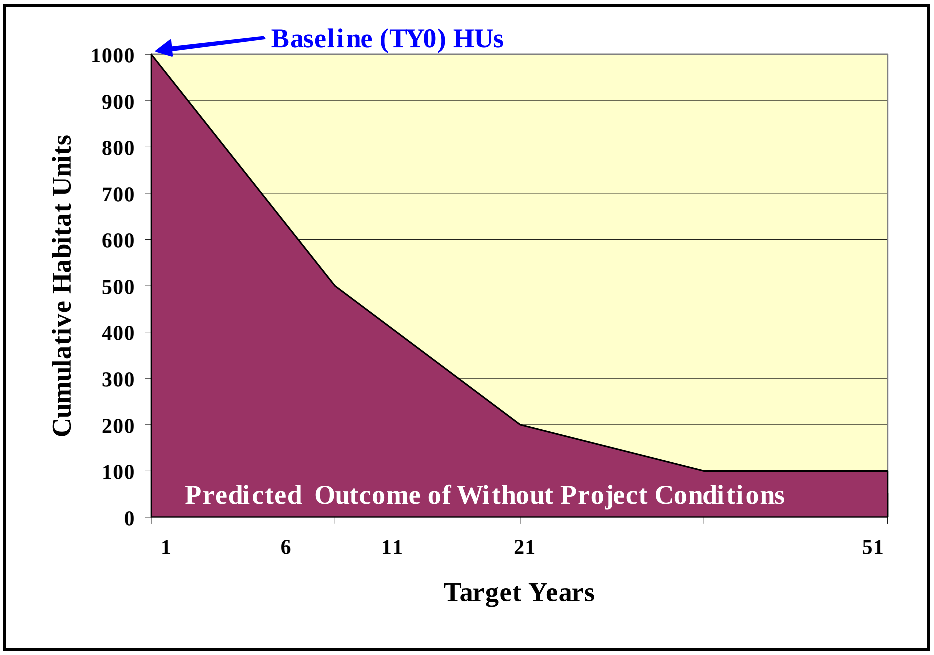

Figure 35. Example of cumulative HU availability under a Without-project scenario.

proposals. The E-Team reviewed these and standardized the proposed trends to some extent, and suggested additional alternatives where reasonable. Alternatives were dropped from the analysis if their approaches were too costly, if their designs were incongruous with the overall "avoidance/minimization/mitigation concept," if their constructed footprints were impossible to achieve because of conflicting relationships or if the results were thought to biologically unproductive. Various design and operation/maintenance activities were discussed in detail, and the outcomes of each were incorporated into the forecasting. The results of this effort are presented in *Chapter 5* of this report.

Step 11: Reporting the Results of the Analyses

The success of any evaluation lies in the planner's ability to discuss the assessment strategies and findings with the public. Reporting simply refers to communicating the methodologies and results of the habitat assessment in a clear and concise manner to the reader. Underlying the HEP process is the concept of "repeatability." To ensure that the assessment is reasonable and reliable, the reader should be able to follow the descriptions of the approach and the application, and repeat the analyses just as the planner did. To ensure the repeatability aspects of the assessments, the planner is advised to document, to the fullest extent, the evaluation in its entirety. This is done most often through an assessment report medium. Typically, depending on the type of planning effort undertaken, there are a series of approximately six or seven chapters provided in every assessment report: *Introduction, Methods, Baseline Results, Without-Project Results, and With-Project Results,* and *Summary/Conclusions*. In addition, the report typically carries a *References* section and an appendix documenting the models used in the assessment. Further reporting of the assessment results can include, but is not limited to, the production of interactive graphics (maps, graphs, tables, etc.) that visually depict the conditions (both Without- and With-project) of the study area under evaluation. In HEP, it is important to document the results of habitat units, quality (indices) and quantity (acres). In addition, any factors that significantly affect the outcome of the study (e.g., minutes of team meetings, data extrapolations, etc.) should be presented.

Introduction to the Cost Analysis Process

Between 1986 and 1987, the Headquarters Office of USACE provided policy directing districts to perform a type of cost analysis referred to as Incremental Cost Analysis (ICA) for all feasibility-level studies. The required ICA is, in effect, a combination of both a Cost-Effectiveness Analysis (CEA) and ICA. Together, the CEA/ICA evaluations combine the environmental outputs of various alternative designs with their associated costs, and systematically compare each alternative on the basis of productivity. Cost-effectiveness analyses focus on the identification of the least cost alternatives and the elimination of the economically irrational alternatives (e.g., alternative designs which are inefficient and ineffective). By definition, inefficient alternative designs produce similar environmental returns at greater expense. Ineffective alternative designs result in reduced levels of output for the same or greater costs. The incremental cost analysis is employed to reveal and interpret changes in costs for increasing levels of environmental outputs.

In 1990, USACE issued Engineer Regulation 1105-2-100 (USACE 1990) directing planners, economists, and resource managers to conduct CEA/ICA for all recommended ecosystem restoration and mitigation plans. Later, in 1991, USACE produced Policy Guidance Letter Number 24 that extended the use of cost analysis to projects that restored fish and wildlife habitat resources (USACE 1991). In the USACE EC 1105-2-210, the incorporation of cost analysis was declared “fundamental” to project formulation and evaluation (USACE 1995). To facilitate the inclusion of these basic economic concepts into the decision-making process, USACE published two reports detailing the procedures to complete both incremental and cost-effective analysis (Orth 1994; Robinson, Hansen, and Orth 1995). Based on these reports, there were nine steps that should be completed to evaluate alternative designs based on CEA/ICA. These were as follows:

A. Formulate all possible combinations of alternative designs by:

1. displaying all outputs and costs;
2. identifying filters, which restrict the combination of alternative designs; and
3. calculating outputs and costs of combinations.

B. Complete a CEA by:

4. eliminating economically inefficient alternative designs; and
5. eliminating economically ineffective alternative designs.

C. Develop an incremental cost curve by:

6. calculating the average costs; and
7. recalculating average costs for additional outputs.

D. Complete an ICA by:

8. calculating incremental costs; and
9. comparing successive outputs and incremental costs.

In ICA terminology, an alternative design is considered the With-project condition (i.e., "Build A Dam," "Develop a Wetland," "Restore the Riparian Zone," "Management Plan A," etc.). Under an alternative design, a series of scales (i.e., variations) can be defined as modifications or derivations of the initial With-project conditions (i.e., "Develop 10 acres of Low Quality Wetlands," "Develop 1,000 acres of High Quality Wetlands," etc.). Often, these scales are based on differences in intensity of similar treatments and, therefore, can be "lumped" under an alternative design class or category. During the first steps of CEA/ICA, all possible combinations of alternative designs and their scales are formed. As a general rule, intra-scale combinations (i.e., combinations of variations within a single alternative design) are not allowed - these activities would occupy the same space and time.

In most instances, CEA/ICA results are displayed in tables, scatter plots, and/or bar charts. These illustrative products assist decision makers in the progressive comparisons of alternative design costs, and the increasing levels of environmental outputs. Before a user makes a decision based upon the outputs generated by the CEA/ICA, he or she must determine whether cost thresholds exist that limit production of the next level of environmental output (i.e., cost affordability). In addition, factors such as curve anomalies (i.e., abrupt changes in the incremental curve), output targets, and output thresholds can influence the selection of alternative design. *Chapter 6* of this report details the CEA/ICA analyses conducted for the MRGBER study's restoration plans. Specifics on cost generation for the proposed alternative mitigation designs, as well as the cost-benefit analysis for the NER plan can be found in the feasibility report (USACE 2010).

3 Baseline Analysis and Results

The baseline conditions for the MRGBER study area were determined on a landscape-level scale on a reach-by-reach basis. Below we present details regarding both the quantity (acreage) and quality (variables) data used in the assessment to characterize the baseline condition of the watershed at this scale.

Acreage Inputs

For the baseline analysis, the 5,321 acres were mapped and classified (i.e., cover typed) inside the study area boundaries. These, in turn, were divided amongst the reaches for the analysis (Table 4 and Figure 36).

Variable Inputs

Field data collected between 2003 and 2008 was compiled on a reach-by-reach basis. Data for each variable per cover type were recorded and the variable means/modes were calculated to generate watershed baseline indices on a reach-by-reach basis. Twenty-four variables were measured across the five reaches following the prescribed sampling protocols detailed in Burks-Copes and Webb 2009.[1]

Baseline Outputs - Indices and Units

The results of the baseline ecosystem assessments for the reaches are summarized below. HSIs captured the quality of the acreage within the reach for the bosque community index model. Units (i.e., HUs) took this quality and applied it to the governing area through multiplication (Quality X Quantity = Units) for both HEP analyses. Interpretations of these findings were generalized in the following manner (Table 5).

Bosque Community (HSI) Modeling Results

In most instances, the individual component indices (i.e., Life Requisite Suitability Indices or LRSIs) and composite HSIs scored in the mid-range of values (<0.5) indicating only a moderate level of functionality in the

[1] Contact Ms. Ondrea Hummel (Table 1) in the Albuquerque District to obtain copies of the original field data collection sheets and GIS shapefiles.

Table 4. Baseline acres classified and assigned to the five eco-reaches in the MRGBER study.

Code	Description	Reaches					Total Project Area
		1	2	3	4	5	
TYPE_1	H&O Class I not treated - MATURE RIPARIAN FOREST (Over 40' – closed canopy, established understory).	414	17	99	110	90	730
TYPE_2T	H&O Class II treated - MATURE RIPARIAN FOREST (Over 40' – nearly closed canopy, limited understory).	239	167	64	433	309	1,212
TYPE_2U	H&O Class II not treated - MATURE RIPARIAN FOREST (Over 40' – nearly closed canopy, limited understory).	27	22	41	11	68	169
TYPE_3	H&O Class III not treated - INTERMEDIATE AGED RIPARIAN WOODLAND (Closed canopy, lots of salt cedar and Russian olive).	65	42	51	56	7	221
TYPE_4T	H&O Class IV treated - INTERMEDIATE AGED RIPARIAN WOODLAND/SAVANNAH (Broken canopy, mostly grass understory).	93	83	85	50	0	311
TYPE_4U	H&O Class IV not treated - INTERMEDIATE AGED RIPARIAN WOODLAND/SAVANNAH (Broken canopy, mostly grass understory).	20	15	5	0	32	72
TYPE_5	H&O Class V shrublands not treated - RIPARIAN SHRUB (no tall trees).	135	206	82	58	98	579
TYPE_6T	H&O Class VI dry (grass) meadow treated - SHORT SHRUBS/GRASSES – Open areas.	6	7	64	2	0	79
TYPE_6U	H&O Class VI dry (grass) meadow not treated - SHORT SHRUBS/GRASSES – Open areas.	91	2	7	6	12	118
TYPE_6W	H&O Class VI wet meadow not treated - SHORT SHRUBS/GRASSES – Open areas and Marsh.	0	0	4	0	0	4
OPENLAND	Open Areas	51	49	36	57	38	231
OPENWATER	Open Water	392	290	229	363	262	1,536
ISLANDS	Islands	0	10	3	9	15	37
UTILITY	Utility Areas	14	8	0	0	0	22
TOTALS:		1,547	918	770	1,155	931	5,321

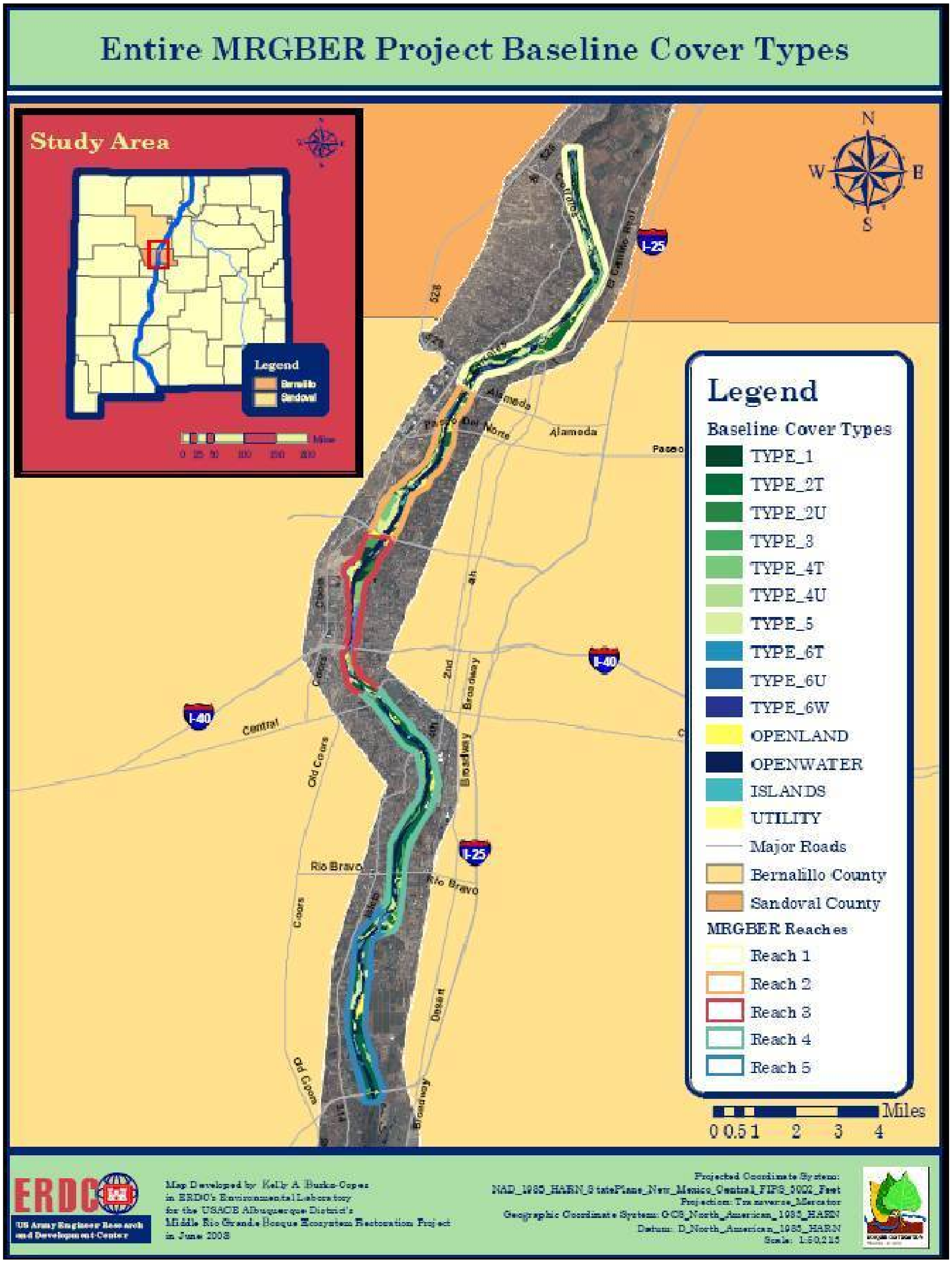

Figure 36. Map of the baseline cover types for the MRGBER study.

Table 5. Interpretation of index scores resulting from HEP assessments.

Index 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 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 functionality
0.3 to 0.39	Fair to moderately low functionality
0.4 to 0 .49	Moderate functionality
0.5 to 0.59	Moderately high functionality
0.6 to .79	High or good functionality
0.8 to0.99	Very high or excellent functionality
1.0	Optimum functionality - the community performs functions at the highest level - the same level as reference standard settings

study area (Table 6 and Figure 37).[1] The highest functioning reach was Reach 1 (HSI = 0.50). This was to be expected – the last vestiges of undisturbed bosque are found in this area. Not surprisingly, Reaches 2 and 3 generated the lowest HSI scores (HSIs ranged from 0.40 to 0.41). Located in the heart of Albuquerque, these areas are highly urbanized and experience extreme levels of disturbance and invasive encroachment. These areas were also targeted for moderate to heavy fire prevention, and as such, their understories had incurred significant impacts.

At baseline, 3,495 acres of bosque habitat were associated with the model across the entire project area (Table 6 and Figure 38). Reaches 1 and 4 held the largest numbers of forested acres (1,090 and 726 acres respectively). Reach 3 had the smallest bosque holdings (just 502 acres). Overall, the study area generated 1,575 habitat units across all reaches. The baseline HUs within the Reaches ranged from 225 units in Reach 2 to 541 units in Reach 1 (Table 6 and Figure 39). In HEP, the maximum HSI score possible was 1.0. Given the total number of applicable bosque acres at baseline (i.e., 3,495 acres), one could derive the optimal conditions and outputs by multiplying the quantity and quality to generate the highest possible outcome (3,495 acres x 1.0 HSI = 3,495 units). By comparing the actual situation to this optimum, the E-Team could determine at what level the ecosystem was functioning. In this case, the watershed was operating at

[1] Data are available upon request - contact the District POC, Ondrea Hummel (Table 1).

Table 6. Baseline tabular HSI results for the bosque community.

Reach Name	HSI Model Component	Life Requisite Suitability Index (LRSI)	Habitat Suitability Index (HSI)	Applicable Acres	Baseline Habitat Units (HUs)
Reach 1	RIP-BIOINTEG	0.41	0.50	1,090	541
	RIP-SPATIAL	0.76			
	RIP-HYDRO	0.32			
Reach 2	RIP-BIOINTEG	0.39	0.40	561	225
	RIP-SPATIAL	0.54			
	RIP-HYDRO	0.28			
Reach 3	RIP-BIOINTEG	0.38	0.41	502	206
	RIP-SPATIAL	0.59			
	RIP-HYDRO	0.26			
Reach 4	RIP-BIOINTEG	0.41	0.42	726	307
	RIP-SPATIAL	0.53			
	RIP-HYDRO	0.33			
Reach 5	RIP-BIOINTEG	0.37	0.48	616	296
	RIP-SPATIAL	0.75			
	RIP-HYDRO	0.33			

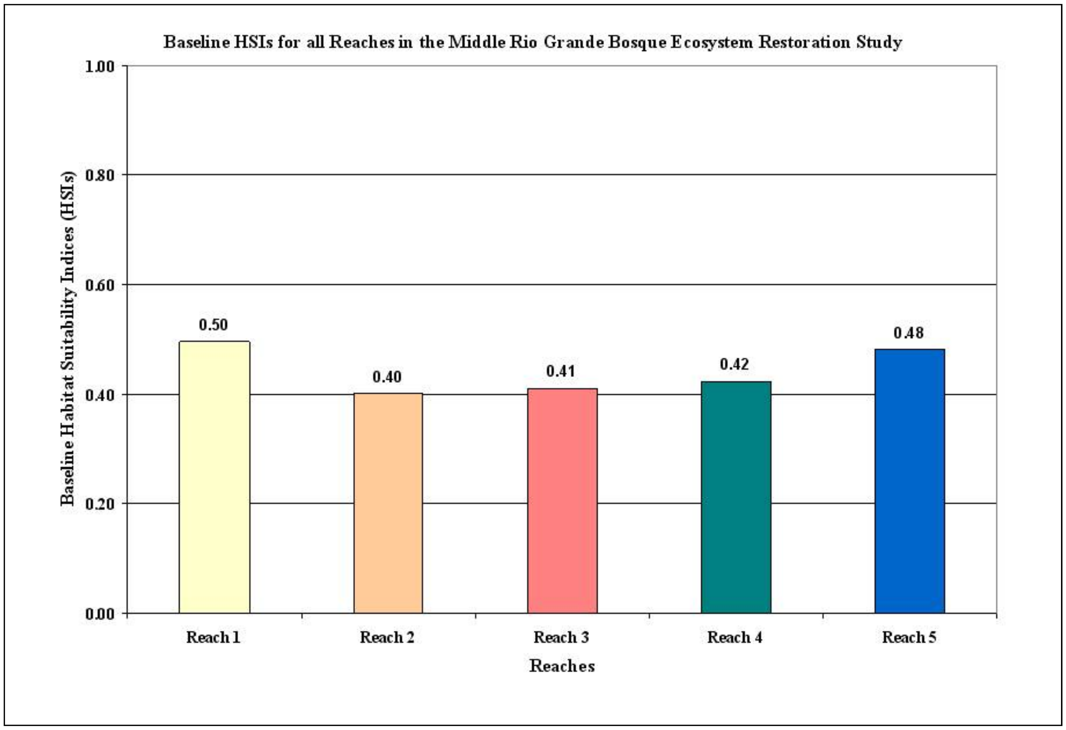

Figure 37. Baseline HSI results for the MRGBER study based on the bosque community index model.

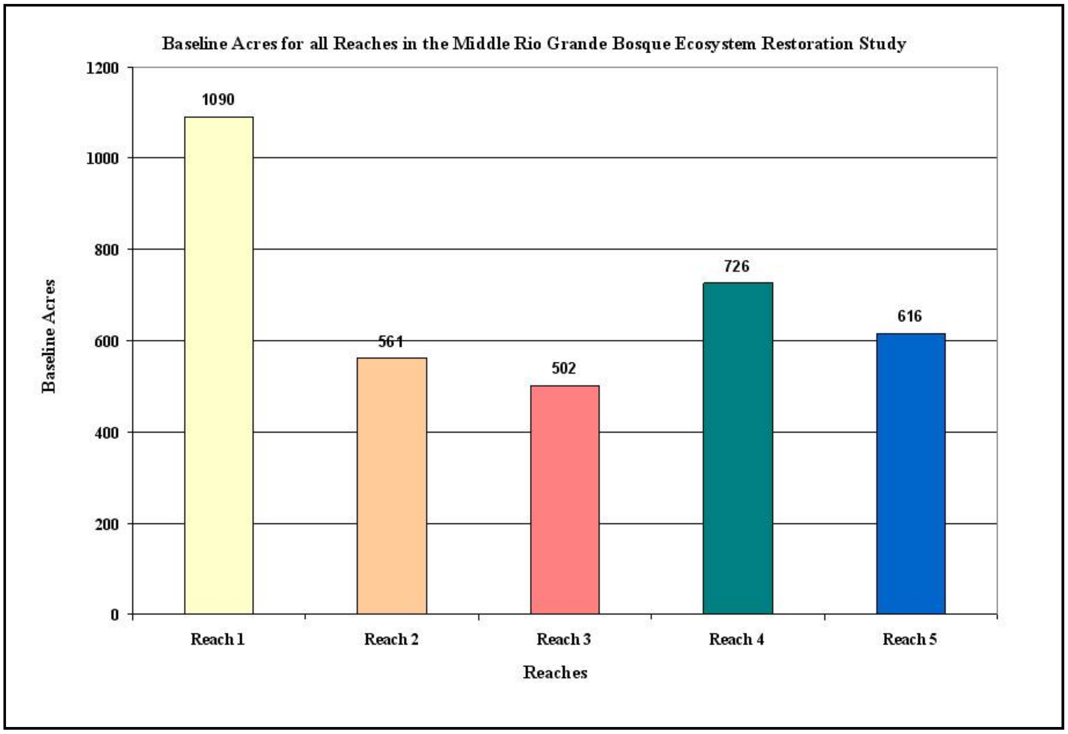

Figure 38. Baseline acre distributions for the MRGBER study based on the bosque community index model.

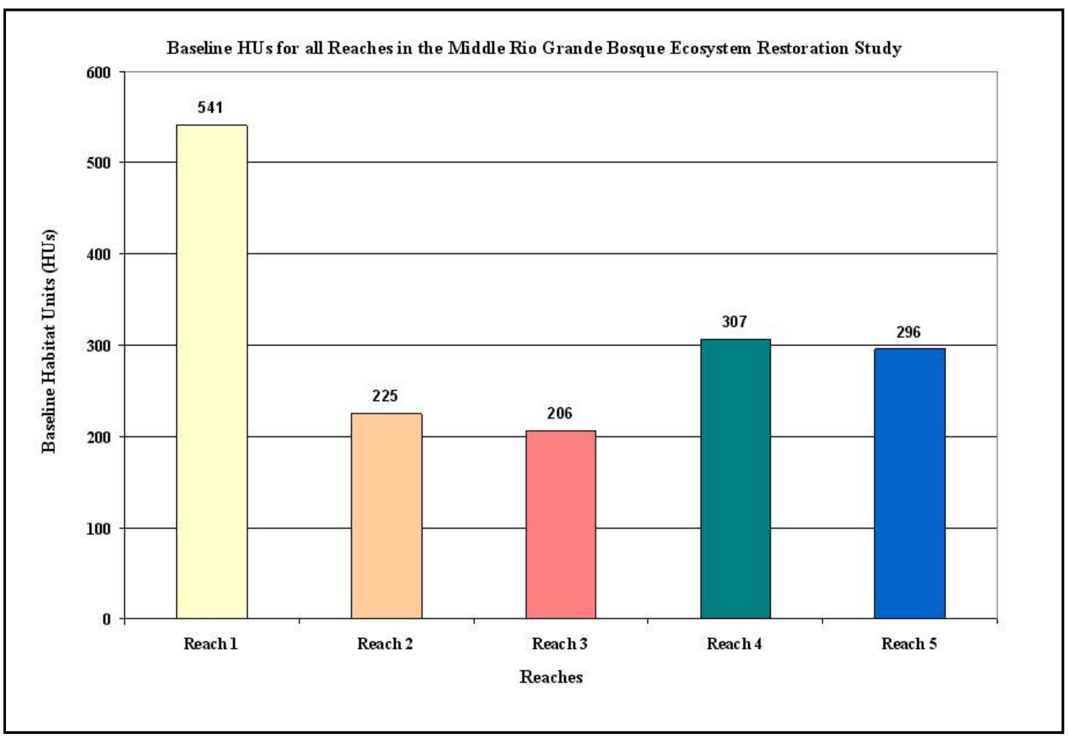

Figure 39. Baseline HU results for the MRGBER study based on the bosque community index model.

approximately 45 percent of its potential habitat suitability (i.e., total habitat outputs across all reaches ÷ possible outputs). Using this same approach, the E-team considered the operational functionality of the five reaches. The individual performances ranged from 40 percent (Reach 2) to 50 percent in Reach 1. Clearly, there were opportunities for improvements – in other words, all the reaches were prime candidates for restoration/ rehabilitation activities in terms of the community structure and functionality.

Baseline Results - Implications

The implications of these 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 bosque ecosystems along the Middle Rio Grande point to an overall decline in ecosystem integrity (i.e., health, biodiversity, stability, sustainability, naturalness, wildness, and beauty) – a finding this model can now quantify (less than optimal HSI, values (to some extent) in all reaches). Furthermore, the results indicate an opportunity to redress losses. There is great potential to restore sustainable bosque communities therein.

4 Without-project (WOP) Analysis and Results

It was the general consensus of the E-Team that the future Without-project conditions of the study area (and the surrounding community) were certain to reflect some losses in ecosystem function (i.e., quality) and presence (i.e., quantity) when faced with the pressures of continued hydrologic alterations (i.e., continued disconnection from the hydrologic pulse perpetuating the recurring life cycle of the bosque's cottonwood community), increased population growth (and urban sprawl), increased risks of catastrophic fires, and escalated invasive species encroachment. In essence, the future bosque was assumed to have a very different character than the current system. The gallery forest was likely to disappear and be replaced with a more shrub-like-savanna character dominated by non-native species. The E-Team addressed these issues in several workshops over the course of the study, and developed trends to capture both the changes in quantity and quality to generate a "No Action" scenario for the study. Numerous assumptions were used to support the projected values - these are presented below.

Predicted WOP Acreage Trends (Quantity)

For the E-Team, the key to quantifying the Without Project conditions for the bosque was to capture the direct linkages between the hydrology and the vegetative community itself. The first step was to recognize that previous water projects on the Middle Rio Grande had significantly altered the functioning of the system and produced an incised river channel with elevated overbanks disconnected from the potential flooding regime that perpetuated the bosque's ability to recruit and persist (USACE 2002, 2003a, 2007, 2010 and references therein). As such, the E-Team acknowledged that this disconnect was likely to continue under the "No Action" scenario.

The E-Team therefore made the assumption that the bosque's riparian vegetation would remain isolated in the study area and would eventually succeed to a nonnative bosque condition dominated by such species as salt cedar, Russian olive, Siberian elm, white mulberry, and tree of heaven. The team further assumed that ongoing vegetation management techniques such as understory clearing and planting of native species would temporarily “reset” patches of bosque to more natural structural states, but that gradual replacement by non-native species was inevitable. Eventual conversion of the entire bosque to a nonnative ecosystem uninfluenced by hydrologic processes, with fire as the new main disturbance mechanism, would diminish the overall productivity of the system and result in a total loss of the bosque’s current character.

To capture the future conditions of the dynamic system, a somewhat intricate rule-based cycle was devised by the E-Team – one in which mature cover types would die back, and shrublands and savannas would become more pervasive. In an effort to capture these significant vegetative changes in the MRGBER study area, the E-Team created spreadsheets to capture acreages changes per cover type on a TY basis – the overall trends are presented in (Table 7) below.

Table 7. WOP acre projections for MRGBER study area eco-reaches.

	Target Year					
	2005	2016	2021	2036	2046	2066
Code	TY0	TY1	TY6	TY21	TY31	TY51
TYPE_1	730	642	602	482	402	241
TYPE_2T	1,212	1,048	974	750	601	303
TYPE_2U	169	158	153	138	128	108
TYPE_3	221	189	175	131	102	44
TYPE_4T	311	266	246	185	144	63
TYPE_4U	72	156	194	308	384	537
TYPE_5	579	712	773	954	1,075	1,318
TYPE_6T	79	79	79	79	79	79
TYPE_6U	118	241	297	464	575	799
TYPE_6W	4	4	4	4	4	4
OPENLAND	231	231	231	231	231	231
OPENWATER	1,536	1,536	1,536	1,536	1,536	1,536
ISLANDS	37	37	37	37	37	37
UTILITY	22	22	22	22	22	22
	5,321	5,321	5,321	5,321	5,321	5,321

As the table indicates, 1,884 acres of mature forest cover types (Types 1,2U/T,3, and4T) are expected to convert to savannas, shrublands and meadows (Types 4U, 5 and 6U) (Figure 40).

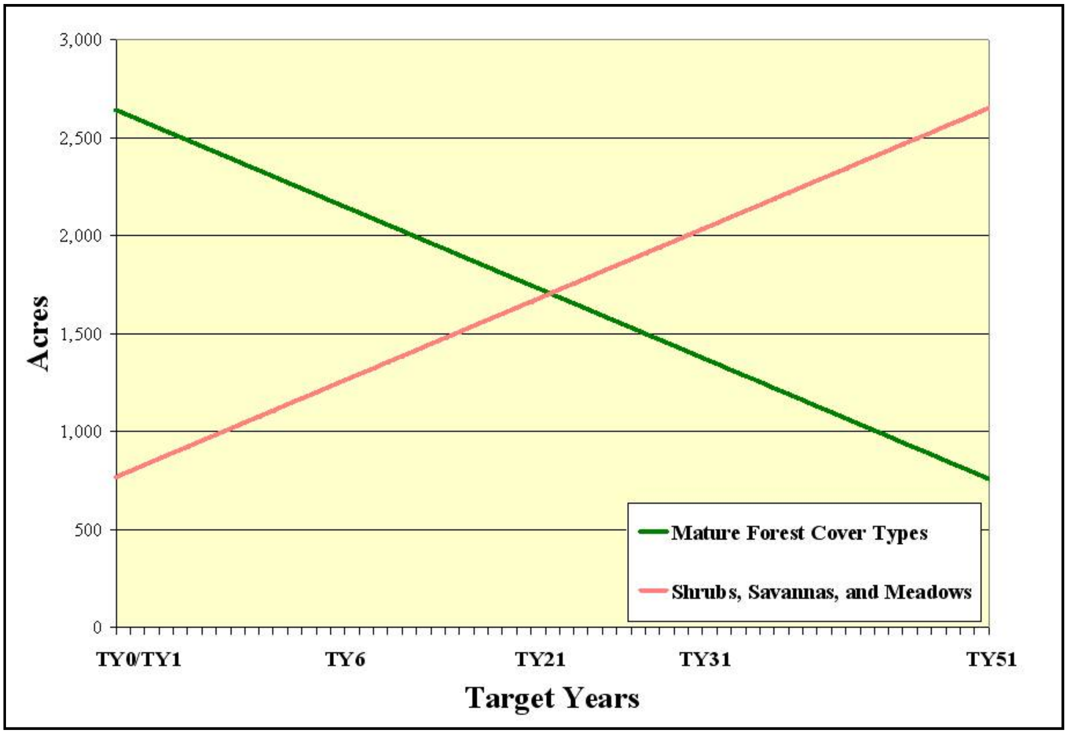

Figure 40. Successional trend hypothesized by the E-Team to correspond with the disconnection between the hydrology and the bosque under the "No Action" scenario.

An existing narrow band of riparian habitat disconnected from the river would continue to exist (of Types 1, 2U/T, 3 and 4T – 759 acres would remain), but would decline over time to a significant extent. The loss of terrestrial and wetland communities that serve as habitat for a myriad of wildlife species is significant.[1]

Predicted WOP Variable Trends (Quality)

The "No Action" alternative assumed the MRGBER study area's current configuration would be maintained. As such, and because of the predicted hydrologic disconnect continuing to influence the vegetative composition of the bosque, community integrity (e.g., habitat suitability and community function) would continue to decline. Below we detail the specific trends of the model.

[1] For summaries of the acreage data generated for the Without-project conditions, contact the District POC, Ondrea Hummel (Table 1).

Bosque Community (HSI) WOP Trends

To simplify matters to some extent, the E-Team made the decision to hold all variables in the Water and Biota components of the bosque community index (HSI) model equal to the baseline conditions for all existing habitat types (Types 1-6) with three exceptions.[1] First, any variables designed to capture invasive species encroachment (i.e., "indicators of undesirable forbs, grasses, and herbs") were altered to reflect declining conditions in the study area. Second, onsite landscape-scale parameters (i.e., patch size and distance between patches) were projected based on direct correlations to the Without-project acreage trends. In other words, declining trends in Type 1 forests dictated a corresponding decline in mean patch size and an increase in distances between Type 1 patches. And third, although the study area was designated as "lands inside the flood control levees constructed along the banks of the Rio Grande," the adjacent land use on the backside of these levees was identified as a critical contributor to the overall health and integrity of the system. Review of the projected population growth trends of the nearest cities/towns adjacent to the MRGBER study area over then next ~50 years was extremely informative (Table 8).[2]

Table 8. Projected population growth for a few of the towns/cities surrounding the MRGBER study area.

County	City	1990	2010	2030	2050	2070
Bernalillo	Albuquerque	386,988	510,226	633,464	756,702	879,940
Sandoval	Rio Rancho	32,551	71,473	110,395	149,317	188,239
Sandoval	Corrales	5,503	7,975	10,447	12,919	15,391

Assuming that the predicted population growth would necessitate land use conversion and infrastructure development, and that those lands closest to the urban centers would be especially vulnerable to conversion over the next 50 years, ERDC-EL (with oversight from the E-Team) developed a rule-

[1] The implications of this strategy are two-fold. First, these trends may not be entirely accurate – they may in fact underestimate the loss of quality experienced under the No Action scenario. And consequently, any proposed restoration features might underestimate the lift attained with project designs. However, the standardization of these trends to this extent has reduced the amount of variability in the data, and reduced the potential for data entry errors, thus implementing a level of quality control on the data. Given that the future is a relatively unknown entity, the E-Team felt that this strategy was a reasonable approach, and the projections could be revisited relatively easily in the event that monitoring and adaptive management provided real-time answers to the question "What does it look like?" in the future.

[2] Population data was provided by the U.S. Census Bureau (http://quickfacts.census.gov/qfd/states/35000lk.html) for the cities of Albuquerque, Rio Rancho and Corrales and were in turn used as the basis for projecting future population trends in a linear fashion.

based urban growth technique to predict these landuse conversions over time. In essence, the approach required that all areas within 2-km of the levees be mapped and categorized as either urban (residential, commercial, industrial), non-urban (agriculturally-based lands such as crops and pastures), or open space (natural areas). These areas were then subjected to urban sprawl pressures (land use conversion) on a TY-by-TY basis. Assuming the growth would move outward in evenly spaced, concentric rings from the edge of the urban polygons (Figure 41), and that agricultural and natural areas alike would be consumed in this expansion (without preference), the E-Team was able to predict the changes in adjacent landuses outside the levees over the life of the project (aka period of analysis) (Figure 42).

This information was exported to a spreadsheet, processed and reclassified in a manner conducive to index application. This concluded the WOP projection trend development for the HSI modeling exercise.[1]

WOP Results

The changes predicted above led to slight declines in projected ecosystem integrity across the study area. Below, we detail these in terms of declines in quantity and quality captured in annualized outputs for the bosque community.

WOP Quality

Based on the findings, the final outputs for the study indicate a relative decline in functionality (and integrity) over the 50-year life of the project (Table 9).

Under the current forecasted Without-project condition, indices will drop well below the recoverable limit. The final HSI scores ranged from 0.34 to 0.38. These results indicate the communities will either cease to exist entirely, or remain as fragmented pockets that have lost a great deal of functionality. By 2066 (TY51), the baseline indices fell well below acceptable standards. In the end, most of the reach scores were well below the 0.5 index midpoint (fair to moderate functionality), which suggests wildlife would abandon the area, and vegetative communities would decline well beyond the level from which they could recover on their own. When reviewed across time, and against one another, these changes are readily apparent (Figure 43).

[1] For electronic summaries of the Without-project data projections generated by the E-Team, contact Ondrea Hummel in the District (Table 1).

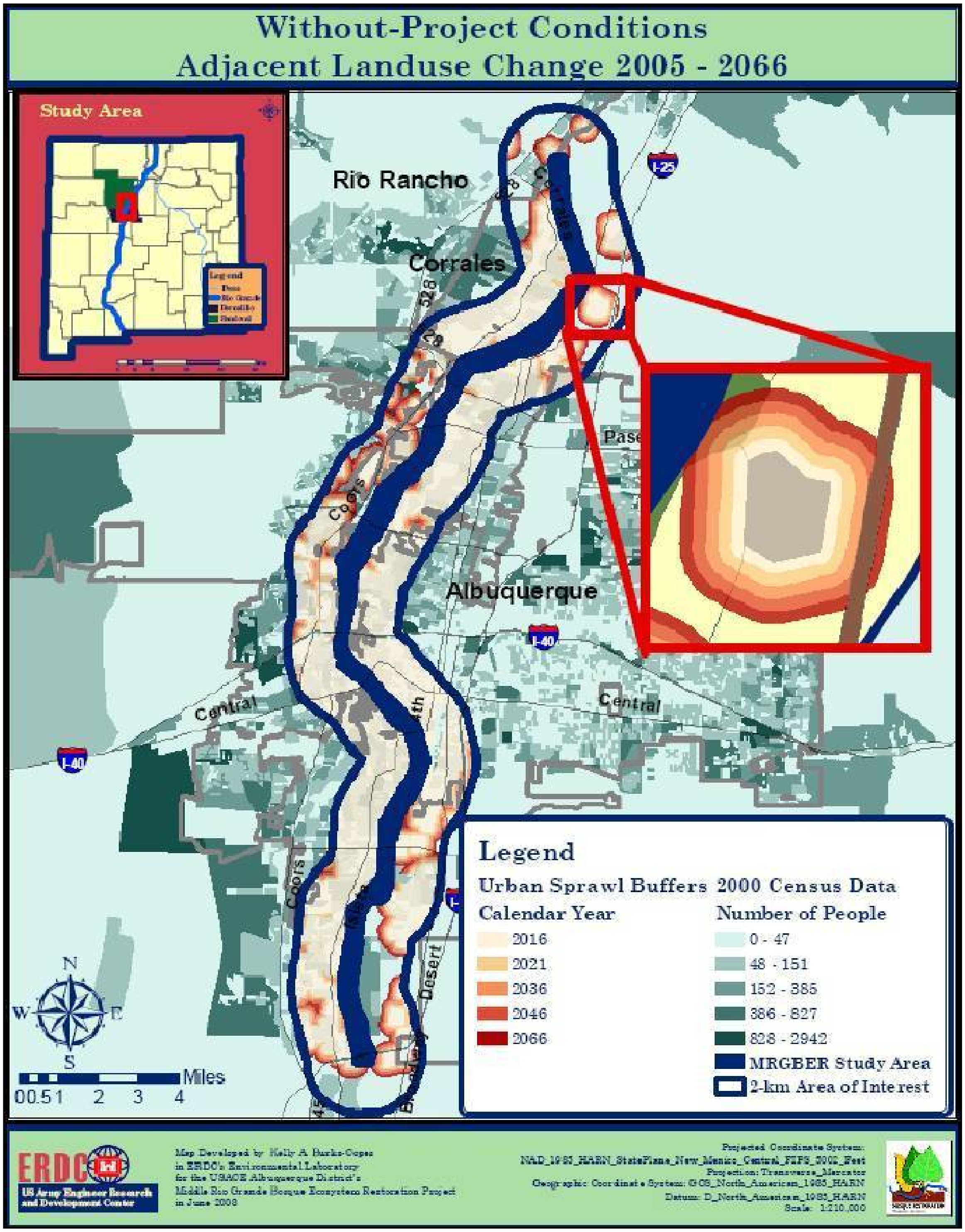

Figure 41. Using concentric buffering rings around the urban centers allowed the E-Team to predict the potential landuse conversions expected as the cities and towns surrounding the study area expanded in the future.

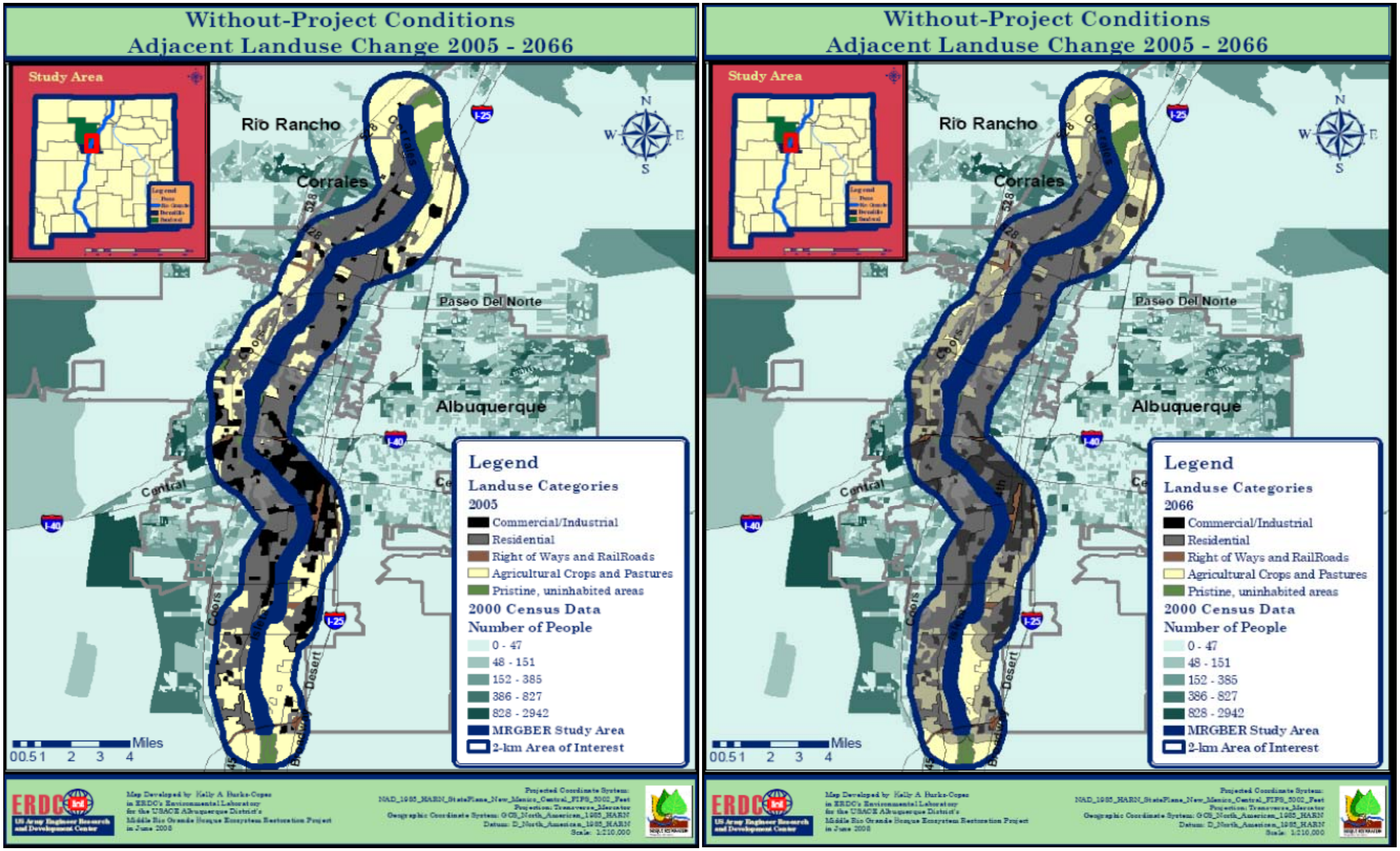

Figure 42. Using the urban sprawl technique, the E-Team could make predictions about the level of urban sprawl outside the levees and relate this to the level of disturbance affecting the bosque inside the levees. On the left, the 2005 landuse classification is portrayed prior to urban sprawl simulation. On the right, the aftermath of urban sprawl conversion indicates massive conversion of agricultural lands and uninhabited areas to urban communities.[1]

[1] To review the interim target year maps depicting the urban sprawl projected for the MRGBER study, contact Ondrea Hummel in the Albuquerque District office (Table 1).

Table 4. Projected WOP results from the HEP analyses for the MRGBER study under the WOP scenario.

Bosque Community HSI Model					
Reach	Final WOP HSI	TY 51 Acres	AAHUs	Net Change in HSIs (TY51-TY0)	Net Change in Acres (TY51-TY0)
Reach 1	0.35	1,090	426	-0.14	0
Reach 2	0.38	561	218	-0.02	0
Reach 3	0.35	502	187	-0.06	0
Reach 4	0.38	726	287	-0.04	0
Reach 5	0.34	616	235	-0.14	0

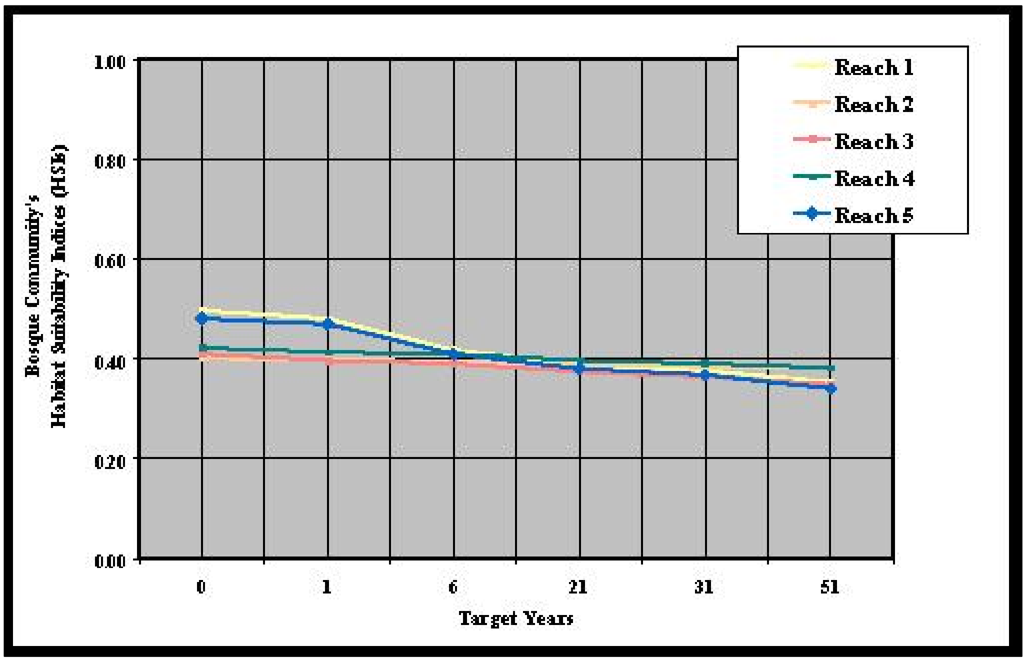

Figure 43. Cumulative changes in HSI under the WOP scenario.

WOP Quantity

At baseline, 5,321 acres were associated with the bosque model. By 2066 (TY51) 70% of the gallery forest (Types 1, 2U/T, 3 and 4T – 1,884 acres) had converted to early non-forested habitat types (Types 4U, 5, and 6U) (Table 10).

WOP Outputs (Quality x Quantity)

When the loss of quality described above was combined with the resultant loss in wetland acreage across the study area, projected future conditions were relatively low (Figure 44).

Table 10. Predicted losses for the MRGBER study area under the WOP scenario.

Code	Target Year						Net Change
	2005	2016	2021	2036	2046	2066	
	TY0	TY1	TY6	TY21	TY31	TY51	
TYPE_1	730	642	602	482	402	241	-489
TYPE_2T	1,212	1,048	974	750	601	303	-909
TYPE_2U	169	158	153	138	128	108	-61
TYPE_3	221	189	175	131	102	44	-177
TYPE_4T	311	266	246	185	144	63	-248
TYPE_4U	72	156	194	308	384	537	465
TYPE_5	579	712	773	954	1,075	1,318	739
TYPE_6T	79	79	79	79	79	79	0
TYPE_6U	118	241	297	464	575	799	681
TYPE_6W	4	4	4	4	4	4	0
OPENLAND	231	231	231	231	231	231	0
OPENWATER	1,536	1,536	1,536	1,536	1,536	1,536	0
ISLANDS	37	37	37	37	37	37	0
UTILITY	22	22	22	22	22	22	0
	5,321	5,321	5,321	5,321	5,321	5,321	

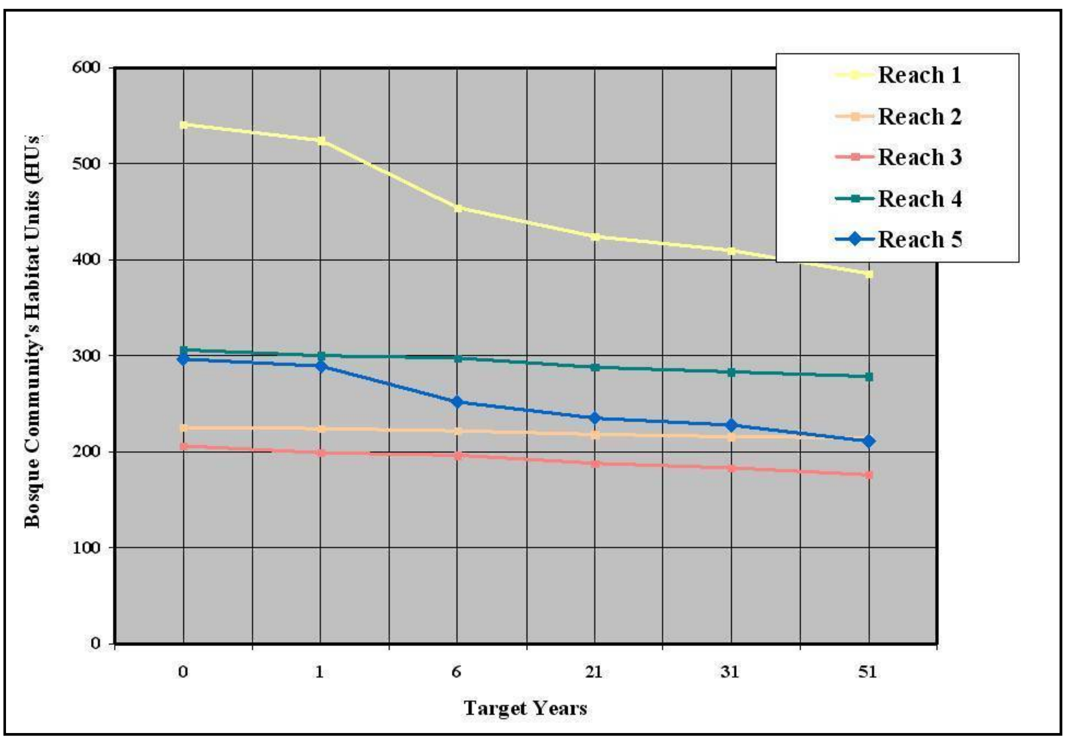

Figure 44. Cumulative changes in HUs under the WOP scenario.

By 2066 (TY51) 20 percent of the bosque community's functionality is lost (Table 11).

Table 11. Predicted losses for the MRGBER study under the WOP scenario based on the HEP analyses.

Bosque Community HSI Model					
Reach	Baseline HUs	TY 51 HUs	Net Change in HUs (TY51-TY0)	Percent Loss of HUs	AAHUs
Reach 1	541	386	-155	29%	426
Reach 2	225	214	-11	5%	218
Reach 3	206	175	-30	15%	187
Reach 4	307	278	-28	9%	287
Reach 5	296	210	-86	29%	235

Reaches 1 and 5 are likely to incur the highest losses (29% each). The middle reaches (2-4) will incur some loss, but are already relatively non-productive.[1]

[1] For electronic summaries of the Without-project results generated by the E Team, contact the Ondrea Hummel in the Albuquerque District (Table 1).

5 With-project (WP) Analysis and Results

For reasons detailed in the District's planning documentation (USACE 2010), the E-Team implemented a proactive strategy to formulate ecosystem restoration plans specifically tailored to focus on restoration initiatives at a landscape level on a system-wide basis. By definition, features and activities were considered the smallest components of the alternative plans. Features were typically structural elements while activities were often nonstructural actions performed continually or in a periodic fashion to support the restoration investment. Ultimately, nine broad categories of feature/activity types were formulated to modify the land/water interface in an attempt to improve the hydrologic, geomorphic and biologic setting of the bosque ecosystem and restore both the community's structure and function to a sustainable level (Table 12). Combinations of these features, referred to as management measures, became the building blocks from which alternative plans were made (Table 13).

In most instances, these features/activities were combined based on general location, implementability, and dependencies. In other words, swales were likely to be aligned in areas where bank destabilization activities were proposed. Water features were often proposed in conjunction with these activities to provide a needed hydrologic input. Jetty jack removal and revegetation features were often considered dependent upon one another.

Numerous management measures had the potential to solve this study's particular problems and restore the bosque ecosystem to a sustainable condition in a somewhat localized fashion. They were often dependent upon factors such as position in the landscape, technical or economic considerations, and predicted environmental conditions. These localized measures were independent of one another, and therefore served as the smallest units of the evaluation. However, their effect was cumulative, and the evaluation of ecosystem restoration benefits was calculated on a reach basis at the larger, landscape-level scale. The management measures evolved over the course of the study, becoming more defined and specific as the planning process progressed.

Table 12. Proposed features and activities considered for ecosystem restoration efforts in the MRGBER study.

Category	Features/Activities	Details
Hydrology and Hydraulics	Wetland Restoration	Wetlands would be established or restored at appropriate locations to create a diverse and high value habitat. Storm water outfalls were numerous throughout the bosque in the Albuquerque area and would be modified to function as wetlands, increasing diversity of habitat and providing some water quality treatment. There was an existing oxbow wetland that would also be restored to function more naturally. Restoration of wetland habitat was critical to ensuring that the dynamic mosaic of the bosque ecosystem's structure and function was perpetuated.
	Channel Modification	In several areas, banks of the Middle Rio Grande would be shaved to create a less incised channel and shelves, or destabilized to create sediment sources. Such areas would increase the diversity of both fringe riparian and aquatic habitat.
	High Flow Channels	Excavation of smaller, high flow channels to convey waters through the bosque during typical spring flows would occur. This would mimic the historic hydrograph and recreate connections between the bosque and the Middle Rio Grande.
	Swales	A number of areas had also been identified for installation of moist soil willow swales that would serve a dual purpose of reestablishing connectivity between the bosque and the river, as well as providing shrub, mid-canopy habitat - an integral piece of the bosque ecosystem mosaic.
Vegetative	Cottonwood Riparian Gallery Forest Communities Restoration	A primary element of the restoration would be the planting and reestablishment of cottonwood/willow gallery forest communities within the bosque. Areas would be cleared of exotic species and replanted with native species of the cottonwood riparian gallery forest. Especially important would be the reestablishment of the mid-canopy vegetation and open grasslands/savannahs to ensure that the dynamic mosaic of the bosque ecosystem was restored.
	Exotic Species Removal	A key element in the restoration of the bosque focuses on the removal of exotic plant species. Salt cedar, Siberian elm, tree of heaven and Russian olive were foreign exotic species that invaded parts of the bosque, forcing out key native species of willow and cottonwood. In addition, removal of exotics would potentially allow the water table to return to higher levels in this area of the Middle Rio Grande bosque because many of these exotic species use more water than native species.. Removal of exotics would improve the potential to reestablish native species over the long term. Exotic removal was considered a precondition for the restoration of natural processes in the bosque. Removal of exotics would also help decrease fuel loads because they comprise most of the understory in denser areas of the bosque.
	Fuel Load Reduction	Another key element to enhancing the health of the bosque would be fuel load reduction. Fuel load reduction entailed removing dead and down wood and excess leaf litter within the cottonwood gallery forest. When the flood disturbance regime was still functional, much of this material would have been removed by periodic flooding. Much of this material represented a fire hazard, and in many instances encroached on recreation systems and limited the surveillance necessary for security within the bosque. Fuel load removal would advance a number of objectives of the study.
Physical Removal	Jetty Jack Removal	Another important measure proposed in alternative development was the removal of jetty jacks. Jetty jacks were originally used to stabilize banks and control floods within the Middle Rio Grande floodplain. Jetty jacks would be removed wherever possible and left only where they were critical to levee stabilization.
	Debris Removal	Illegally dumped debris and fill foreign to the floodway system would be removed to create a suitable restoration substrate. Debris would be completely removed except where it was part of an existing levee.

Table 13. Crosswalk of planning concerns (problems, opportunities, objectives and management measures) for the MRGBER study.

Problem	Opportunity	Planning Objective	Management Measure
Lack of scour, sediment deposition and periodic inundation of the bosque has curtailed seedling recruitment of native tree species. This has resulted in a skewed age structure in the remaining cottonwood stands, and resulted in significant build-up of leaf litter and dead and down wood.	Recreate overbank flow to restore the essential functions of forest renewal and nutrient cycling.	Increase the number of locations and overall acreage of inundation as wells as its duration.	Reconnect existing or create high-flow side channels, destabilize and bench banks and expand embayments that flood in high flow events.
Due to confinement and deepening of the river channel, the low sloping bank and shallow near bank habitat no longer exists to provide a wet soil environment and shallow slackwater at the water-land interface.	Provide sloping riverbank habitat.	Increase the area of sloping, wet riverbank and shallow, slower velocity aquatic habitats.	De-vegetate and destabilize banks by shaving and benching them.
Loss of wetlands, braided channels and backwaters.	Restore and create new wetland habitat and backwaters	Increase number and acreage of wetlands and backwater areas.	Excavate to enlarge existing or create new wetlands and expand areas of backwater habitat. Establish wetland plants to jumpstart benefits and functions.
Lowering of the water table has curtailed seedling recruitment of native tree species and increased the mortality rate of existing cottonwoods and willows.	Establish new growth forest where root zones reach the shallow water table.	Improve bosque habitat heterogeneity by Increasing the number and areas of sustainable, new growth forest and other habitat types.	Excavate swales, trenches and expand existing wet habitats then establish native plants.
Coordinate with other agencies and projects in the study area.	Promote communication and cooperation among stake-holders while integrating various project goals.	Increase frequency and number of coordination efforts, meetings and information exchange between stakeholders.	Organize stakeholder meetings and lines of communication, solicit stakeholder input and provide updated project status during study.
Presence of informal trails, trash, accidental fires and high-impact recreational uses.	Rehabilitate disturbed areas and establish uncommon habitat types.	Increase high value bosque habitat while promoting community involvement and pride.	Promote education within the community about bosque values. Establish formal trail system.
The cumulative impact of the loss of inundation, confinement of the channel, the lower water table, cottonwood mortality and urbanization has led to the replacement of the mosaic of native woodlands and wetlands in many parts of the Study Area by dense stands of non-native salt cedar, Russian olive, Siberian elm, tree of heaven and white mulberry trees.	Remove non-native species and re-vegetate with various native plant communities.	Increase area and relative value of habitat while increasing heterogeneity of structure and function.	Remove large stands of non-native plants and those in the understory and replant areas with native plant communities and native understory plants that provide food and shelter for wildlife.

Problem	Opportunity	Planning Objective	Management Measure
The altered vegetation structure of the bosque has increased the potential for a catastrophic fire in the bosque. The brushy growth form of non-native trees creates a hazardous fuel condition. The brush and jetty jacks can also make fighting a fire difficult and potentially dangerous.	Remove hazardous fuels and obstacles to emergency access.	Reduce the risk of catastrophic fire while increasing habitat values. Improve access for emergency and maintenance purposes.	Remove jetty jacks and live and dead vegetation considered hazardous. Replace with non-hazardous plants to create fire breaks such as open habitat types.
The change from a mosaic of native plant communities of various structures and ages to increasingly large stands of non-native forest has affected the overall value of aquatic and terrestrial wildlife habitat provided by the bosque.	Rehabilitate the existing bosque into a dynamic mosaic of native vegetation patches of various ages, structure types and constituent species.	Restore the native bosque communities while creating greater stand diversity in terms of stand age, size and composition within the bosque.	Establish select native plants where appropriate to provide interpretive components to existing habitat and remove non-native stands and re-vegetate to provide uncommon interpretive or new age class of native vegetation.
The uncontrolled access, neglect and degradation of the bosque ecosystem have impaired interpretive, educational and recreational uses of the bosque.	Develop existing trails into a highly educational, aesthetically pleasing and safe interpretive system that furthers the overall goal of restoration.	Expand, improve and connect the existing trail system and create new educational amenities.	Connect existing and create new trails throughout project area, provide interpretive amenities and provide ADA compliant facilities.
			Develop and implement a long-term operations and maintenance plan, which incorporates long-term monitoring of proposed restoration features.
Perception of unfair distribution of open space resources.	Ensure fair distribution of resources.	Expand, improve and connect the existing trail system and create new access points.	Connect existing and create new trails throughout project area. Create periodic access points in areas currently lacking them.
		Ensure a distribution of habitat improvements through all reaches of study area.	Impose rule to alternative analysis that requires some improvements in all reaches of study area.
Lack of awareness of bosque values and connection to cultural uses.	Make use of highly visible and accessible natural area as an educational resource to instill pride and ownership of the restoration.	Increase educational awareness and promote community buy-in.	Install interpretive/educational signage, wildlife viewing blinds.
			Engage public participation during study and implementation.

Alternative plans then, were formulated from various combinations of management measures, added together, eliminated, rescaled and otherwise modified so that the resultant suite of formulated alternatives addressed the planning goals and objectives enumerated earlier. All told, 20,736 separate plans could be formed from all possible combinations of activities and features identified (Table 14).

Table 14. Formulation of all possible combinations of activities and features revealed a substantial number of alternative plans for the MRGBER study.

Reach	Number of Management Measures	Number of All Possible combinations
1	13	8,192
2	13	8,192
3	8	256
4	11	2,048
5	11	2,048
Total		20,736

Given the study's schedule and the resources available to complete the evaluation, the E-Team made the decision to screen these alternatives on the basis of the four standard planning criteria (i.e., completeness, efficiency, effectiveness, and acceptability) (USACE 2000). To simplify the process somewhat, the E-Team retained both the "maximum effort" alternative (the one that implemented all possible measures in combination) and the "minimum effort" alternative (the plan with the smallest footprint of potential effort) for each reach (Figure 45 – Figure 49).

In an attempt to evenly distribute the restoration efforts across the study area (and within each reach), the E-Team used simple rules to screen these plans further. The formulation focused on placing measures throughout the reach in an effort to distribute the restorative efforts as widely as possible and with as much equity as possible to provide localized restoration benefits to as many stakeholders as possible. An attempt was made to formulate plans for the right banks, the left banks, and then combinations on either side of the river.

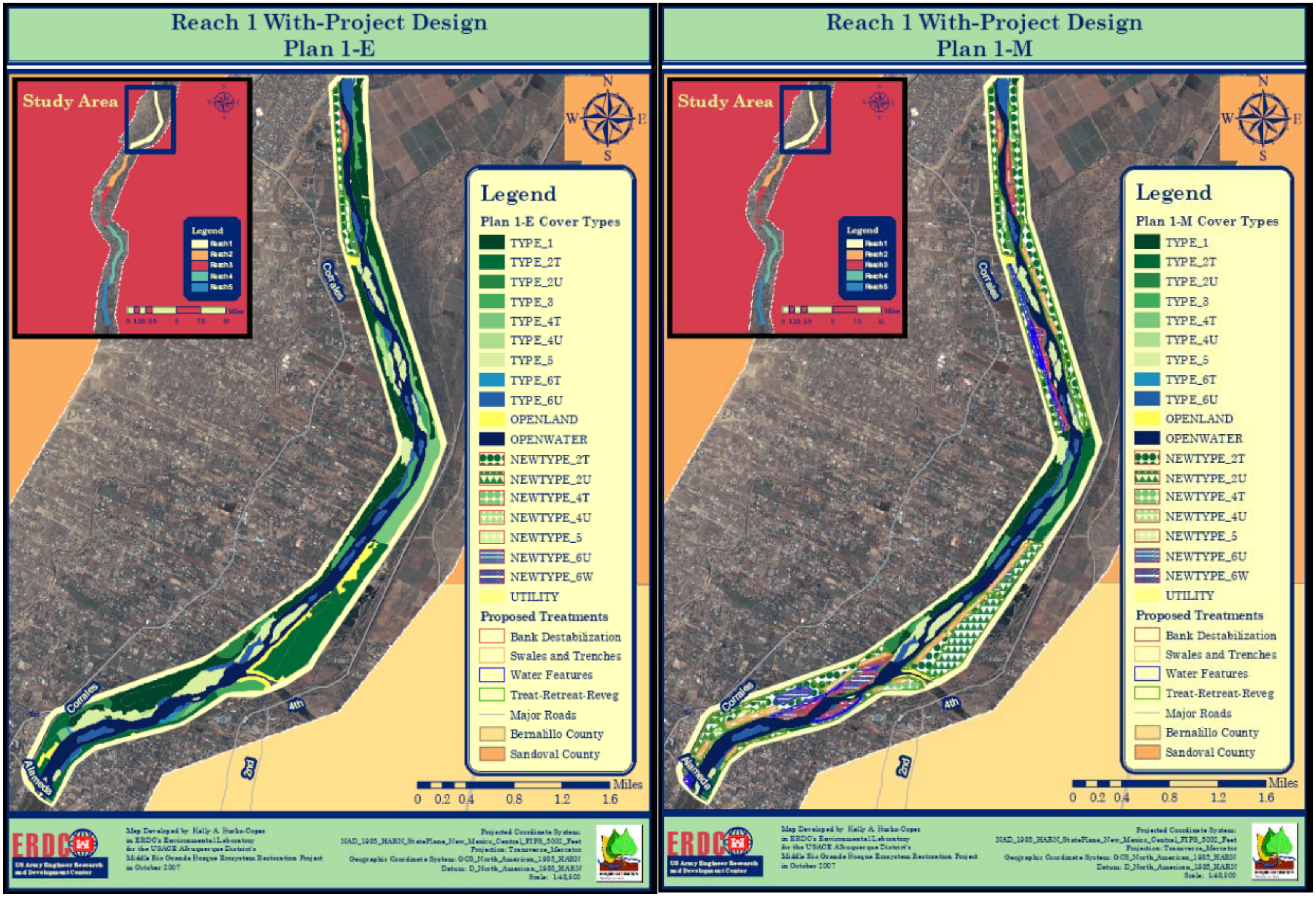

Figure 45. “Maximum” and “Minimum” plans for Reach 1 in the MRGBER study.

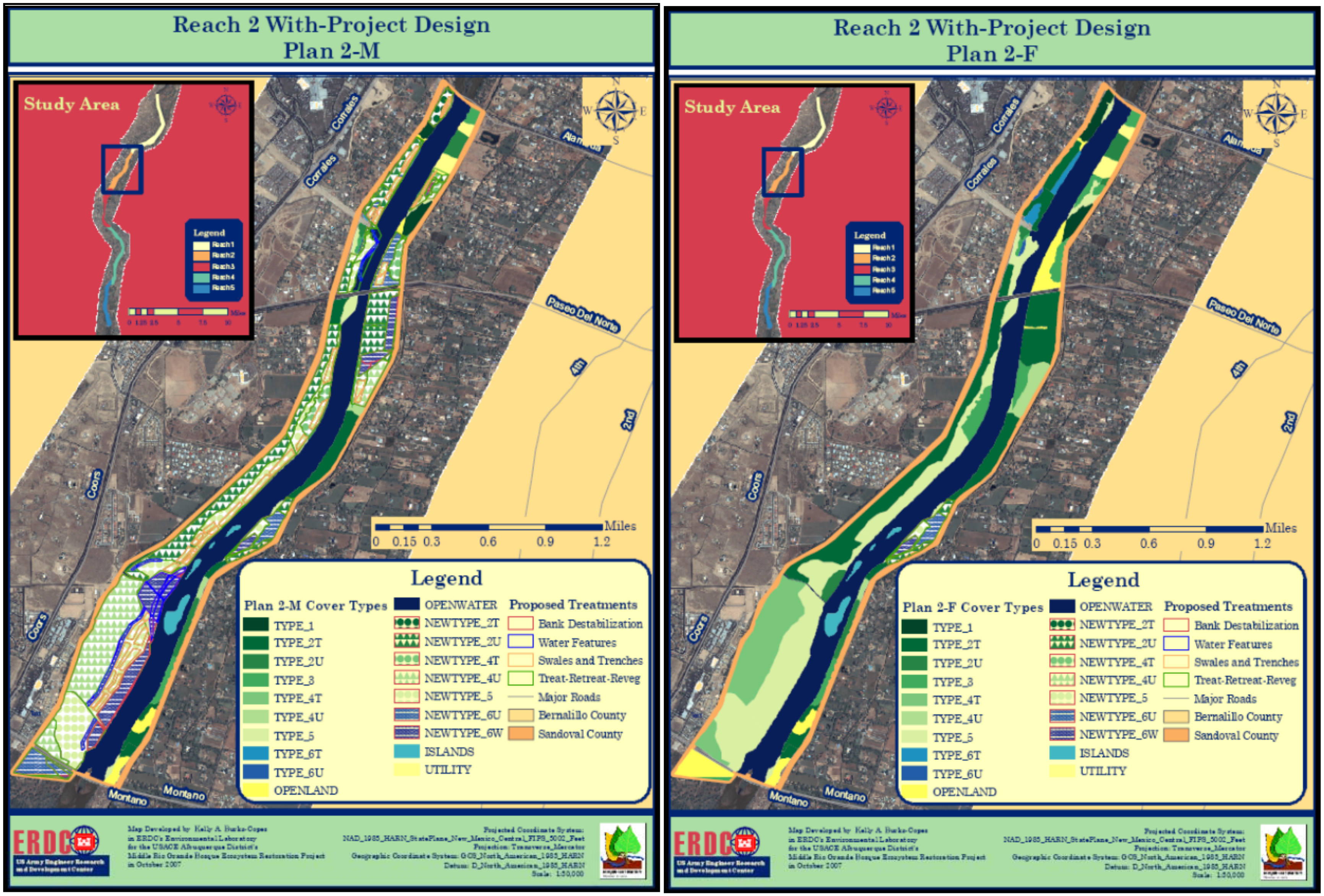

Figure 46. “Maximum” and “Minimum” plans for Reach 2 in the MRGBER study.

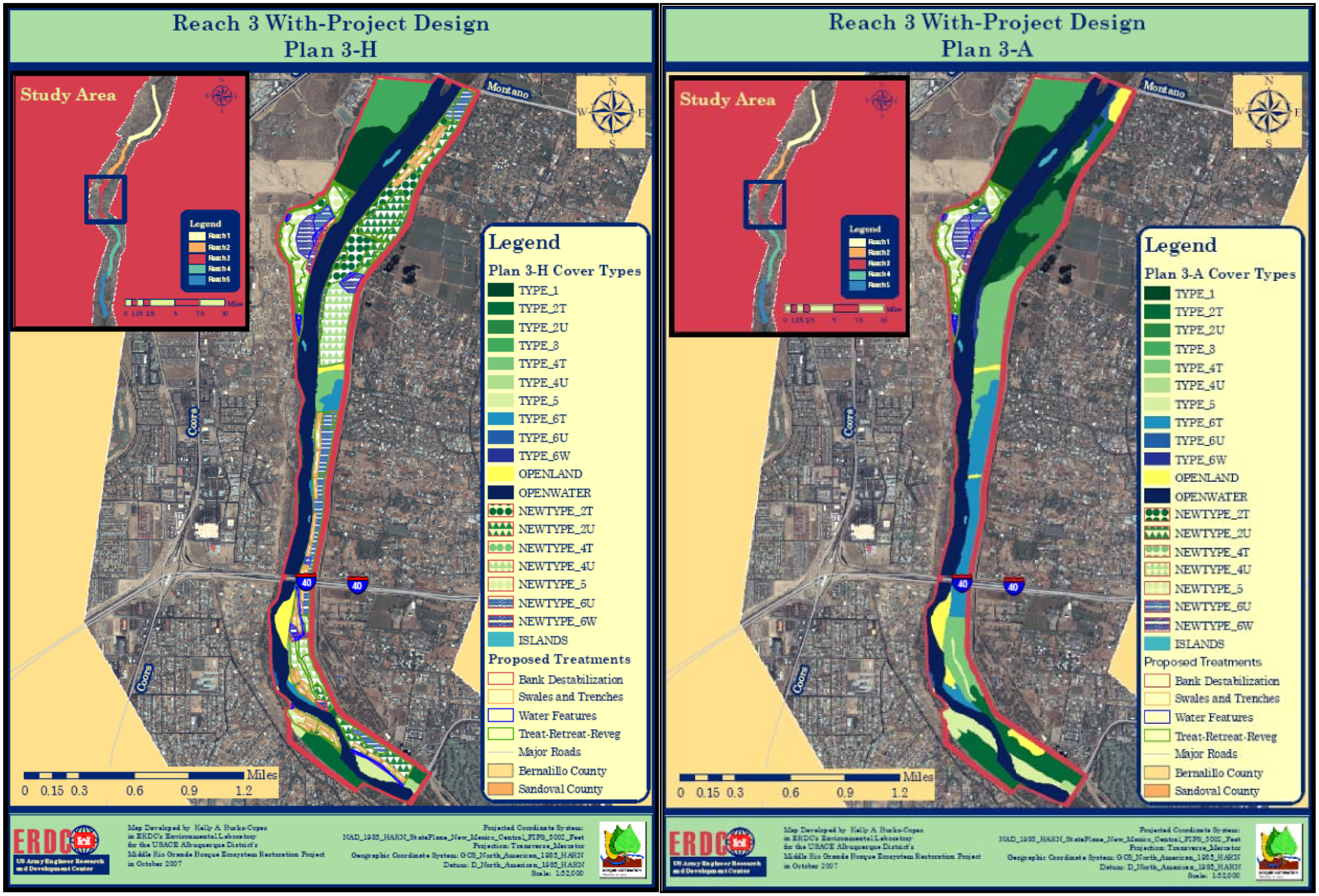

Figure 47. “Maximum” and “Minimum” plans for Reach 3 in the MRGBER study.

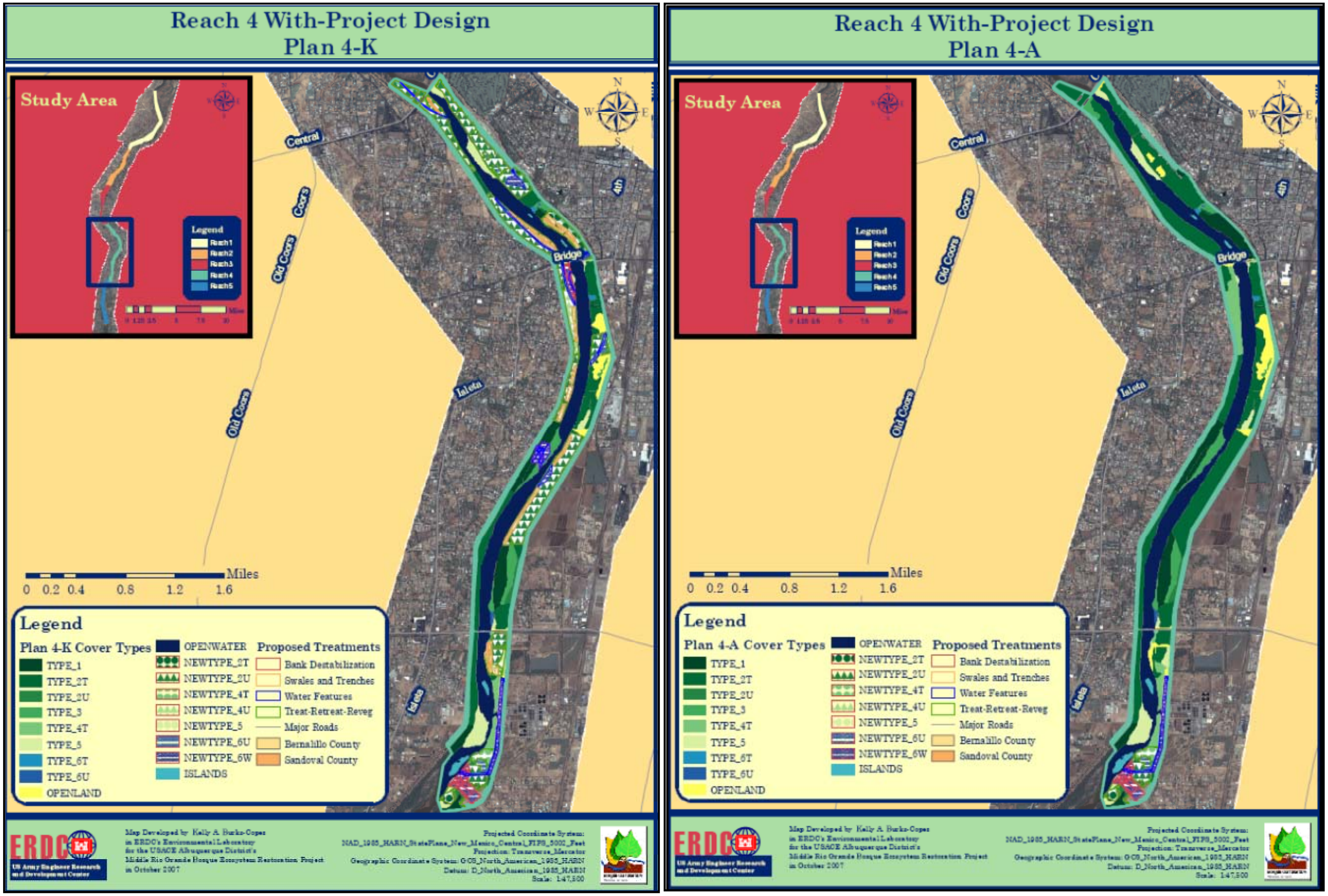

Figure 48. "Maximum" and "Minimum" plans for Reach 4 in the MRGBER study.

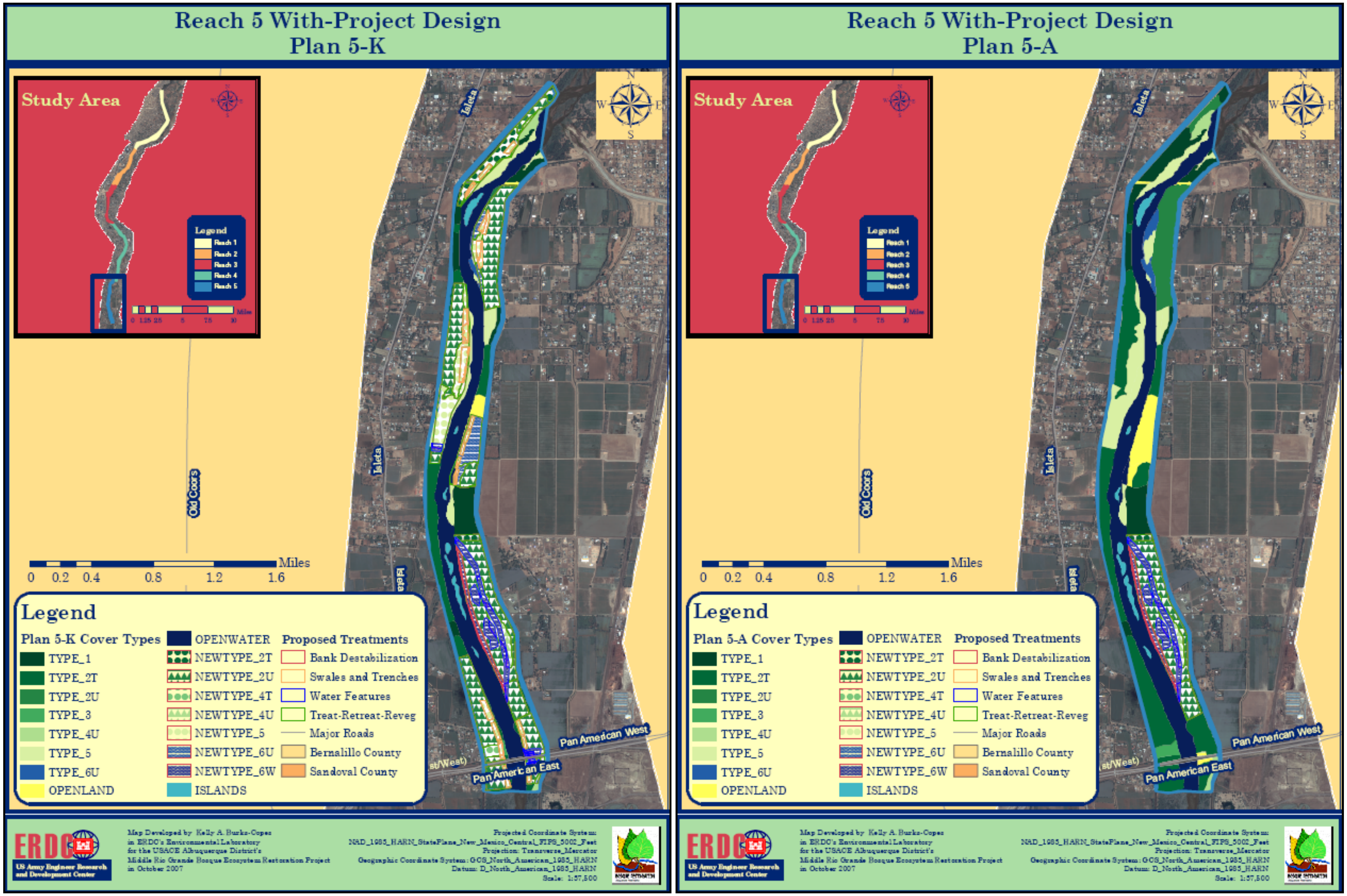

Figure 49. "Maximum" and "Minimum" plans for Reach 5 in the MRGBER study

In Reach 3, the last vestiges of marsh habitat in the Middle Rio Grande can be found only in a region colloquially referred to as the "San Antonio Oxbow." The E-Team made a informed decision to use the restoration of this wetland as a base plan. In other words, Plan 3-A is restoring the oxbow. Plan 3-B proposes to restore the oxbow and restore a cluster immediately across the river from the oxbow. Every alternative in Reach 3 has at its heart, the restoration of the oxbow first and foremost. For more details regarding the formulation for the study's plans, refer to the District's planning documentation (USACE 2010). All told, 5,632 alternatives were iteratively paired down to 56 final alternatives that were then carried forward into detailed hydraulic, economic, and environmental analyses (8-13 plans per reach) (Table 15). [1]

Each plan was then assessed with HEP and compared using cost analyses. Refer to the *Predicted WP Acreage Trends (Quantity)* and the *Predicted WP Variable Trends (Quality)* sections below to review the analyses and assumptions that went into the ecosystem assessment of benefits for these plans. The cost analyses process are described immediately thereafter.

Predicted WP Acreage Trends (Quantity)

The first step to evaluate the benefits of the proposed alternatives was to develop acreage projections over the life of the project (for the period of analysis) for each plan.[2] It is important to note that the successional trends envisioned by the E-Team in the Without-project conditions were retained in these restoration plans, in order to capture the cyclical nature of the bosque ecosystem. Newly developed habitats were assigned "NEW" cover type codes in order to capture the burgeoning contribution to the restoration of the bosque's structure and function.

Predicted WP Variable Trends (Quality)

Over the course of several years and numerous workshops, the E-Team developed projected future conditions for the With-project design scenarios. In essence, these were quantified on a variable-by-variable basis for every cover type under each proposed alternative for every reach (individual means of variables were estimated, and these, in turn, were applied to the SI graphs). Rather than presenting copious amounts of data documenting

[1] Contact the Ondrea Hummel in the Albuquerque District to obtain copies of the GIS shapefiles (Table 1).

[2] For summaries of the acreage data generated for the With-project conditions, contact Ondrea Hummel in the Albuquerque District (contact information can be found in Table 1).

Table 15. Alternative plan matrix for the ecosystem restoration efforts in the MRGBER study.

Reach	Plan Name	Plan Description	Total Active Footprint (acres)[1]	Feature Types within the Measures: Bank Destabilization (total acres)	Swales and Trenches (total acres)	Water Features (total acres)	Treat Revegetation (total acres)	Jetty Jack Removal (total units)
Reach 1	Plan 1-A	Located on the southernmost extent of the reach. Activities on both the left and right banks. Water features include the construction of hi-flow channel(s), creation of wetlands in general, and the construction of a wetland specifically at the outfall. Several sets of swales (distributed across both banks) are proposed in conjunction with bank destabilization.	278	42	29	34	278	2,004
	Plan 1-B	Located in middle of the reach on the right bank. Water features include the construction of hi-flow channel(s) and the creation of wetlands. No swales are proposed, but bank destabilization is included.	79	18	0	28	79	334
	Plan 1-C	Combination of Plans A & B	357	60	29	62	357	2,338
	Plan 1-D	Located on the northernmost extent of the reach along the left bank. No water features are proposed, but bank destabilization in conjunction with a series of swales is included.	75	13	4	0	75	334
	Plan 1-E	Located on the northernmost extent of the reach along the right bank. No water features are proposed, but bank destabilization in conjunction with a series of swales is included.	63	7	2	0	63	334
	Plan 1-F	Combination of Plans D & E	138	20	6	0	138	668
	Plan 1-G	Located in middle of the reach on the left bank. No water features or bank destabilization features are proposed, but a series of swales are included.	92	0	9	0	92	334
	Plan 1-H	Located in the southern section of the reach on the left bank. No water features or bank destabilization features are proposed, but a series of swales are included.	181	0	25	0	181	668
	Plan 1-I	Combination of Plans G & H	273	0	35	0	273	1,002
	Plan 1-J	Combination of Plans C & G	449	60	38	62	449	2,672
	Plan 1-K	Combination of Plans A & F & G	508	62	44	34	508	3,006
	Plan 1-L	Combination of Plans B & E & H	323	24	27	28	323	1,336
	Plan 1-M	All Plans Combined - (Maximum Footprint and Effort)	768	80	69	62	768	4,008

[1]The active footprint is not necessarily equal to the sum of the footprints of the feature types – often these overlapped on the landscape.

Reach	Plan Name	Plan Description	Total Active Footprint (acres)[1]	Feature Types within the Measures				
				Bank Destabilization (total acres)	Swales and Trenches (total acres)	Water Features (total acres)	Treat Revegetation (total acres)	Jetty Jack Removal (total units)
Reach 2	Plan 2-A	Located mid-reach (southern end) on the right bank. Water features include the construction of hi-flow channel(s), ground water channel(s), and diversion of the outfall channel. Several sets of swales (distributed across both banks) are proposed in conjunction with bank destabilization.	113	6	15	23	113	0
	Plan 2-B	Located mid-reach (northern end) on the left bank. Water features include enhancing the ditch for wetland habitat and creating a wet meadow. A series of swales are proposed, but bank destabilization is omitted.	79	0	5	14	79	0
	Plan 2-C	Combination of Plans A & B	192	6	20	38	192	0
	Plan 2-D	Located on the northernmost end of the reach on both banks. Water features include the construction of hi-flow channel(s) and wetlands. Several sets of swales (distributed across both banks) are proposed, but bank destabilization is omitted.	61	0	181	3	61	1,000
	Plan 2-E	Located mid-reach on the right bank. No water features or bank stabilization features are proposed, but a series of swales is included.	43	0	6	0	43	1,000
	Plan 2-F	Located mid-reach (southern end) on the left bank. Water features include the creation of wetlands, but no bank destabilization or swales features are indicated.	23	0	0	4	23	1,000
	Plan 2-G	Located on the southernmost end of the reach on the right bank. Water features include the construction of hi-flow channel(s) and creation of wetlands. Swales and bank destabilization features are also included in the plan.	195	24	14	10	195	1,000
	Plan 2-H	Combination of Plans D & G	256	24	196	13	256	2,000
	Plan 2-I	Combination of Plans B & H & E	378	24	207	27	378	3,000
	Plan 2-J	Combination of Plans G & A	308	29	30	33	308	1,000
	Plan 2-K	Combination of Plans G & B	274	24	19	24	274	1,000
	Plan 2-L	Combination of Plans C & D & F	276	6	202	44	276	2,000
	Plan 2-M	All Plans Combined - (Maximum Footprint and Effort)	514	29	222	54	514	4,000

[11]The active footprint is not necessarily equal to the sum of the footprints of the feature types – often these overlapped on the landscape.

Reach	Plan Name	Plan Description	Total Active Footprint (acres)[1]	Feature Types within the Measures				
				Bank Destabilization (total acres)	Swales and Trenches (total acres)	Water Features (total acres)	Treat Revegetation (total acres)	Jetty Jack Removal (total units)
Reach 3	Plan 3-A	Located in the northern section of the reach in the area referred to commonly as the "Oxbow" along the right bank. Water features include the restoration of open water habitat (in the "Oxbow" itself), construction of a water control structure, and reconfiguring the South-end and Namaste outfalls. No swales have been proposed, but bank destabilization features are included.	88	5	0	20	88	800
	Plan 3-B	Located in the northern portion of the reach (inclusive of the "Oxbow") along both banks. All features described in Plan A above, as well as additional outfall wetlands and swales will be constructed.	248	5	8	26	248	1,600
	Plan 3-C	Located in the both the northern and southern portions of the reach (inclusive of the "Oxbow") along both banks. All features described in Plans B above, as well as additional bank destabilization and swale features proposed. Additional water features include the reconnection of hi-flow channels, and the removal of a berm.	298	7	15	31	298	2,400
	Plan 3-D	Located in the both the northern and southern portions of the reach (inclusive of the "Oxbow") along both banks. All features described in Plan A above, as well as a reconfiguration of the Duranes outfall and the construction of swales.	127	5	9	21	127	800
	Plan 3-E	Located in mid-reach and inclusive of the "Oxbow" along both banks. All features described in Plan D above, as well as the construction of additional swales and the creation of outfall wetlands.	288	5	17	26	288	1,600
	Plan 3-F	Located in mid-reach and inclusive of the "Oxbow" along both banks. All features described in Plan A above, as well as additional bank destabilization and swale features. Additional water features include the removal of a berm, reconnection of hi-flow channels, the creation of outfall wetlands and the construction of an additional hi-flow channel.	180	7	15	28	180	1,600
	Plan 3-G	Located in the southern portion of the reach (inclusive of the "Oxbow") along both banks. All features described in Plan F above, as well as the construction of additional swales and outfall wetlands.	340	7	15	34	340	2,400
	Plan 3-H	All Plans Combined - (Maximum Footprint and Effort)	380	7	32	34	380	2,400

[11]The active footprint is not necessarily equal to the sum of the footprints of the feature types – often these overlapped on the landscape.

Reach	Plan Name	Plan Description	Total Active Footprint (acres)[1]	Feature Types within the Measures				
				Bank Destabilization (total acres)	Swales and Trenches (total acres)	Water Features (total acres)	Treat Revegetation (total acres)	Jetty Jack Removal (total units)
Reach 4	Plan 4-A	Located in the southern portion of the reach along the left bank. Water features will be constructed in conjunction with bank destabilization and swales.	34	13	7	27	34	0
	Plan 4-B	Located mid-reach along both banks. Numerous water features will be constructed including the removal of a berm, the construction of hi-flow channels and outfall wetlands. No bank destabilization is proposed, but swales are included.	139	0	21	20	139	400
	Plan 4-C	Located mid-reach and in the northern portion of the reach along both banks. Numerous water features will be undertaken including the improvement of wetland habitats, making connections to the river, creation of water features and the construction of hi-flow channels. No bank destabilization is proposed, but swales are included.	128	0	9	18	128	0
	Plan 4-D	Combination of Plans B & C	267	0	30	38	267	400
	Plan 4-E	Combination of Plans A & D	300	13	37	66	300	400
	Plan 4-F	Located in the northernmost section of the reach along the left bank. Only 1 water feature is proposed - an outfall wetland. No bank stabilization or swales are included.	81	0	0	6	81	0
	Plan 4-G	Contains not only Plan F's footprint, but also a small portion of the southern end of the reach along the left bank.	109	0	5	6	109	0
	Plan 4-H	Combination of Plans A & G	143	13	12	33	143	0
	Plan 4-I	Combination of Plans B & H	282	13	33	53	282	400
	Plan 4-J	Combination of Plans A & C & F	241	13	16	51	241	0
	Plan 4-K	All Plans Combined - (Maximum Footprint and Effort)	410	13	42	71	410	400
[11]The active footprint is not necessarily equal to the sum of the footprints of the feature types – often these overlapped on the landscape.								
Reach 5	Plan 5-A	Located in the southern section of the reach along the left bank. Water features include the construction of a hi-flow channel and several wetlands. Bank stabilization is proposed, but swales are omitted.	130	14	0	30	130	0
	Plan 5-B	Located in the southern section of the reach along the left bank. All features described in Plan A above, as well as wetland improvements, and connections established to both the wetland and the river. Swales are included in this plan as well.	162	14	4	36	162	0

Reach	Plan Name	Plan Description	Total Active Footprint (acres)[1]	Feature Types within the Measures				
				Bank Destabilization (total acres)	Swales and Trenches (total acres)	Water Features (total acres)	Treat Revegetation (total acres)	Jetty Jack Removal (total units)
Reach 5	Plan 5-C	Building from Plan B, and extending north upward along both banks. All features described above in Plan B, as well as improvement of the Black Mesa Outfall, and additional swales are proposed	251	14	14	38	251	0
	Plan 5-D	Building from Plan C, and extending north upward along both banks. All features described above in Plan C, as well as reconnecting the wetlands to each other, and additional swales are proposed	291	14	18	38	291	0
	Plan 5-E	Building from Plan B, and extending north upward along both banks. All features described above in Plan B, as well as additional swales are proposed	229	14	12	36	229	0
	Plan 5-F	Building from Plan C, and extending north upward along both banks. All features described above in Plan C, as well as reconnecting the wetlands to each other, and additional swales are proposed.	318	14	22	38	318	0
	Plan 5-G	Located throughout the reach along both banks. Although no water features or bank stabilization features are proposed, several swales are included.	215	0	26	0	215	0
	Plan 5-H	Building from Plan D along both banks, but absent the most southern tip of restoration activities and focusing on mid-reach restoration along the left bank rather than the right bank. All features described above in Plan D, but only half the acreage dedicated to swales, and water features are constrained to the hi-flow channel construction and wetland creation.	210	14	9	30	210	0
	Plan 5-I	Building from Plan C, but absent the most southern tip of restoration activities and focusing on the northern end of the reach along both banks. All features described above in Plan C, but slightly fewer swales, and water features are constrained to the hi-flow channel construction, the wetland creation, and the improvement of the Black Mesa outfall.	259	14	15	32	259	0
	Plan 5-J	Building from Plan H, and extending south along both banks. All features described above in Plan H, as well as reconnecting the wetlands to each other, enhancing the north and south wetlands, and additional swales are proposed.	242	14	13	36	242	0
	Plan 5-K	All Plans Combined - (Maximum Footprint and Effort)	466	14	39	38	466	0

[11]The active footprint is not necessarily equal to the sum of the footprints of the feature types – often these overlapped on the landscape.

variable projections here, the authors chose to provide a brief synopsis of general WP trends (and the E-Team assumptions supporting these trends). For those interested in reviewing the data projections developed by the E-Team in greater detail, hyperlinks have been added to the sections below to open attached electronic files.

Bosque Community (HSI) WP Trends (Existing and New)

As mentioned previously, the E-Team made the assumption that successional trends in the last vestiges of gallery forests and shrublands (Types 1-5) would continue. As such, they assumed these areas would continue to experience the ongoing successional changes experienced by the sites under the "No Action" scenario – with a few rehabilitative activities and structural components incorporated into the designs. For example, within these existing stands, some of the larger trees would be removed to open up the canopy and allow for introductions of younger species to accelerate regeneration for the next generations. As such, distance between the larger trees would be increased (fewer trees equates to a greater distance between each tree), and the areas would experience a slight increase in shrub and herbaceous canopy cover.

For all existing habitats (Types 1-6) subject to active rehabilitation, species lists for the planting schema were devised (USACE 2010) that encouraged the introduction of native species, leading to significant increases in native species richness. Invasive species management would be implemented on a regular basis to reduce the numbers of exotics and invasives in the bosque as well (USACE 2010). In those areas where water features were planned, the hydrologic regime (duration, flooding frequency, wetted surface area, and depth to groundwater) would be improved. The projected trends for these parameters were developed by Mr. Steve Boberg (Albuquerque District Hydrologist) based on extensive hydrologic modeling performed on the designs (USACE 2010). GIS-derived parameters (i.e., patch size, distance between patches, etc.) were measured and incorporated into the analysis at TY1. Spatially, the patch sizes and distances between patches would continue to decline (even under these rehabilitative actions).[1]

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[1] This was an artifact of the reach-level modeling approach; as patches of existing habitat were sacrificed to create areas of new habitat, patch sizes declined and the distance between patches increased.

Newly developed forested cover types (New Types 1-4) were expected to achieve a sustainable setting by TY51. In these instances, representative community characteristics such as tree canopy cover, understory structure and ground coverages would reach optimal conditions (i.e., >50%, >40%, >80% respectively) in 50 years. The E-Team assumed that active invasive species management and plantings of desirable species (i.e., natives) would maintain the level of desired ecosystem integrity necessary to encourage active recruitment and regeneration in the bosque. Again, where possible water features were deployed to support the creation of these ecotones.

Newly developed shrublands (New Type 5) were expected to achieve a sustainable setting much earlier (by TY6). In these instances, representative community characteristics such as shrub canopy cover, tree canopy, and ground coverages would reach optimal conditions (i.e., >50%, >50%, >75% respectively) within 5 years and remain in that state throughout the life of the project (during that period of analysis). Again, active invasive species management and structured plantings of desirable species (mentioned on previous page) would maintain the level of desired ecosystem integrity necessary to encourage active recruitment and regeneration in the bosque. Newly developed meadows/marshes (New Type 6s) too were expected to achieve a functioning condition much sooner (by TY6). Herbaceous canopies (forbs, grasses, and sedges) were expected to optimize (attain >20% coverage) by that time.

The projected hydrologic conditions in the "new" areas were modeled by the District and provided to the E-Team for model inclusion. Again, spatial parameters were measured with GIS and incorporated into the analysis at TY1 - in general, these trends were positively inclined. In other words, the E-Team specifically designed their alternatives to meet the threshold conditions of patch size and distance by creating new patches greater than 40 acres in size (the optimum threshold for the PATCHSIZE parameter) and situated in an optimum landscape setting (between 500 and 1,500 meters apart – the optimum threshold for the DISTPATCH variable).[1]

WP Results

The changes predicted above under the proposed restoration plans resulted in quantifiable benefits for all metrics measured across the study area (Table 16 and Figure 50).

[1] For those interested in reviewing the data projections developed by the E-Team in greater detail, contact Ondrea Hummel in the Albuquerque District (contact information can be found in Table 1).

Table 16. Final results for the ecosystem restoration analysis.

Reach	Plan	Habitat Potential (AAHUs)	Habitat Potential (Net Lift in HSI)	Reach	Plan	Habitat Potential (AAHUs)	Habitat Potential (Net Lift in HSI)	Reach	Plan	Habitat Potential (AAHUs)	Habitat Potential (Net Lift in HSI)
Reach 1	Plan 1-A	138	0.16	Reach 3	Plan 3-A	100	0.00	Reach 5	Plan 5-A	144	0.00
	Plan 1-B	3	0.16		Plan 3-B	110	0.23			141	0.30
	Plan 1-C	193	0.00		Plan 3-C	106	0.24		Plan 5-C	143	0.30
	Plan 1-D	8	0.22		Plan 3-D	103	0.24			141	0.30
	Plan 1-E	6	0.00		Plan 3-E	109	0.23		Plan 5-E	139	0.30
	Plan 1-F	18	0.00		Plan 3-F	104	0.24			141	0.30
	Plan 1-G	9	0.02		Plan 3-G	112	0.23		Plan 5-G	155	0.30
	Plan 1-H	42	0.01		Plan 3-H	118	0.24			157	0.29
	Plan 1-I	51	0.04						Plan 5-I	144	0.30
	Plan 1-J	222	0.06							156	0.30
	Plan 1-K	231	0.25						Plan 5-K	157	0.29
	Plan 1-L	65	0.27								
	Plan 1-M	264	0.07								
Reach 2	Plan 2-A	146	0.00	Reach 4	Plan 4-A	36	0.00				
	Plan 2-B	155	0.30		Plan 4-B	40	0.05				
	Plan 2-C	155	0.30		Plan 4-C	39	0.07				
	Plan 2-D	139	0.31		Plan 4-D	63	0.07				
	Plan 2-E	143	0.29		Plan 4-E	85	0.11				
	Plan 2-F	139	0.30		Plan 4-F	34	0.13				
	Plan 2-G	151	0.28		Plan 4-G	39	0.06				
	Plan 2-H	153	0.30		Plan 4-H	62	0.06				
	Plan 2-I	153	0.30		Plan 4-I	80	0.09				
	Plan 2-J	162	0.32		Plan 4-J	70	0.11				
	Plan 2-K	172	0.32		Plan 4-K	108	0.10				
	Plan 2-L	159	0.32								
	Plan 2-M	176	0.31								

Note: Blank cells are place holders indicating that no additional alternatives were formulated for that reach.

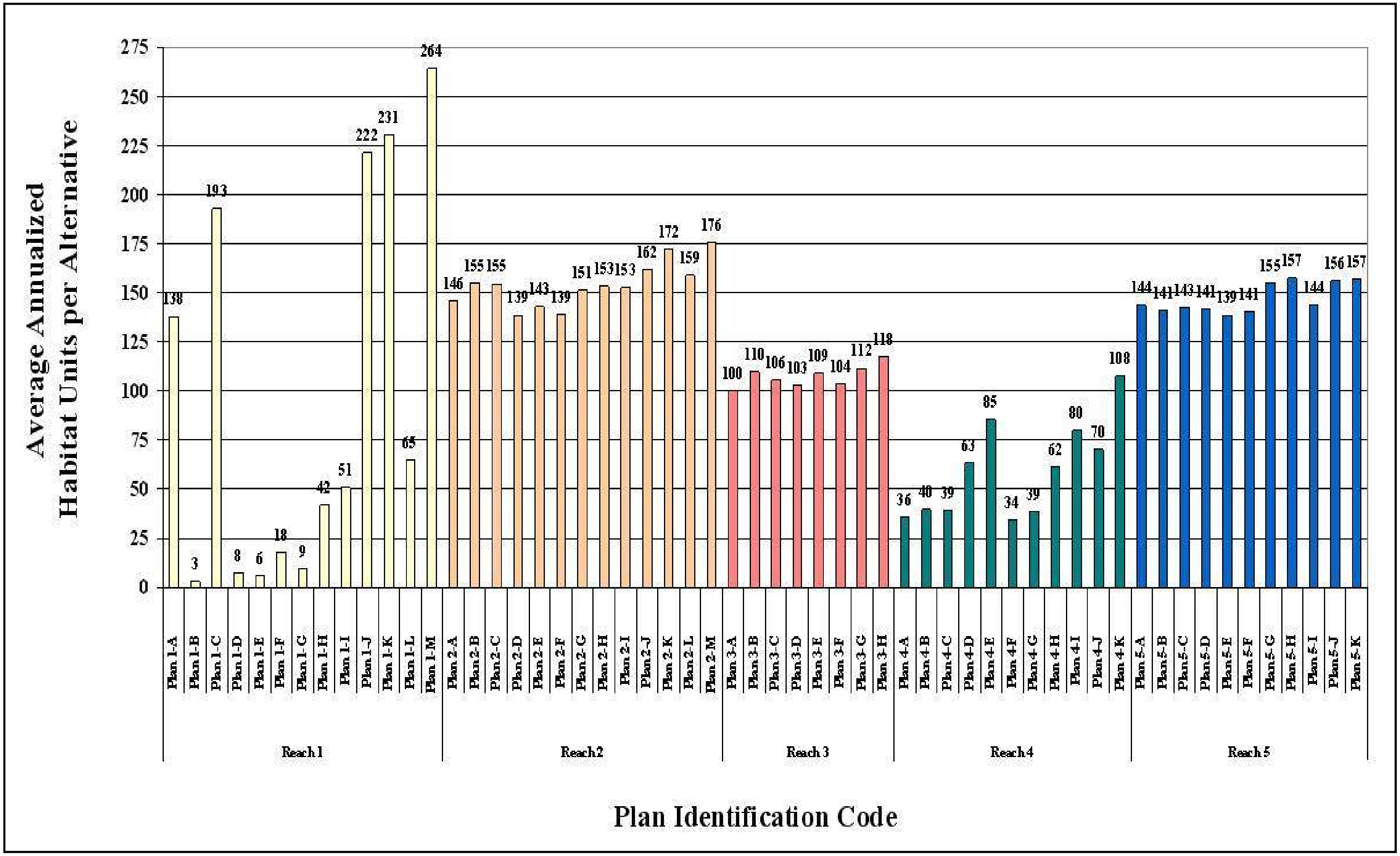


Figure 50. Final results of the MRGBER study HEP analysis.

The outputs for these alternatives ranged from **3** to **264** AAHUs for the bosque (riparian) community index model. As one might expect, the "maximum effort" plans (***Plan 1-M***, ***Plan 2-M***, ***Plan 3-H***, ***Plan 4-K***, and ***Plan 5-K***) produced the most benefits (AAHUs ranged from 108 to 264.

Four plans (3-A, 3-B, 3-D, and 3-E) proved to be low-scoring options. Decision scores for these four plans ranged from 0.135 to 0.225. Plans 3-C had an intermediate decision score of 0.347. As was the case for Reach 2, a wide range of decision scores combined with the occurrence of clustered scores within the range offered a basis both for discrimination and flexibility in the final choice among alternatives.

Ultimately, the identification of a recommended plan for each reach hinged upon the cost analyses comparisons of the proposed alternatives. Below we detail the cost comparative analyses that evaluated the productivity of the proposed plans for the study.

Cost Analysis

Cost effectiveness (CEA) and incremental cost analyses (ICA) were performed using the IWR Planning Suite software.[1] Because the study is likely to be approved and funded at the project-level rather than on a reach-by-reach basis, the MRGBER team consulted with Mr. Leigh Skaggs (Institute of Water Resources) to discuss the benefits of conducting a nested CEA/ICA analysis.[2] Following advice received from Mr. Skaggs, the MRGBER Team first performed the cost analyses on a reach-by-reach basis, and as such, the cost-effective and incremental "Best Buys" were determined for each reach. These "Best Buys" were then carried into a project-level cost analysis where combinations of Best Buy solutions for each reach were combined to generate a project-level solution. Again, the cost-effective and incrementally effective solutions were determined – but this time for the entire study area. The sections below summarize the outputs, costs and CEA/ICA results generated as the E-Team evaluated the suite of MRGBER restoration alternatives in this nested approach.[3]

Plan Costs

The District developed annualized costs for the proposed restoration plans using a 4.875% interest rate and a 0.05372 amortization rate for construc-

[1] http://www.pmcl.com/iwrplan/

[2] Personal Communication with Mr. Leigh Skaggs, Institute of Wake Resources. March – June 2008.

[3] For electronic summaries of the cost results generated by the E-Team contact Ondrea Hummel in the Albuquerque District office (Table 1).

tion (amortized over the 50-year period of analysis or project life).[1] These costs were then added to the annualized Operation and Maintenance (O&M) costs for each measure and summed to generate the total annualized costs per measure (Table 17).

Table 17. Annualized costs input into the cost analyses for the MRGBER study.

Reach	Plan	Cost	O&M	Annualized Cost	Total Avg. Annual Cost
Reach 1	Plan 1-A	$7,108,722	$367,668	$348,349	$716,017
	Plan 1-B	$425,270	$72,730	$20,840	$93,570
	Plan 1-C	$7,533,992	$440,398	$369,188	$809,586
	Plan 1-D	$1,049,631	$31,489	$51,435	$82,924
	Plan 1-E	$672,318	$20,170	$32,946	$53,115
	Plan 1-F	$1,721,949	$51,658	$84,381	$136,039
	Plan 1-G	$1,092,684	$17,908	$53,545	$71,453
	Plan 1-H	$2,518,227	$68,870	$123,401	$192,270
	Plan 1-I	$3,610,912	$86,778	$176,946	$263,723
	Plan 1-J	$8,626,677	$458,306	$422,733	$881,039
	Plan 1-K	$9,923,355	$437,235	$486,274	$923,509
	Plan 1-L	$3,615,815	$161,769	$177,186	$338,955
	Plan 1-M	$12,866,852	$578,834	$630,514	$1,209,349
Reach 2	Plan 2-A	$2,294,462	$68,834	$112,436	$181,269
	Plan 2-B	$2,077,602	$66,902	$101,809	$168,711
	Plan 2-C	$4,372,064	$135,736	$214,244	$349,980
	Plan 2-D	$9,302,053	$199,290	$455,829	$655,118
	Plan 2-E	$6,668,673	$13,679	$326,785	$340,464
	Plan 2-F	$642,983	$20,240	$31,508	$51,748
	Plan 2-G	$3,325,570	$89,326	$162,963	$252,288
	Plan 2-H	$12,627,624	$288,615	$618,791	$907,407
	Plan 2-I	$21,373,898	$369,197	$1,047,385	$1,416,582
	Plan 2-J	$5,620,032	$158,159	$275,398	$433,558
	Plan 2-K	$5,403,173	$156,227	$264,772	$420,999
	Plan 2-L	$14,317,100	$355,266	$701,581	$1,056,847
	Plan 2-M	$24,311,343	$458,271	$1,191,329	$1,649,599

[1] Refer all questions regarding cost generation to the District.

Reach	Plan	Cost	O&M	Annualized Cost	Total Avg. Annual Cost
Reach 3	Plan 3-A	$2,492,563	$11,632	$122,143	$133,775
	Plan 3-B	$4,022,416	$39,535	$197,110	$236,645
	Plan 3-C	$4,690,824	$57,940	$229,864	$287,804
	Plan 3-D	$2,999,754	$26,847	$146,997	$173,844
	Plan 3-E	$4,529,608	$54,750	$221,964	$276,715
	Plan 3-F	$3,816,182	$49,693	$187,004	$236,697
	Plan 3-G	$5,346,036	$77,596	$261,972	$339,568
	Plan 3-H	$5,853,227	$92,812	$286,826	$379,637
Reach 4	Plan 4-A	$1,277,224	$38,317	$62,588	$100,905
	Plan 4-B	$2,489,116	$68,476	$121,974	$190,450
	Plan 4-C	$2,731,960	$67,639	$133,874	$201,513
	Plan 4-D	$5,221,076	$136,115	$255,848	$391,963
	Plan 4-E	$6,498,300	$174,431	$318,436	$492,868
	Plan 4-F	$1,054,476	$31,634	$51,673	$83,307
	Plan 4-G	$1,381,380	$41,441	$67,692	$109,133
	Plan 4-H	$2,658,604	$79,758	$130,280	$210,038
	Plan 4-I	$4,820,817	$138,427	$236,234	$374,661
	Plan 4-J	$5,063,660	$137,590	$248,135	$385,724
	Plan 4-K	$7,552,777	$215,873	$370,109	$585,981
Reach 5	Plan 5-A	$3,333,124	$99,994	$163,333	$263,327
	Plan 5-B	$4,203,149	$122,111	$205,967	$328,078
	Plan 5-C	$5,078,081	$148,359	$248,841	$397,200
	Plan 5-D	$5,434,831	$159,062	$266,323	$425,385
	Plan 5-E	$4,838,731	$141,149	$237,112	$378,261
	Plan 5-F	$5,713,664	$167,397	$279,987	$447,383
	Plan 5-G	$1,957,685	$58,701	$95,932	$154,633
	Plan 5-H	$4,048,101	$121,443	$198,369	$319,812
	Plan 5-I	$4,564,806	$136,944	$223,689	$360,633
	Plan 5-J	$4,918,126	$143,561	$241,003	$384,563
	Plan 5-K	$7,035,766	$207,060	$344,774	$551,833

These plans, in turn, were compared against the total outputs generated in the HEP analyses using CE/ICA (Table 18).

Table 18. Costs and outputs submitted to CEA/ICA analysis for the cost comparison of the reach-level solutions in the MRGBER study.

Reach	Plan	Annualized Costs	AAHUs	Annualized Costs per Output ($/AAHU)
Reach 1	Plan 1-A	$716,017	138	$5,189
	Plan 1-B	$93,570	3	$31,190
	Plan 1-C	$809,586	193	$4,195
	Plan 1-D	$82,924	8	$10,365
	Plan 1-E	$53,115	6	$8,853
	Plan 1-F	$136,039	18	$7,558
	Plan 1-G	$71,453	9	$7,939
	Plan 1-H	$192,270	42	$4,578
	Plan 1-I	$263,723	51	$5,171
	Plan 1-J	$881,039	222	$3,969
	Plan 1-K	$923,509	231	$3,998
	Plan 1-L	$338,955	65	$5,215
	Plan 1-M	$1,209,349	264	$4,581
Reach 2	Plan 2-A	$181,269	146	$1,242
	Plan 2-B	$168,711	155	$1,088
	Plan 2-C	$349,980	155	$2,258
	Plan 2-D	$655,118	139	$4,713
	Plan 2-E	$340,464	143	$2,381
	Plan 2-F	$51,748	139	$372
	Plan 2-G	$252,288	151	$1,671
	Plan 2-H	$907,407	153	$5,931
	Plan 2-I	$1,416,582	153	$9,259
	Plan 2-J	$433,558	162	$2,676
	Plan 2-K	$420,999	172	$2,448
	Plan 2-L	$1,056,847	159	$6,647
	Plan 2-M	$1,649,599	176	$9,373
Reach 3	Plan 3-A	$133,775	100	$1,336
	Plan 3-B	$236,645	110	$2,159
	Plan 3-C	$287,804	106	$2,726
	Plan 3-D	$173,844	103	$1,685
	Plan 3-E	$276,715	109	$2,538
	Plan 3-F	$236,697	104	$2,286
	Plan 3-G	$339,568	112	$3,041
	Plan 3-H	$379,637	118	$3,227

Reach	Plan	Annualized Costs	AAHUs	Annualized Costs per Output ($/AAHU)
Reach 4	Plan 4-A	$100,905	36	$2,811
	Plan 4-B	$190,450	40	$4,813
	Plan 4-C	$201,513	39	$5,170
	Plan 4-D	$391,963	63	$6,183
	Plan 4-E	$492,868	85	$5,769
	Plan 4-F	$83,307	34	$2,449
	Plan 4-G	$109,133	39	$2,815
	Plan 4-H	$210,038	62	$3,415
	Plan 4-I	$374,661	80	$4,681
	Plan 4-J	$385,724	70	$5,494
	Plan 4-K	$585,981	108	$5,448
Reach 5	Plan 5-A	$263,327	144	$1,832
	Plan 5-B	$328,078	141	$2,326
	Plan 5-C	$397,200	143	$2,785
	Plan 5-D	$425,385	141	$3,007
	Plan 5-E	$378,261	139	$2,730
	Plan 5-F	$447,383	141	$3,182
	Plan 5-G	$154,633	155	$998
	Plan 5-H	$319,812	157	$2,031
	Plan 5-I	$360,633	144	$2,506
	Plan 5-J	$384,563	156	$2,465
	Plan 5-K	$551,833	157	$3,520

Reach-Level Cost-Effective Analysis and Results

Cost-effective analyses identified the least-costly plans for each level of output. The three criteria used for identifying non-cost-effective plans or combinations include: (1) the same level of output could be produced by another plan at less cost; (2) a larger output level could be produced at the same cost; or (3) a larger output level could be produced at the least cost.

Reach 1

Table 19 and Figure 51 below detail the results of the cost-effective analyses for Reach 1. Twelve plans were considered cost effective in both analyses. The average annual costs ranged from $53,115 to $1,209,348 and produced between 6 and 264 AAHUs for the bosque.

Table 19. Cost-effective analysis results for Reach 1.

Count	Alternative	Average Annual Cost	AAHUs	Average Annual Cost per AAHU
1	No Action	0	0	-
2	Plan 1-E	$53,115	6	$8,853
3	Plan 1-G	$71,453	9	$7,939
4	Plan 1-F	$136,039	18	$7,558
5	Plan 1-H	$192,270	42	$4,578
6	Plan 1-I	$263,723	51	$5,171
7	Plan 1-L	$338,955	65	$5,215
8	Plan 1-A	$716,017	138	$5,189
9	Plan 1-C	$809,586	193	$4,195
10	Plan 1-J	$881,039	222	$3,969
11	Plan 1-K	$923,509	231	$3,998
12	Plan 1-M	$1,209,349	264	$4,581

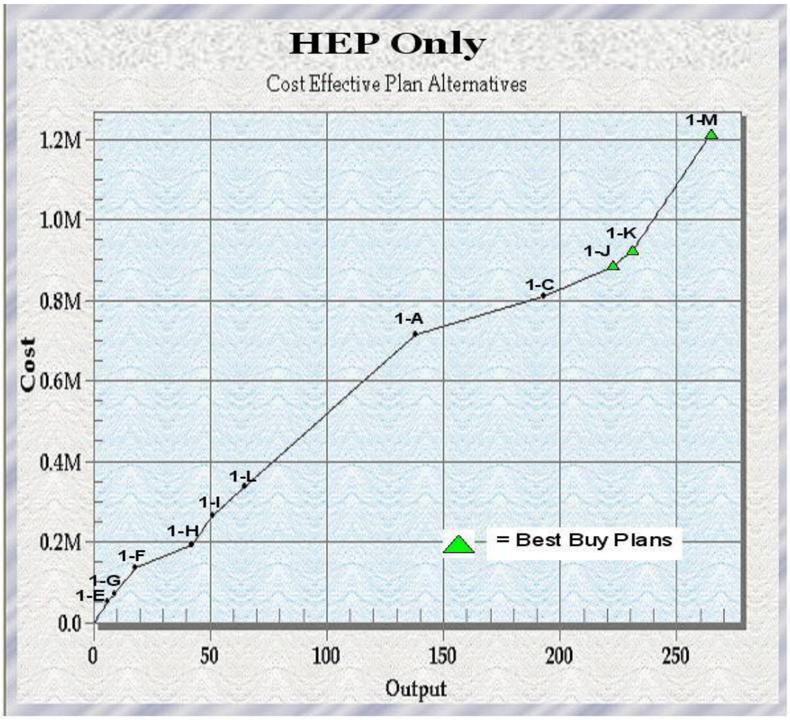


Figure 51. Cost-effective analysis results (graphical depiction) for Reach 1 plans.

Reach 2

Table 20 and Figure 52 below detail the results of the cost-effective analyses for Reach 2. Between five and ten plans were considered cost effective in the analyses. The average annual costs ranged from $51,748 to $1,658,763 and produced between 139 and 176 AAHUs for the bosque.

Table 20. Cost-effective analysis results for Reach 2.

Count	Alternative	Average Annual Cost	AAHUs	Average Annual Cost per AAHU
1	No Action	0	0	-
2	Plan 2-F	$51,748	139	$372
3	Plan 2-B	$168,711	155	$1,088
4	Plan 2-K	$420,999	172	$2,448
5	Plan 2-M	$1,658,763	176	$9,425

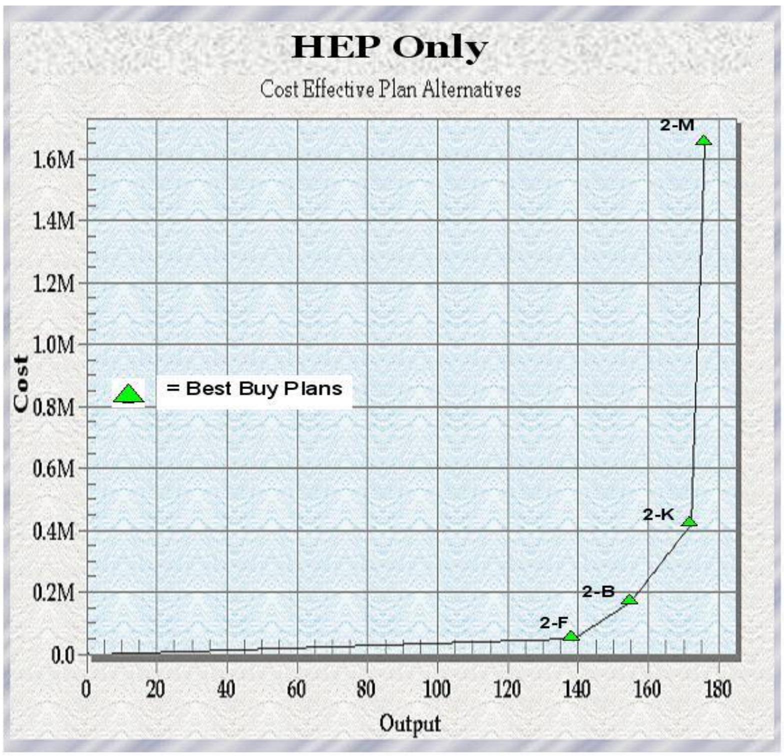


Figure 52. Cost-effective analysis results (graphical depiction) for Reach 2 plans.

Reach 3

Table 21 and Figure 53 below detail the results of the cost-effective analyses for Reach 3. Between six and seven plans were considered cost-effective in the analyses. The average annual costs ranged from $133,774 to $379,637 and produced between 100 and 118 AAHUs for the bosque.

Table 21. Cost-effective analysis results for Reach 3.

Count	Alternative	Average Annual Cost	AAHUs	Average Annual Cost per AAHU
1	No Action	0	0	-
2	Plan 3-A	$133,775	100	$1,336
3	Plan 3-D	$173,844	103	$1,685
4	Plan 3-B	$236,645	110	$2,159
5	Plan 3-G	$339,568	112	$3,041
6	Plan 3-H	$379,637	118	$3,227

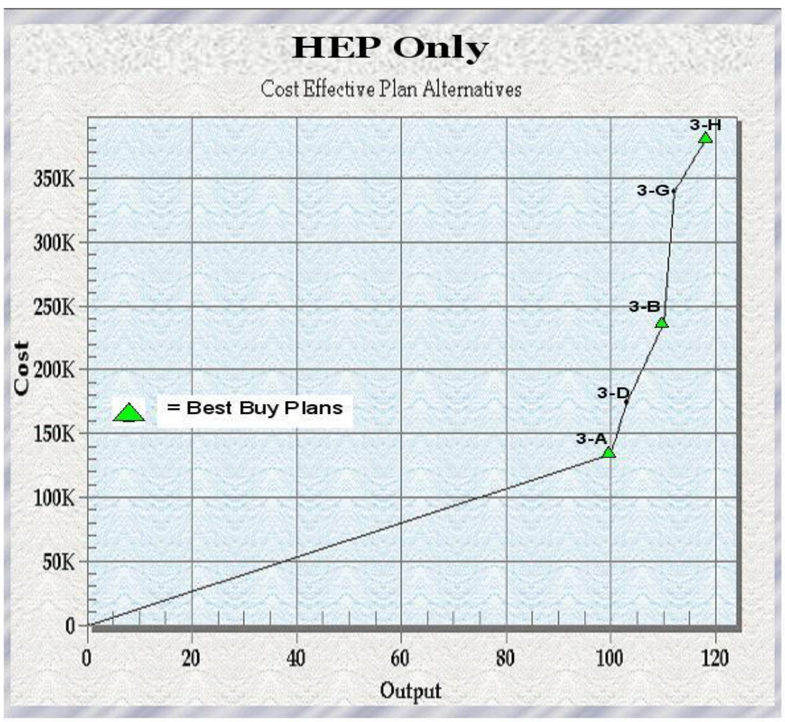


Figure 53. Cost-effective analysis results (graphical depiction) for Reach 3 plans.

Reach 4

Table 22 and Figure 54 below detail the results of the cost-effective analyses for Reach 4. Nine plans were considered cost effective in both analyses. The average annual costs ranged from $83,307 to $585,981 and produced 34 and 108 AAHUs for the bosque.

Table 22. Cost-effective analysis results for Reach 4.

Count	Alternative	Average Annual Cost	AAHUs	Average Annual Cost per AAHU
1	No Action	0	0	-
2	Plan 4-F	$83,307	34	$2,449
3	Plan 4-A	$100,905	36	$2,811
4	Plan 4-G	$109,133	39	$2,815
5	Plan 4-B	$190,450	40	$4,813
6	Plan 4-H	$210,038	62	$3,415
7	Plan 4-I	$374,661	80	$4,681
8	Plan 4-E	$492,868	85	$5,769
9	Plan 4-K	$585,981	108	$5,448

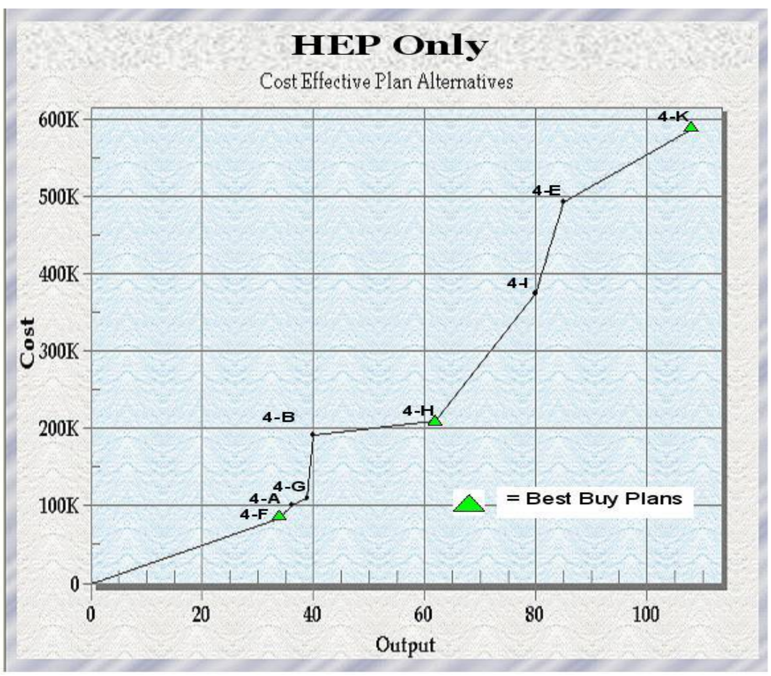


Figure 54. Cost-effective analysis results (graphical depiction) for Reach 4 plans.

Reach 5

Table 23 and Figure 55 below detail the results of the cost-effective analyses for Reach 5. Between two and eight plans were considered cost effective in the two analyses. The average annual costs ranged from $154,633 to $551,833, and produced between 155 and 157 AAHUs for the bosque.

Table 23. Cost-effective analysis results for Reach 5.

Count	Alternative	Average Annual Cost	AAHUs	Average Annual Cost per AAHU
1	No Action	0	0	-
2	Plan 5-G	$154,633	155	$998
3	Plan 5-H	$319,812	157	$2,031

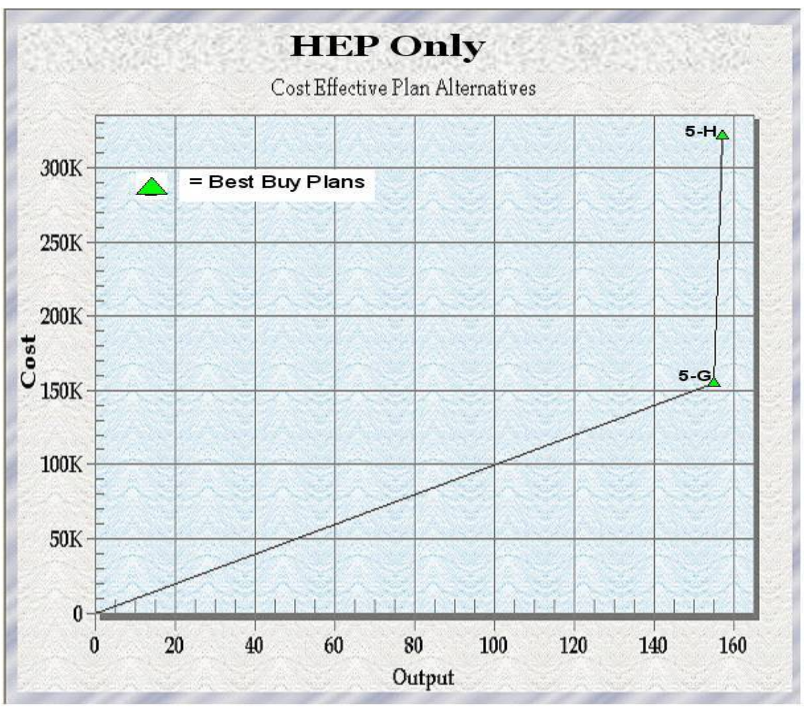


Figure 55. Cost-effective analysis results (graphical depiction) for Reach 5 plans.

Reach-Level Incremental Cost Analysis and Results

ICA compared the incremental costs for each additional unit of output on a reach-by-reach basis. The first step in developing “Best Buy” plans was to determine the incremental cost per unit. The plan with the lowest incremental cost per unit over the No Action Alternative was the first incremental Best Buy plan. Plans that had higher incremental costs per unit for a lower level of output were eliminated. The next step was to recalculate the incremental cost per unit for the remaining plans. This process was reiterated until the lowest incremental cost per unit for the next level of output was determined. The intent of the incremental analysis was to identify large increases in cost relative to output. The process was repeated independently for each reach.

Reach 1

Table 24 and Figure 56 below detail the results of the incremental cost analyses for the Reach 1 plans. Between four and five plans were considered incrementally cost effective in these analyses. The average annual costs ranged from $881,039 to $1,209,348, and produced between 222 and 264 AAHUs for the bosque.

The obvious "Best-Buy" for Reach 2 would be **Plan 1-J** which produced more than 84% of the outputs for less than 23% of the incremental costs.

Reach 2

Table 25 and Figure 57 below detail the results of the incremental cost analyses for the Reach 2 plans. Five plans were considered incrementally cost effective in both analyses. The average annual costs ranged from $51,748 to $1,658,763, and produced between 139 and 176 AAHUs for the bosque.

Table 24. Incremental cost-analysis results for the Reach 1 plans.

Incremental Results for the HEP-only Analysis							
Counter	Alternative	Annualized Output (AAHUs)	Annualized Cost	Average Cost ($/AAHU)	Incremental Cost ($)	Incremental Output (AAHUs)	Incremental Cost per Output ($/AAHU)
1	No Action	0	$0	-	-	-	-
2	Plan 1-J	222	$881,039	$3,969	$881,039	222	$3,969
3	Plan 1-K	231	$923,509	$3,998	$42,470	9	$4,719
4	Plan 1-M	264	$1,209,349	$4,581	$285,840	33	$8,662

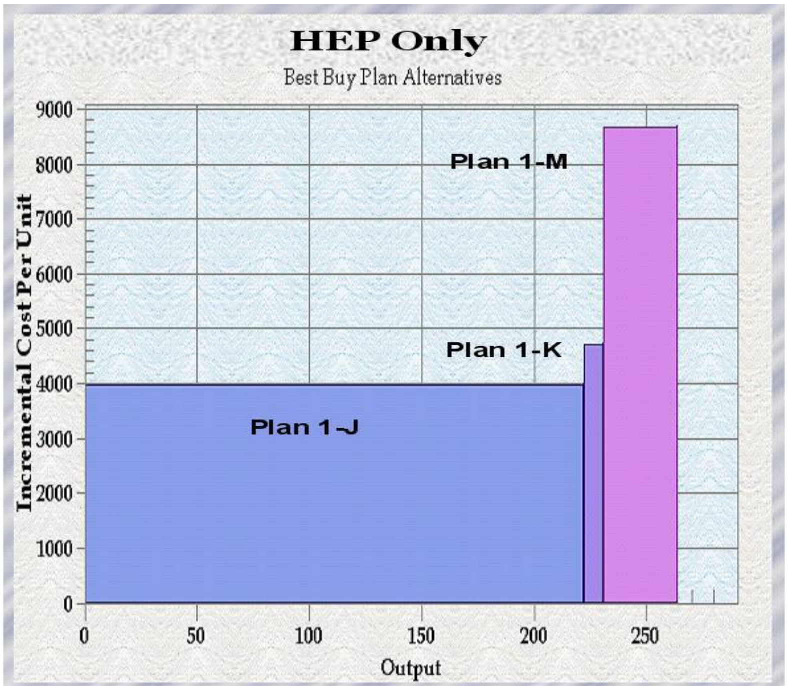


Figure 56. Incremental cost analysis results (graphical depiction) for the Reach 1 plans.

Table 25. Incremental cost analysis results for the Reach 2 plans.

Incremental Results for the HEP-only Analysis							
Counter	Alternative	Annualized Output (AAHUs)	Annualized Cost	Average Cost ($/AAHU)	Incremental Cost ($)	Incremental Output (AAHUs)	Incremental Cost per Output ($/AAHU)
1	No Action	0	$0	-	-	-	-
2	Plan 2-F	139	$51,748	$372	$51,748	139	$372
3	Plan 2-B	155	$168,711	$1,088	$116,962	16	$7,310
4	Plan 2-K	172	$420,999	$2,448	$252,288	17	$14,840
5	Plan 2-M	176	$1,658,763	$9,425	$1,237,764	4	$309,441

The obvious “Best-Buy” for Reach 2 would be **Plan 2-F** which produced more than 79% of the outputs for minimal costs when compared to the remaining plans.

Reach 3

Table 26 and Figure 58 below detail the results of the incremental cost analyses for the Reach 3 plans. Between three and four plans were considered incrementally cost effective in these analyses. The average annual costs ranged from $133,775 to $379,637 and produced between 100 and 118 AAHUs for the bosque.

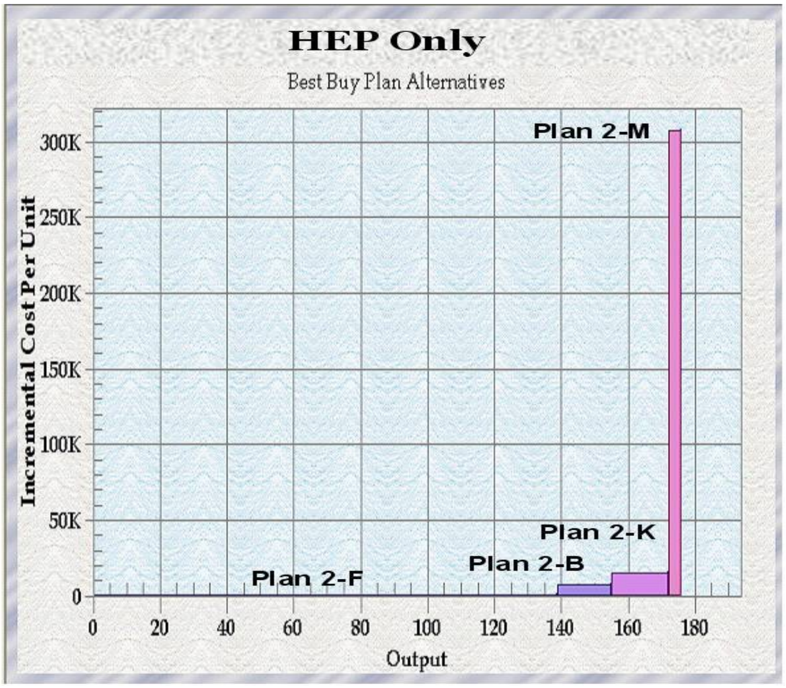


Figure 57. Incremental cost-analysis results (graphical depiction) for the Reach 2 plans.

Table 26. Incremental cost-analysis results for the Reach 3 plans.

Incremental Results for the HEP-only Analysis							
Counter	Alternative	Annualized Output (AAHUs)	Annualized Cost	Average Cost ($/AAHU)	Incremental Cost ($)	Incremental Output (AAHUs)	Incremental Cost per Output ($/AAHU)
1	No Action	0	$0	-	-	-	-
2	Plan 3-A	100	$133,775	$1,338	$133,775	100	$1,338
3	Plan 3-B	110	$236,645	$2,151	$102,870	10	$10,287
4	Plan 3-H	118	$379,637	$3,217	$142,992	8	$17,874

The obvious “Best-Buy” for Reach 3 would be **Plan 3-A,** which produced more than 85% of the outputs for minimal incremental costs (5%) when compared to the remaining plans.

Reach 4

Table 27 and Figure 59 below detail the results of the incremental cost analyses for the Reach 4 plans. Four plans were considered incrementally cost effective in both analyses. The average annual costs ranged from $83,307 to $585,981 and produced between 34 and 108 AAHUs for the bosque.

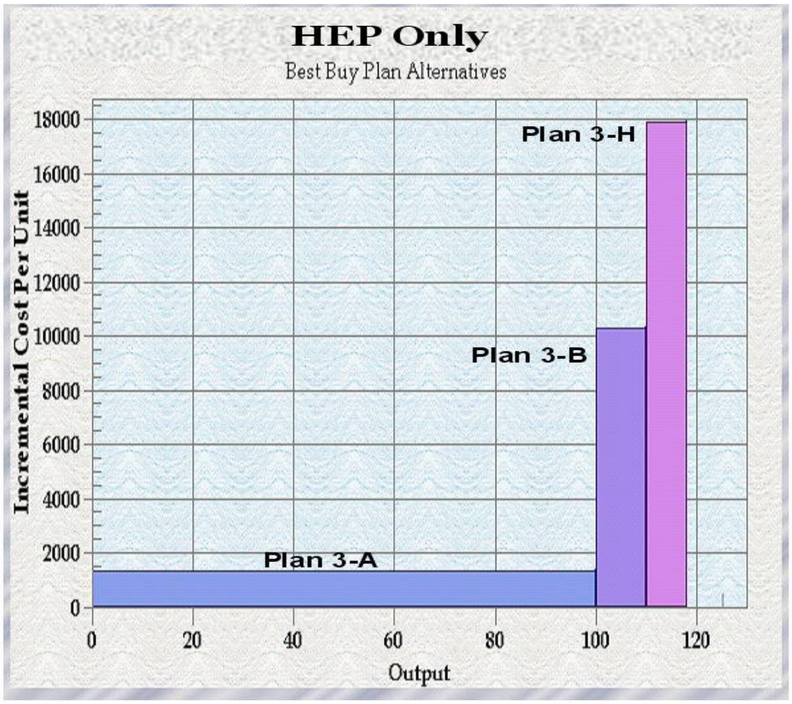


Figure 58. Incremental cost-analysis results (graphical depiction) for the Reach 3 plans.

Table 27. Incremental cost-analysis results for the Reach 4 plans.

Incremental Results for the HEP-only Analysis							
Counter	Alternative	Annualized Output (AAHUs)	Annualized Cost	Average Cost ($/AAHU)	Incremental Cost ($)	Incremental Output (AAHUs)	Incremental Cost per Output ($/AAHU)
1	No Action	0	$0	-	-	-	-
2	Plan 4-F	34	$83,307	$2,450	$83,307	34	$2,450
3	Plan 4-H	62	$210,038	$3,388	$126,731	28	$4,526
4	Plan 4-K	108	$585,981	$5,426	$375,944	46	$8,173

The most likely “Best-Buy” for Reach 4 would be **Plan 4-H,** which produced more than 57% of the outputs for less than 46% of the incremental costs of the remaining plans.

Reach 5

Table 28 and Figure 60 below detail the results of the incremental cost analyses for the Reach 5 plans. Between three and four plans were considered incrementally cost effective in these analyses. The average annual costs ranged from $154,633 to $551,833, and produced between 155 and 157 AAHUs for the bosque.

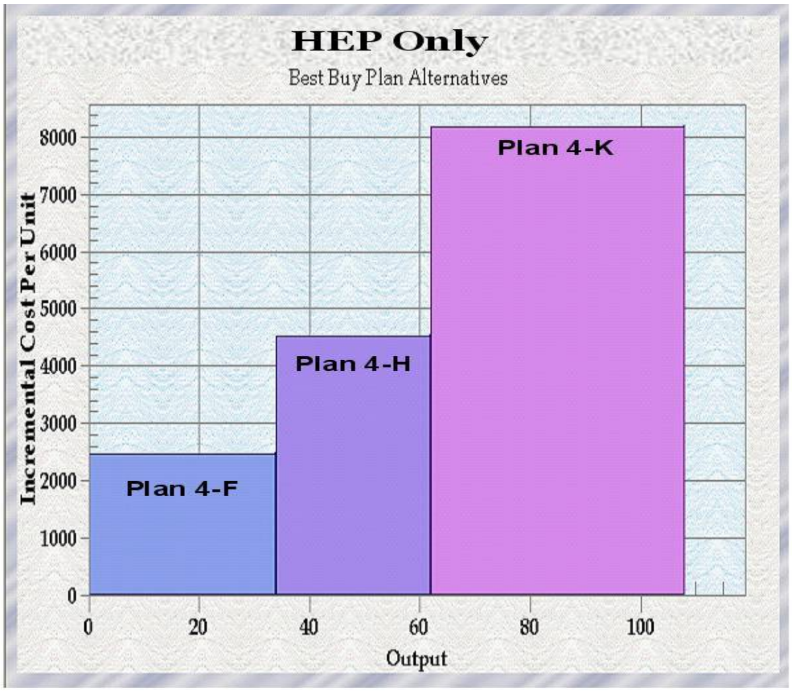


Figure 59. Incremental cost-analysis results (graphical depiction) for the Reach 4 plans.

Table 28. Incremental cost-analysis results for the Reach 5 plans.

Incremental Results for the HEP-only Analysis							
Counter	Alternative	Annualized Output (AAHUs)	Annualized Cost	Average Cost ($/AAHU)	Incremental Cost ($)	Incremental Output (AAHUs)	Incremental Cost per Output ($/AAHU)
1	No Action	0	$0	-	-	-	-
2	Plan 5-G	155	$154,633	$998	$154,633	155	$998
3	Plan 5-H	157	$319,812	$2,037	$165,179	2	$82,590

The obvious “Best-Buy” for Reach 5 would be **Plan 5-G,** which produced more than 99% of the outputs for less than 1% of the incremental costs of the remaining plans.

Summary of Reach-Level Cost Analyses

The outputs for the final suite of incrementally productive alternatives ranged from 34 to 264 Average Annual Habitat Units (AAHUs) for the bosque (riparian) community index model under the HEP-only analyses (see Table 29). This resulted in the potential creation of between 23 to 767 acres of new bosque habitat and the restoration/rehabilitation of an additional 97 to 1,012 acres of existing bosque habitat (see Figure 61).

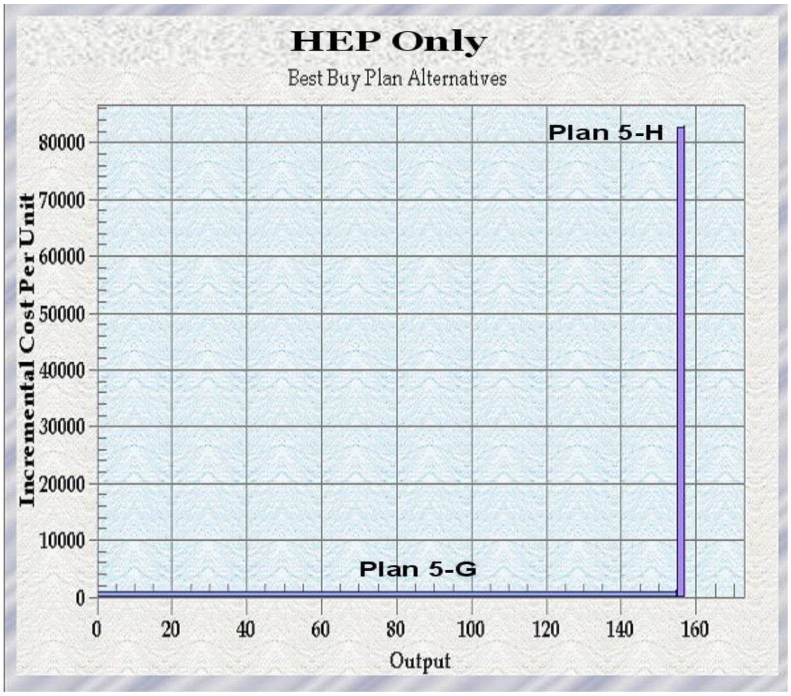
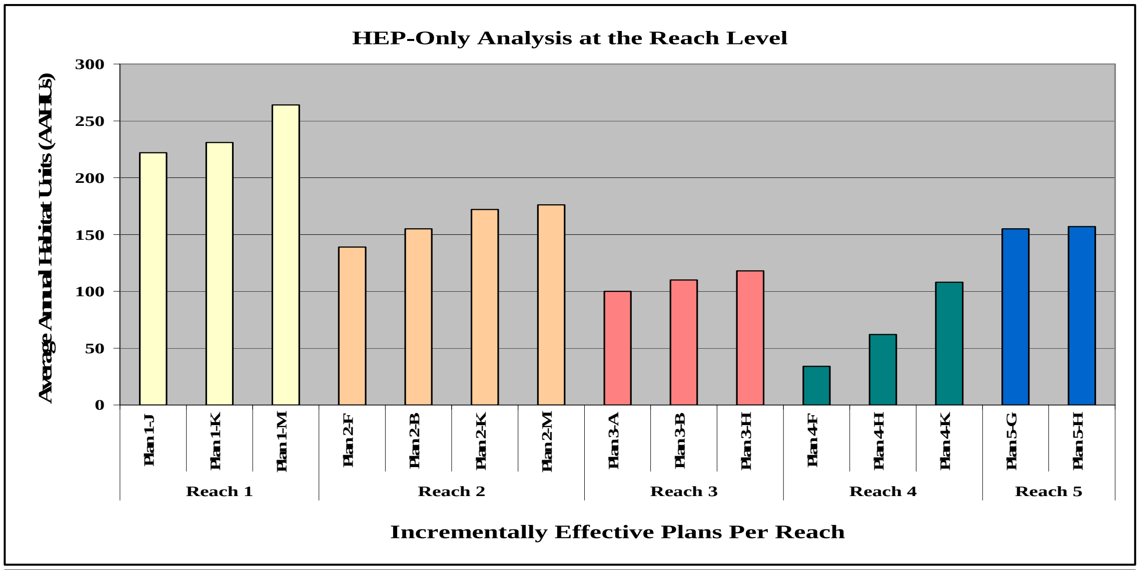


Figure 60. Incremental cost-analysis results (graphical depiction) for the Reach 5 plans.

Table 29. Final summary of predicted outputs for the proposed suite of incrementally effective solutions per reach in the MRGBER study.

HEP-only Results						
		Acres				
Reach	Alternative	Preserved	Established and/or Rehabilitated	Total Actionable Acres	Output (AAHUs)	Total Reach Cost
Reach 1	Plan 1-J	651	449	1,100	222	$44,051,967
	Plan 1-K	593	507	1,100	231	$46,175,444
	Plan 1-M	359	767	1,126	264	$60,467,428
Reach 2	Plan 2-F	546	23	569	139	$2,587,414
	Plan 2-B	499	75	574	155	$8,435,531
	Plan 2-K	307	270	577	172	$21,049,952
	Plan 2-M	97	501	598	176	$82,938,153
Reach 3	Plan 3-A	435	73	508	100	$6,688,739
	Plan 3-B	288	228	516	110	$11,832,260
	Plan 3-H	167	357	524	118	$18,981,868
Reach 4	Plan 4-F	661	68	729	34	$4,165,340
	Plan 4-H	582	164	746	62	$10,501,885
	Plan 4-K	336	419	755	108	$29,299,072
Reach 5	Plan 5-G	435	208	643	155	$7,731,650
	Plan 5-H	433	210	643	157	$15,990,607



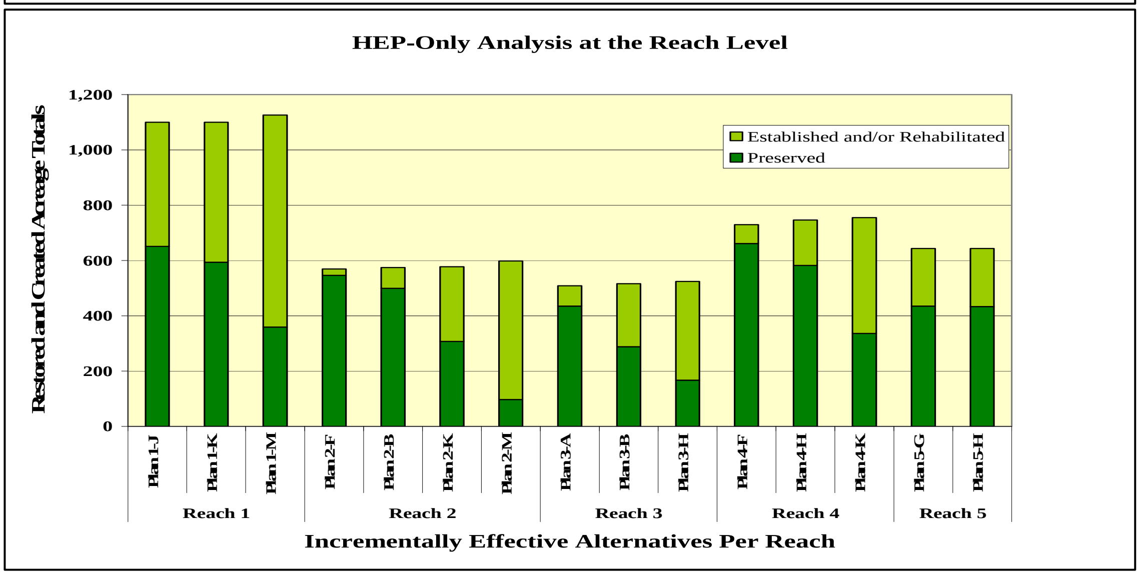


Figure 61. Comparison of Best Buy solutions for the MRGBER study on a reach-by-reach basis (ecosystem outputs and established/preserved acreages).

Project-Level Cost-Effective Analysis and Results

Given the overarching goal of system-wide bosque ecosystem restoration, and given the advice of Mr. Leigh Skaggs (IWR), the MRGBER Team conducted a second series of cost comparisons at the project level to identify cost-effective solutions for the entire study (pers. communication, June 2008). This time, the MRGBER Team made a decision to evaluate all possible combinations of plans across the entire project area using two combination options:

1. No rules governing the possible outcomes;

2. A rule-based approach that mandated the inclusion of at least one plan in each reach to address stakeholder interests and the concept of holistic and comprehensive restoration of the entire bosque on a system-wide basis.

In other words, the team used the IWR Planning Suite software to form all possible combinations across the surviving “Best-Buys” in each of the five reaches (Table 30), but under the second option, a requirement was made in the software to mandate action in each and every reach. In this way, the MRGBER team was able to promote project completeness and ensure stakeholder acceptance of the overall restoration concept.

Table 30. Costs and outputs submitted to CEA/ICA analysis for the cost comparison of the project-level solutions in the MRGBER study.

HEP Only Outputs			
Reach	Alternative	Output (AAHUs)	Annualized Cost
Reach 1	Plan 1-J	222	$881,039
	Plan 1-K	231	$923,509
	Plan 1-M	264	$1,209,349
Reach 2	Plan 2-F	139	$51,748
	Plan 2-B	155	$168,711
	Plan 2-K	172	$420,999
	Plan 2-M	176	$1,658,763
Reach 3	Plan 3-A	100	$133,775
	Plan 3-B	110	$236,645
	Plan 3-H	118	$379,637
Reach 4	Plan 4-F	34	$83,307
	Plan 4-H	62	$210,038
	Plan 4-K	108	$585,981
Reach 5	Plan 5-G	155	$154,633
	Plan 5-H	157	$319,812

It is important to note that the combination of reach plans was assumed to be additive with respect to the outputs and costs. Using the first approach (the “No-Rules” option), 32,768 alternative combinations were generated and evaluated at the project level using the HEP-based (only) data for outputs. Using the more restrictive “Rule-based” approach, 217 alternative combinations were possible.

Cost-Effective Results at the Project Level

(Table 31) below details the results of the project level cost-effective analyses compared under both the “Rule-based” and the “No Rules” cost comparison approaches. As expected, a large number of plans (49) were considered cost-effective above and beyond the No Action Plan when no rules were used to restrict the cost comparisons. The average annual costs ranged from $51,748 to $4,153,542 and produced between 139 and 823 AAHUs for the bosque (Figure 62). It should be noted that 23 of the plans omitted activities in at least one of the reaches, and in particular, activities in Reach 1 were not considered cost effective until a threshold was met (above plan #20 where costs exceeded $2,170.40/output). Alternatively, 27 plans beyond the No Action Plan were considered cost effective using the rule-based, cost-comparison approach. Here, the average annual costs ranged from $1,304,502 to $4,153,542 and produced between 650 and 823 AAHUs for the bosque.

Project-Level Incremental Cost Analysis and Results

The same process described above in the previous incremental analyses was used to evaluate the project-level solutions. Again, the E-Team was interested in comparing and contrasting the Rule-based vs. No Rule options, so the incremental cost analyses were conducted two times.

Best-Buy Results at the Project Level

(Table 32) below provides the results of these comparisons. As expected, a larger number of plans (15) were considered incrementally effective above and beyond the No Action Plan when no rules were used to restrict the cost comparisons. The average incremental cost per output ranged from $372 to $$309,441 and incrementally produced between 139 and 4 outputs for the bosque (Figure 63). It should be noted that the first 5 Best-Buy plans omitted activity in at least one of the reaches, and in particular, activities in Reach 1 were not considered incrementally effective until a threshold was met (above plan #6 where costs exceeded $2,755 as an incremental cost per output). Alternatively, 12 plans beyond the No Action Plan were considered incrementally effective using the rule-based, cost-comparison approach. Here, the average incremental cost per output ranged from $2,007 to $309,441 and incrementally produced between 650 and 4 outputs for the bosque.

Table 31. Cost-effective results for the entire MRGBER project under the two options (no rule vs. rule-based comparison).

Option 1: No Rule Approach					Option 2: Rule-Based Approach				
No.	Alternative	Output	Annual Cost	Average Cost	No.	Alternative	Output	Annual Cost	Average Cost
1	No Action Plan	0	$0.00	–	1	No Action Plan	0	$0.00	–
2	Plans –, 2-F, –, –, –,	139	$51,748.28	$372.29	2	Plans 1-J, 2-F, 3-A, 4-F, 5-G	650	$1,304,502.17	$2,006.93
3	Plans –, 2-F, –, 4-F, –,	173	$135,055.07	$780.67	3	Plans 1-K, 2-F, 3-A, 4-F, 5-G	659	$1,346,971.71	$2,043.96
4	Plans –, 2-F, 3-A, –, –,	239	$185,523.05	$776.25	4	Plans 1-J, 2-F, 3-B, 4-F, 5-G	660	$1,407,372.60	$2,132.38
5	Plans –, 2-F, –, –, 5-G	294	$206,381.28	$701.98	5	Plans 1-J, 2-B, 3-A, 4-F, 5-G	666	$1,421,464.50	$2,134.33
6	Plans –, 2-F, –, 4-F, 5-G	328	$289,688.07	$883.20	6	Plans 1-J, 2-F, 3-A, 4-H, 5-G	696	$1,431,233.07	$2,056.37
7	Plans –, 2-F, 3-A, –, 5-G	394	$340,156.05	$863.34	7	Plans 1-K, 2-F, 3-A, 4-H, 5-G	705	$1,473,702.61	$2,090.36
8	Plans –, 2-F, 3-A, 4-F, 5-G	428	$423,462.84	$989.40	8	Plans 1-J, 2-F, 3-B, 4-H, 5-G	706	$1,534,103.50	$2,172.95
9	Plans –, 2-F, 3-B, 4-F, 5-G	438	$526,333.27	$1,201.67	9	Plans 1-J, 2-B, 3-A, 4-H, 5-G	712	$1,548,195.40	$2,174.43
10	Plans –, 2-B, 3-A, 4-F, 5-G	444	$540,425.17	$1,217.17	10	Plans 1-K, 2-F, 3-B, 4-H, 5-G	715	$1,576,573.04	$2,205.00
11	Plans –, 2-F, 3-A, 4-H, 5-G	474	$550,193.74	$1,160.75	11	Plans 1-K, 2-B, 3-A, 4-H, 5-G	721	$1,590,664.94	$2,206.19
12	Plans –, 2-F, 3-B, 4-H, 5-G	484	$653,064.17	$1,349.31	12	Plans 1-J, 2-B, 3-B, 4-H, 5-G	722	$1,651,065.83	$2,286.79
13	Plans –, 2-B, 3-A, 4-H, 5-G	490	$667,156.07	$1,361.54	13	Plans 1-K, 2-B, 3-B, 4-H, 5-G	731	$1,693,535.37	$2,316.74
14	Plans –, 2-B, 3-B, 4-H, 5-G	500	$770,026.50	$1,540.05	14	Plans 1-M, 2-F, 3-A, 4-H, 5-G	738	$1,759,542.30	$2,384.20
15	Plans –, 2-B, 3-H, 4-H, 5-G	508	$913,018.65	$1,797.28	15	Plans 1-K, 2-B, 3-H, 4-H, 5-G	739	$1,836,527.52	$2,485.15
16	Plans –, 2-K, 3-B, 4-H, 5-G	517	$1,022,314.92	$1,977.40	16	Plans 1-M, 2-F, 3-B, 4-H, 5-G	748	$1,862,412.73	$2,489.86
17	Plans –, 2-B, 3-A, 4-K, 5-G	518	$1,043,099.82	$2,013.71	17	Plans 1-M, 2-B, 3-A, 4-H, 5-G	754	$1,876,504.63	$2,488.73
18	Plans 1-K, 2-F, –, –, 5-G	525	$1,129,890.15	$2,152.17	18	Plans 1-M, 2-B, 3-B, 4-H, 5-G	764	$1,979,375.06	$2,590.81
19	Plans –, 2-B, 3-B, 4-K, 5-G	528	$1,145,970.25	$2,170.40	19	Plans 1-M, 2-B, 3-H, 4-H, 5-G	772	$2,122,367.21	$2,749.18
20	Plans 1-J, 2-F, –, 4-F, 5-G	550	$1,170,727.40	$2,128.60	20	Plans 1-M, 2-K, 3-B, 4-H, 5-G	781	$2,231,663.48	$2,857.44
21	Plans 1-K, 2-F, –, 4-F, 5-G	559	$1,213,196.94	$2,170.30	21	Plans 1-M, 2-B, 3-A, 4-K, 5-G	782	$2,252,448.38	$2,880.37
22	Plans 1-J, 2-F, 3-A, –, 5-G	616	$1,221,195.38	$1,982.46	22	Plans 1-M, 2-B, 3-B, 4-K, 5-G	792	$2,355,318.81	$2,973.89
23	Plans 1-K, 2-F, 3-A, –, 5-G	625	$1,263,664.92	$2,021.86	23	Plans 1-M, 2-B, 3-H, 4-K, 5-G	800	$2,498,310.95	$3,122.89
24	Plans 1-J, 2-F, 3-A, 4-F, 5-G	650	$1,304,502.17	$2,006.93	24	Plans 1-M, 2-K, 3-B, 4-K, 5-G	809	$2,607,607.23	$3,223.25
25	Plans 1-K, 2-F, 3-A, 4-F, 5-G	659	$1,346,971.71	$2,043.96	25	Plans 1-M, 2-K, 3-H, 4-K, 5-G	817	$2,750,599.37	$3,366.71
26	Plans 1-J, 2-F, 3-B, 4-F, 5-G	660	$1,407,372.60	$2,132.38	26	Plans 1-M, 2-K, 3-H, 4-K, 5-H	819	$2,915,778.50	$3,560.17

Option 1: No Rule Approach					Option 2: Rule-Based Approach				
No.	Alternative	Output	Annual Cost	Average Cost	No.	Alternative	Output	Annual Cost	Average Cost
27	Plans 1-J, 2-B, 3-A, 4-F, 5-G	666	$1,421,464.50	$2,134.33	27	Plans 1-M, 2-M, 3-H, 4-K, 5-G	821	$3,988,363.39	$4,857.93
28	Plans 1-J, 2-F, 3-A, 4-H, 5-G	696	$1,431,233.07	$2,056.37	28	Plans 1-M, 2-M, 3-H, 4-K, 5-H	823	$4,153,542.52	$5,046.83
29	Plans 1-K, 2-F, 3-A, 4-H, 5-G	705	$1,473,702.61	$2,090.36					
30	Plans 1-J, 2-F, 3-B, 4-H, 5-G	706	$1,534,103.50	$2,172.95					
31	Plans 1-J, 2-B, 3-A, 4-H, 5-G	712	$1,548,195.40	$2,174.43					
32	Plans 1-K, 2-F, 3-B, 4-H, 5-G	715	$1,576,573.04	$2,205.00					
33	Plans 1-K, 2-B, 3-A, 4-H, 5-G	721	$1,590,664.94	$2,206.19					
34	Plans 1-J, 2-B, 3-B, 4-H, 5-G	722	$1,651,065.83	$2,286.79					
35	Plans 1-K, 2-B, 3-B, 4-H, 5-G	731	$1,693,535.37	$2,316.74					
36	Plans 1-M, 2-F, 3-A, 4-H, 5-G	738	$1,759,542.30	$2,384.20					
37	Plans 1-K, 2-B, 3-H, 4-H, 5-G	739	$1,836,527.52	$2,485.15					
38	Plans 1-M, 2-F, 3-B, 4-H, 5-G	748	$1,862,412.73	$2,489.86					
39	Plans 1-M, 2-B, 3-A, 4-H, 5-G	754	$1,876,504.63	$2,488.73					
40	Plans 1-M, 2-B, 3-B, 4-H, 5-G	764	$1,979,375.06	$2,590.81					
41	Plans 1-M, 2-B, 3-H, 4-H, 5-G	772	$2,122,367.21	$2,749.18					
42	Plans 1-M, 2-K, 3-B, 4-H, 5-G	781	$2,231,663.48	$2,857.44					
43	Plans 1-M, 2-B, 3-A, 4-K, 5-G	782	$2,252,448.38	$2,880.37					
44	Plans 1-M, 2-B, 3-B, 4-K, 5-G	792	$2,355,318.81	$2,973.89					
45	Plans 1-M, 2-B, 3-H, 4-K, 5-G	800	$2,498,310.95	$3,122.89					
46	Plans 1-M, 2-K, 3-B, 4-K, 5-G	809	$2,607,607.23	$3,223.25					
47	Plans 1-M, 2-K, 3-H, 4-K, 5-G	817	$2,750,599.37	$3,366.71					
48	Plans 1-M, 2-K, 3-H, 4-K, 5-H	819	$2,915,778.50	$3,560.17					
49	Plans 1-M, 2-M, 3-H, 4-K, 5-G	821	$3,988,363.39	$4,857.93					
50	Plans 1-M, 2-M, 3-H, 4-K, 5-H	823	$4,153,542.52	$5,046.83					

Note: "—" indicates a No Action solution for the individual reaches. (Continued)

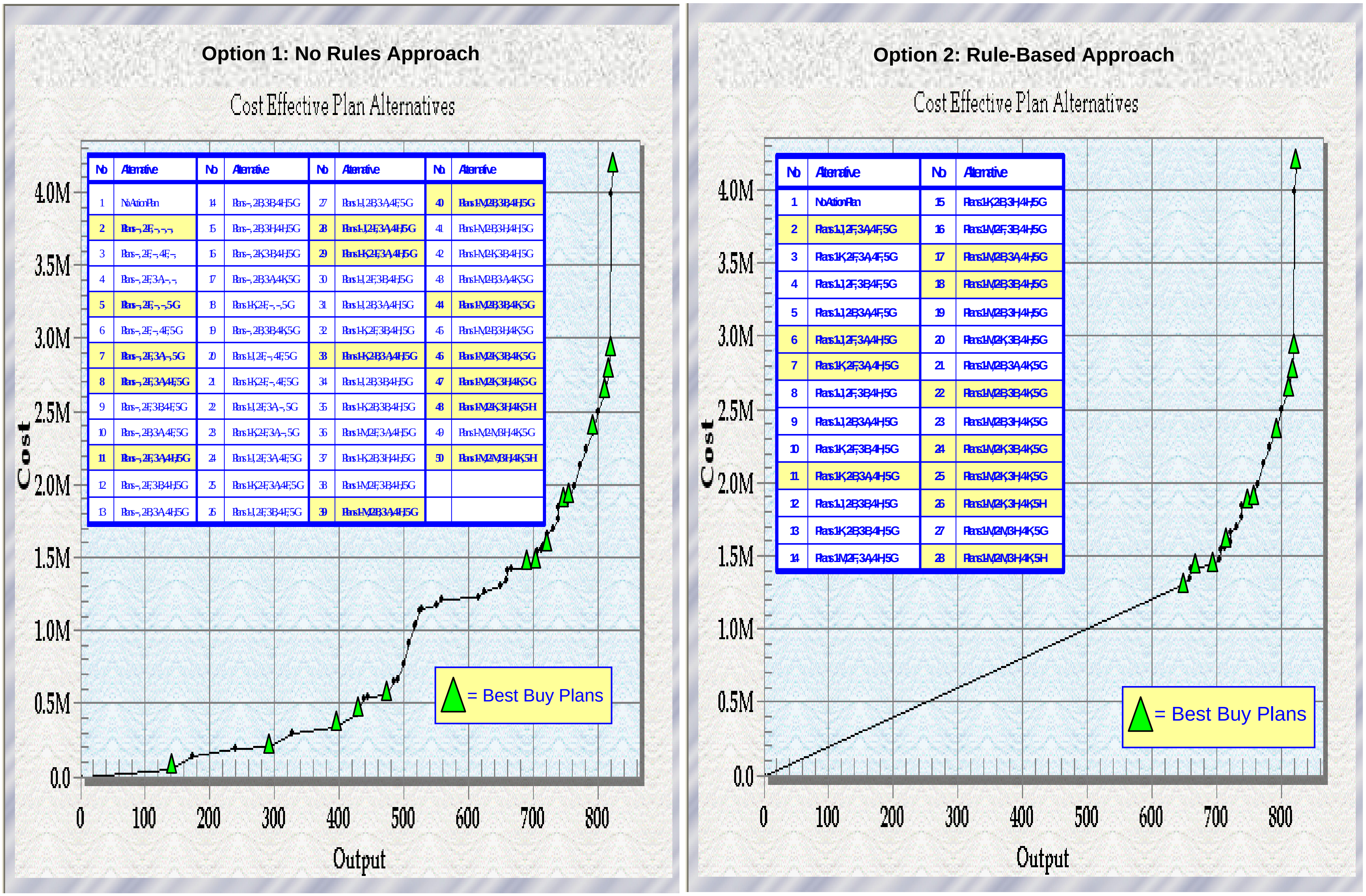


Figure 62. Graphical comparison of the cost-effective results for the entire MRGBER project under the two options (the "No rule" option is on the left and the "Rule-based" option is on the right).

Table 32. ICA results for the entire MRGBER project under the two options (no rule vs. rule-based comparison).

No Rules Approach							
No.	Alternative	Output	Annual Cost	Average Cost	Incremental Cost	Incremental Output	Incremental Cost per Output
1	No Action Plan	0	$0	–	–	0	–
2	Plans –, 2-F, –, –, –,	139	$51,748	$372	$51,748	139	$372
3	Plans –, 2-F, –, –, 5-G	294	$206,381	$702	$154,633	155	$998
4	Plans –, 2-F, 3-A, –, 5-G	394	$340,156	$863	$133,775	100	$1,338
5	Plans –, 2-F, 3-A, 4-F, 5-G	428	$423,463	$989	$83,307	34	$2,450
6	Plans –, 2-F, 3-A, 4-H, 5-G	474	$550,194	$1,161	$126,731	46	$2,755
7	Plans 1-J, 2-F, 3-A, 4-H, 5-G	696	$1,431,233	$2,056	$881,039	222	$3,969
8	Plans 1-K, 2-F, 3-A, 4-H, 5-G	705	$1,473,703	$2,090	$42,470	9	$4,719
9	Plans 1-K, 2-B, 3-A, 4-H, 5-G	721	$1,590,665	$2,206	$116,962	16	$7,310
10	Plans 1-M, 2-B, 3-A, 4-H, 5-G	754	$1,876,505	$2,489	$285,840	33	$8,662
11	Plans 1-M, 2-B, 3-B, 4-H, 5-G	764	$1,979,375	$2,591	$102,870	10	$10,287
12	Plans 1-M, 2-B, 3-B, 4-K, 5-G	792	$2,355,319	$2,974	$375,944	28	$13,427
13	Plans 1-M, 2-K, 3-B, 4-K, 5-G	809	$2,607,607	$3,223	$252,288	17	$14,840
14	Plans 1-M, 2-K, 3-H, 4-K, 5-G	817	$2,750,599	$3,367	$142,992	8	$17,874
15	Plans 1-M, 2-K, 3-H, 4-K, 5-H	819	$2,915,779	$3,560	$165,179	2	$82,590
16	Plans 1-M, 2-M, 3-H, 4-K, 5-H	823	$4,153,543	$5,047	$1,237,764	4	$309,441
Rule-Based Approach							
No.	Alternative	Output	Annual Cost	Average Cost	Incremental Cost	Incremental Output	Incremental Cost per Output
1	No Action Plan	0	$0	–	–	0	–
2	Plans 1-J, 2-F, 3-A, 4-F, 5-G	650	$1,304,502	$2,007	$1,304,502	650	$2,007
3	Plans 1-J, 2-F, 3-A, 4-H, 5-G	696	$1,431,233	$2,056	$126,731	46	$2,755
4	Plans 1-K, 2-F, 3-A, 4-H, 5-G	705	$1,473,703	$2,090	$42,470	9	$4,719
5	Plans 1-K, 2-B, 3-A, 4-H, 5-G	721	$1,590,665	$2,206	$116,962	16	$7,310
6	Plans 1-M, 2-B, 3-A, 4-H, 5-G	754	$1,876,505	$2,489	$285,840	33	$8,662
7	Plans 1-M, 2-B, 3-B, 4-H, 5-G	764	$1,979,375	$2,591	$102,870	10	$10,287
8	Plans 1-M, 2-B, 3-B, 4-K, 5-G	792	$2,355,319	$2,974	$375,944	28	$13,427
9	Plans 1-M, 2-K, 3-B, 4-K, 5-G	809	$2,607,607	$3,223	$252,288	17	$14,840
10	Plans 1-M, 2-K, 3-H, 4-K, 5-G	817	$2,750,599	$3,367	$142,992	8	$17,874
11	Plans 1-M, 2-K, 3-H, 4-K, 5-H	819	$2,915,779	$3,560	$165,179	2	$82,590
12	Plans 1-M, 2-M, 3-H, 4-K, 5-H	823	$4,153,543	$5,047	$1,237,764	4	$309,441

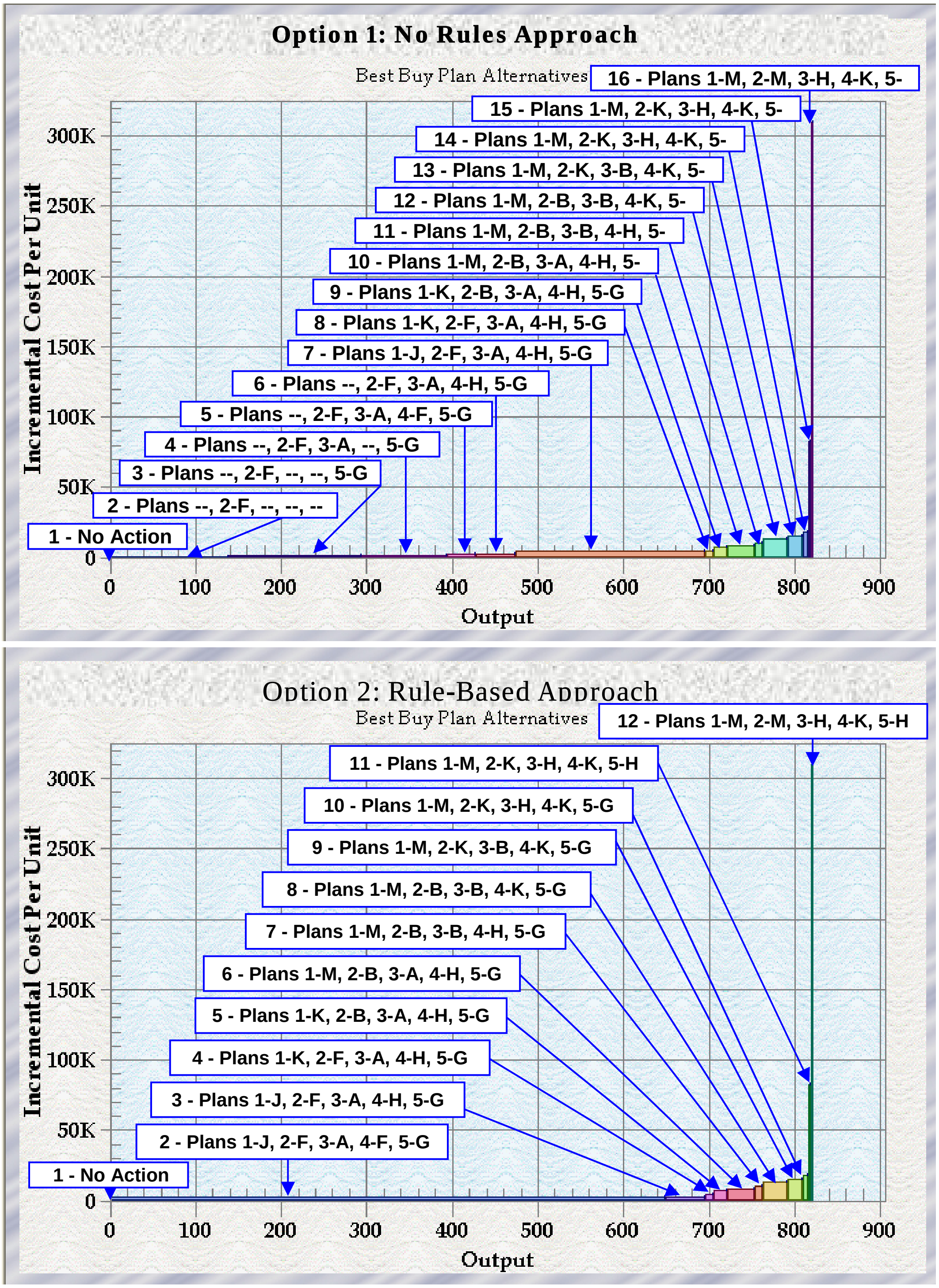


Figure 63. Graphical comparison of the ICA results for the entire MRGBER project under the two options (the “No rule” option is on the top and the “Rule-based” option is on the bottom).

6 Summary and Conclusions

Summary of Results

So what do the results of these multiple analyses offer to the District decision makers and their stakeholders in their search for a recommended plan? Generalities can be made easily enough. Overall, the District can expect that the proposed MRGBER ecosystem restoration efforts will provide significant benefits in terms of bosque habitat: 67-80% improvement over the No Action Plan when features are implemented in all five reaches (Table 33).

Table 33. Final 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.

No Rules Approach						
No.	Alternative	Annualized Outputs	Total Plan Costs	Improvement Over the No Action Plan[1]	Percent of Virtual Reference[2]	Final HSI[3]
1	No Action Plan	0	$0	0%	0%	0.36
2	Plans --, 2-F, --, --, --,	139	$2,478,947	13%	6%	0.41
3	Plans --, 2-F, --, --, 5-G	294	$5,222,055	29%	12%	0.46
4	Plans --, 2-F, 3-A, --, 5-G	394	$5,093,231	38%	16%	0.50
5	Plans --, 2-F, 3-A, 4-F, 5-G	428	$10,192,167	42%	22%	0.51
6	Plans --, 2-F, 3-A, 4-H, 5-G	474	$12,439,871	44%	23%	0.51
7	Plans 1-J, 2-F, 3-A, 4-H, 5-G	696	$24,527,570	67%	39%	0.59
8	Plans 1-K, 2-F, 3-A, 4-H, 5-G	705	$26,344,476	68%	40%	0.60
9	Plans 1-K, 2-B, 3-A, 4-H, 5-G	721	$28,354,665	69%	40%	0.60
10	Plans 1-M, 2-B, 3-A, 4-H, 5-G	754	$32,479,093	71%	41%	0.60
11	Plans 1-M, 2-B, 3-B, 4-H, 5-G	764	$34,474,601	72%	41%	0.60
12	Plans 1-M, 2-B, 3-B, 4-K, 5-G	792	$41,480,438	76%	42%	0.62
13	Plans 1-M, 2-K, 3-B, 4-K, 5-G	809	$46,140,227	78%	42%	0.62
14	Plans 1-M, 2-K, 3-H, 4-K, 5-G	817	$48,705,559	79%	42%	0.62
15	Plans 1-M, 2-K, 3-H, 4-K, 5-H	819	$51,634,650	79%	42%	0.62
16	Plans 1-M, 2-M, 3-H, 4-K, 5-H	823	$78,390,802	80%	42%	0.62

[1] Values are a comparison of total Habitat Units (HUs) over the life of the project (i.e., the period of analysis), but not annualized.

[2] Values derived through relative weighting of reach contribution by area.

Furthermore, if one compares the proposed restoration initiatives to a "virtual" reference condition (a condition in which the components of the HSI bosque model are optimized at 1.0 HSI by the first year of evaluation, and the maximum number of acres are restored in each reach), one would find that the proposed plans can achieve approximately 40% of the maximum potential. And if one were to merely consider the level of quality or integrity achieved given the final HSI outputs for the proposed plans, one would find that the majority of the plans achieve at least a 0.60 HSI ("high or good functionality" based on the interpretative descriptions provided in Table 5 earlier in this report) by the end of the study period.

As was discussed in earlier chapters, the MRGBER's primary goal was to provide the necessary engineering, economic and environmental plans in a timely manner to establish viable ecosystem restoration projects that would restore the structure and function of the bosque, while providing a solution that was acceptable to the public, local sponsors, and USACE (USACE 2002, 2003a, 2007, 2010). Given the results documented in the previous chapters of this report, the District can reasonably assume that this goal can be met. Under the final array of ecologically productive, incrementally effective alternative scenarios, the bosque community can increase in both quantity and quality as a direct result of reconnecting the hydrology to the system and re-establishing a dynamic mosaic of multi-aged stands of cottonwood forests, coyote willow shrublands, wet meadows, wetlands, oxbow ponds, and open water areas with a variety of depths and flows (Figure 64).

Interestingly, several of the narrowly focused efforts that propose restoration in only a few reaches (e.g., Plans 2 through 6), generate net gains in habitat units over the without-project condition, but over time, show a decline in productivity as the un-addressed reaches decline in overall productivity. These results support the selection of more costly alternatives (although still incrementally effective plans) that redress landscape-level restoration of the entire bosque in the Middle Rio Grande on a larger scale (Plans 7-12).

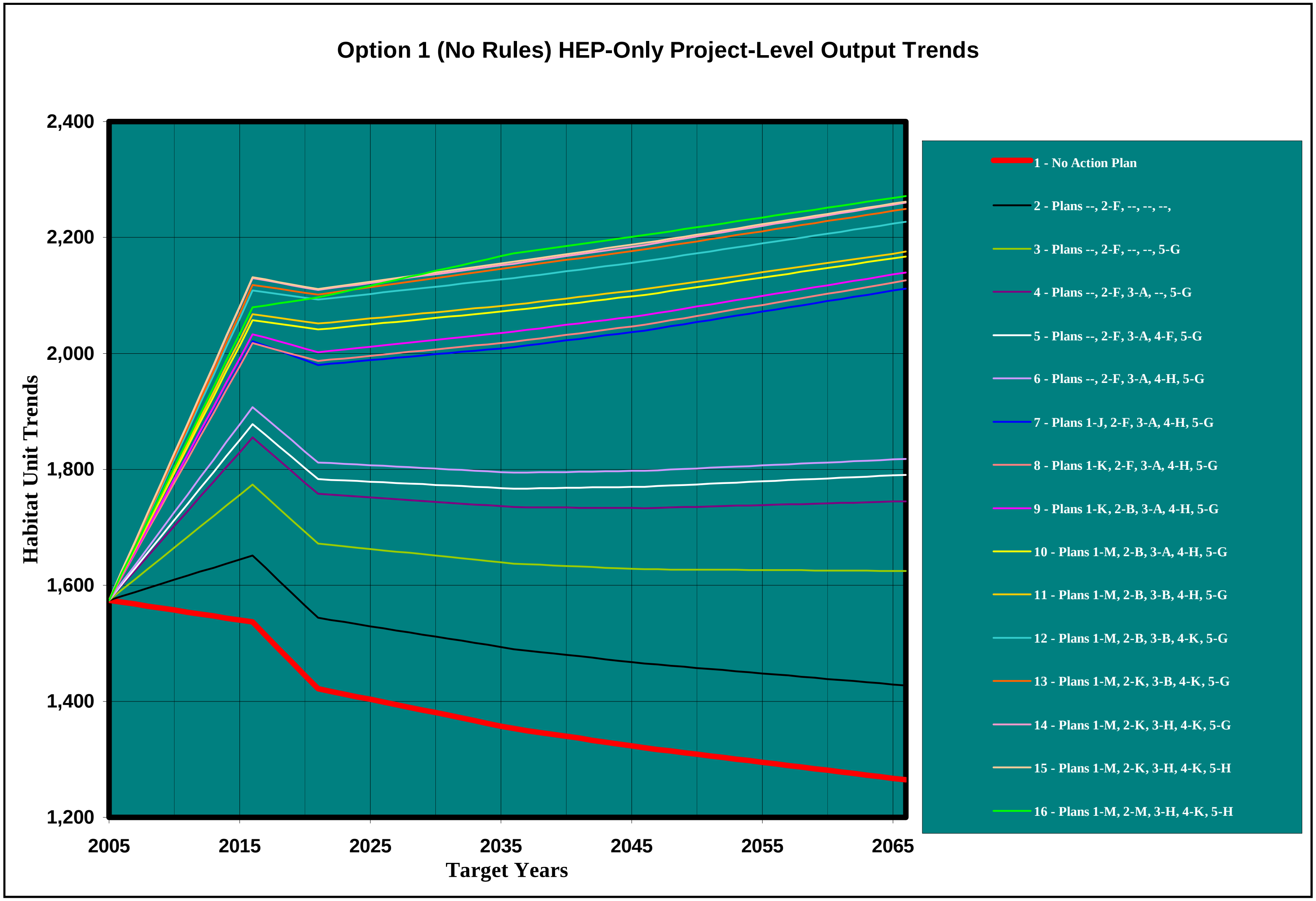


Figure 64. Based on the HEP results alone, and assuming no rules are used to restrict the numbers of combinations of alternatives formulated and compared using cost analyses, the study's decision makers can assume that the proposed Best Buy solutions will generate a net gain in bosque community integrity (habitat quality and quantity) over the next 50 years.

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Appendix A: Notation

AAHU	Average Annual Habitat Unit
AOSD	City of Albuquerque Open Space Division
BOR	Bureau of Reclamation
CEA	Cost Effectiveness Analysis
CT	Cover Type
CV	Coefficient of Variation
EA	Environmental Assessment
EC	Engineering Circular
ERDC-EL	Engineer Research and Development Center, Environmental Laboratory
E-Team	Ecosystem Assessment Team
EXHEP	EXpert Habitat Evaluation Procedures Module
EXHGM	EXpert Hydrogeomorphic Approach to Wetland Assessments Module
GIS	Geographic Information System
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HGM	Hydrogeomorphic Wetland Assessment
HSI	Habitat Suitability Index
HU	Habitat Unit
ICA	Incremental Cost Analysis
ISC	Interstate Stream Commission
ITRT	Independent Technical Review Team
IWR	Institute for Water Resources
LRSI	Life Requisite Suitability Index
LPDT	Laboratory-based Project Delivery Team
LPP	Locally Preferred Plan
LTR	Laboratory-based Technical Review
LTRT	Laboratory-based Technical Review Team
LULC	Land Use/Land Cover
MRGBER	Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study
MRGCD	Middle Rio Grande Conservancy District
NER	National Ecosystem Restoration Plan
NEPA	National Environmental Policy Act

NHNM	Natural Heritage New Mexico
NMDGF	New Mexico Department of Game and Fish
NMSFD	New Mexico State Forestry Division
NRC	National Research Council
NRCS	Natural Resources Conservation Service
O&M	Operations and Maintenance
PDT	Project Delivery Team
PMIP	USACE Planning Models Improvement Program
RMRS	Rocky Mountain Research Station
RA	Relative Area
SERI	Society of Ecological Restoration International
SI	Suitability Index
TY	Target Year
UNM	University of New Mexico
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WOP	Without-project Condition
WP	With-project Condition

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, Hansen, and Orth 1995).

Alternative (i.e., Alternative Plan, Plan, or Solution)

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

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

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

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

Alternative (cont)

Alternative 3: 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 be used 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 (i.e., period of analysis), where:

Cumulative HUs =

∑ (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 your local USFWS office.

Calibration The use of known (reference) data on the observed relationship between a dependent variable and an independent variable to make estimates of 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 2003b).

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 Function

Ecosystem functions are the dynamic attributes of ecosystems, including interactions among organisms and interactions between organisms and their environment (SERI 2004). Some restoration ecologists limit the use of the term "ecosystem functions" to those dynamic attributes which most directly affect metabolism, principally the sequestering and transformation of energy, nutrients, and moisture. Examples are carbon fixation by photosynthesis, trophic interactions, decomposition, and mineral nutrient cycling. When ecosystem functions are strictly defined in this manner, other dynamic attributes are distinguished as "ecosystem processes" such as substrate stabilization, microclimatic control, differentiation of habitat for specialized species, pollination and seed dispersal. Functioning at larger spatial scales is generally conceived in more general terms, such as the long-term retention of nutrients and moisture and overall ecosystem sustainability.

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 (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 interrelationship. For example, for optimal wood duck habitat conditions, at least 20 percent of an area should be composed of cover types providing brood-cover habitat (a life requisite). If an area has less than 20 percent 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, Hansen, and Orth 1995).
Field Data	This information is collected on various parameters (i.e., 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.

Habitat Suitability Index Model (HSI) (cont)	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, Hansen, and Orth 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) (aka 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.
National Economic Development (NED) Plan	For all project purposes except ecosystem restoration, the alternative plan that reasonably maximizes net economics benefits consistent with protecting the Nation’s environment, the NED plan, shall be selected. 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, shall be selected. 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 there is no federal action 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, Hansen, and Orth 1995).

Program Combinations of recommended plans from different sites make up a program. Where the recommended plan at each such site within a program is measured in the same units, a cost analysis can be applied in a programmatic evaluation (Robinson, Hansen, and Orth 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 wetland 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.

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 acres. 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, Hansen, and Orth 1995).
Single Formula Model (SM)	In habitat assessments, there are two potential types of models 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, Hansen, and Orth 1995).
Solutions (aka 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., a 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 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) 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, Hansen, and Orth 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 an 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 (0r behaves) as it was intended.

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

Without-project Condition(WOP) (aka 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 (aka period of analysis), 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: Index Model Components and Variables

Below, the component algorithms and variables associated with the bosque community index model developed for the MRGBER study are provided in tabular format (Table C1). For further details refer to Burks-Copes and Webb 2009.

Table C1. Variables used in the MRGBER community index model.

Variable Code	Variable Description	Cover Type Cross-Reference
CANFORB	Canopy Cover Of Forb Species (%)	TYPE_6T TYPE_6U TYPE_6W
CANGRASS	Canopy Cover Of Grass Species (%)	TYPE_6T TYPE_6U TYPE_6W
CANHERB	Canopy Cover Of Herbaceous Vegetation (%)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
CANSEDGE	Canopy Cover Of Sedge Species (%)	TYPE_6T TYPE_6U TYPE_6W
CANSHRUB	Canopy Cover Of Shrubs (%)	ALL
CANTREE	Canopy Cover Of Overstory Trees (%)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
COVGRND	Ground Cover Present (%)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
CTGRNDCOV	Count of Ground Cover Categories Present	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
DEPTHGW	Depth To Groundwater (ft)	ALL
DEPTHOM	Depth Of Organic Matter (cm)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
DISTBIGTR	Distance To Biggest Tree From Sample Point (m)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
DISTPATCH	Distance To Nearest Patch (aka Nearest Neighbor of Forest or Meadow) (m)	ALL
DURATION	Average Duration Of Flooding Events (days)	ALL

Variable Code	Variable Description	Cover Type Cross-Reference
FLOODFREQ	Frequency Of Flooding (#/yr)	ALL
INDICATFB	Percent Of Forb Canopy That Is Undesirable Indicator Species (%)	TYPE_6T TYPE_6U TYPE_6W
INDICATGR	Percent Of Grass Canopy That Is Undesirable Indicator Species (%)	TYPE_6T TYPE_6U TYPE_6W
INDICATHB	Percent Of Herbaceous Canopy That Is Undesirable Indicator Species (%)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
NATIVESDG	Percent Of Sedge Canopy That Is Desirable Indicator Species (%)	TYPE_6T TYPE_6U TYPE_6W
NATIVETREE	Percent Of Tall Overstory Tree Canopy That Is Native Species (%)	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
PATCHSIZE	Size Of Patch (ac)	ALL
SPPCOUNT	Number Of Native Tree & Shrub Species (presence/absence)	ALL
TYPDISTURB	Type of Human Disturbance (aka Adjacent Landuse Within 2 km)	ALL
WETTEDAREA	Percent Of Polygon That Is Wet (%)	ALL

Appendix D: Model Certification/One-Time-Use Approval

One-time-use approval was granted by the Eco-PCX and the memo has been included here.

DEPARTMENT OF THE ARMY
MISSISSIPPI VALLEY DIVISION, CORPS OF ENGINEERS
P.O. BOX 80
VICKSBURG, MISSISSIPPI 39181-0080

REPLY TO
ATTENTION OF:

CEMVD-RB-T 23 April 2009

MEMORANDUM FOR Commander, South Pacific Division
ATTN: (Paul Bowers, CESPD-PDC)

SUBJECT: Middle Rio Grande Bosque Feasibility, New Mexico General Investigation Detailed Feasibility Study, Ecosystem Restoration Planning Center of Expertise Endorsement of Review Plan

1. References:
a. EC 1105-2-410, Review of Decision Documents, 22 August 2008.

2. The enclosed Review Plan (RP) complies with all applicable policy and provides an adequate peer review of the plan formulation, engineering, and environmental analyses, and other aspects of the plan development. The Ecosystem Restoration Planning Center of Expertise (ECO-PCX) has reviewed the RP and documentation of the review is attached.

3. The ECO-PCX concurs with the conclusion that Independent External Peer Review of this project is not necessary. Documentation and review of the Bosque Community Habitat Suitability Index Model is sufficient to demonstrate technical and system quality of the model for single-use on this project. Non-substantive changes to this RP do not require further approval.

3. The ECO-PCX recommends the RP for approval by the MSC Commander. Upon approval of the RP, please provide a copy of the approved RP, a copy of the MSC Commander approval memorandum, and the link to where the RP is posted on the District to Jodi Staebell and Valerie Ringold.

4. Thank you for the opportunity to assist in the preparation of the Review Plan. Please continue to coordinate the Agency Technical Review efforts outlined in the RP with the ECO-PCX.

Enclosure

Jodi Staebell
Operational Director,
National Ecosystem Planning
Center of Expertise

CF:
CEMVD-RB-T (D. Vigh, J. Staebell)
CEMVD-PD-N (Smith, Wilbanks)
CEPOA-EN-CW-PF (V. Ringold)
CESPD-PDC (P. Bowers, P. Devitt)
CESPD-PDS-P (F. Tabatai)
CESPA-PM-C (A. Austin-Johnson)
CESPA-PM-L (K. Schaeffer, M. Mann)

Appendix E: 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 perform a review of both the model development process and the model itself. To ensure 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. Mr. Todd Caplan (Parametrix) – technical (lead E-Team) reviewer
2. Dr. Andrew Casper (ERDC-EL) – technical (peer) reviewer,
3. Ms. Kristine Nemec (Kansas City District) – technical (peer) reviewer,
4. Janean Shirley – editorial review (Technical Editor),
5. Ms. Antisa Webb - management review (Branch Chief),
6. Dr. Edmond J. Russo – management review (Division Chief),
7. Dr. Steve Ashby – program review (System-wide Water Resources Research Program, Program Manager),
8. Dr. Al Cofrancesco – program review (Technical Director), and
9. 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 ensuring <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

[1] Resumes for Dr. Casper and Ms. Nemec (i.e., the technical peer reviewers) and Mr. Todd Caplan (lead E-Team reviewer) can be found immediately following the comment/response tables at the end of this appendix.

2. Whether the analytic methods used were environmentally sound, appropriate, reasonable, fall within policy guidelines, and yielded reliable results
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
5. Whether the products met the customer's needs and expectations

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 (Table E1 and Table E2). In the EL Electronic Manuscript Review System (ELEMRS) 2.0, both peer 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."

Table E1. Review comments and responses.

Review Comments				
Project:	Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP) Analyses, Results and Documentation		Review Focus: Assessment Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)	
Reviewer	Page/ Para	Chapter	Reviewer Comments	Response
Kristine Nemec	Throughout doc	NA	Grammar and spelling suggestions made in track changes format	Concur and incorporated.
	References	References	Missing or references included that were not cited in text.	Concur and rectified
	Pg. 13 Para 2	2	"uses a single formula to describe the relationship between quality and carrying capacity for the site." Previous page says HEP is not a carrying capacity model so since HIS is nested within HEP and describes carry by capacity within a site this is a little confusing.	Concur and corrected
	Pg. 104	Table 10	Explain why some cells are shaded black	Concur and explanation incorporated into table footnote.
Andy Casper	Throughout doc	NA	Grammar and spelling suggestions made in track changes format	Concur and incorporated.
	References	References	Missing or references included that were not cited in text.	Concur and rectified
	Pg. 22 Study Background	1	I think this is a REALLY informative section – especially for a stakeholder who does not understand how/why these projects get going. Definitely keep it.	Concur

Review Comments				
Project:	Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP) Analyses, Results and Documentation		Review Focus: Assessment Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)	
Reviewer	Page/ Para	Chapter	Reviewer Comments	Response
Andy Casper	Pg. 29	1 first para	“The MRGBER study team made the decision to assess ecosystem benefits using HEP and a single community-based functional HSI model (Burks-Copes and Webb 2009) therein.” Statement implies there was a choice - Is there a need to state what they selected against using (i.e. what are the alternatives and why were they not chosen) or is HEP the default/required by the USACE regulations?	Although the authors concur with the advice, a definitive discussion of methodology selection and defense is not appropriate here (in this forum), and has been addressed in numerous past and ongoing R&D activities at the EL. The authors refer the reviewer to a particular white paper written by Stakhiv et al in 2001 (refer to references in this report for full citation). For now, the authors have decided to forgo a lengthy discussion of the pros/cons of various methodologies and rephrased the selection statement in the text.
	Pg. 40	2	“Several evaluation techniques have been developed to capture or quantify ecosystem health and function.” And they are? Perhaps you can cite an articles/documents that names them and reviews their pros & cons	Concur, citations provided.
	Pg. 40	2 3rd para	Need to explicitly link equate HSI and HEP?	Absolutely – the authors acknowledge that the community of practice (in error) interchangeably uses the terms HEP model and HSI models, when in fact HEP is an accounting methodology, whereas the “mathematical models” used with the HEP accounting framework are in fact HSI models. It is the authors’ intent to reinforce the concept that there is no such thing as a “HEP model,” but rather that there are HSI models used inside the HEP methodology.

Review Comments				
Project:	Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP) Analyses, Results and Documentation		Review Focus: Assessment Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)	
Reviewer	Page/ Para	Chapter	Reviewer Comments	Response
Andy Casper	Pg. 41	2	"... with less than a landscape scientists training or experience in this arena." Ouch! Disrespectful? After all they are the ones we want to embrace the approach....	Do not concur – it is a statement of fact, evidenced by the minimal number of certified HEP scientists in the USACE.
	Pg. 43	2	Multiple Formula Models After reading the paragraph I am not sure whether this is synonymous with community HIS or not?	Concur – verbiage revised.
	Pg. 44	2	"Applying HEP to the MRGBER Study: 12 Steps" This is a good section	Concur and appreciate the reviewer's comment.
	Pg. 110	3	"... variables)" This doesn't seem like a qualitative term –" the bottom land is of 'variable' condition" – perhaps you should list a couple of the variable states instead?	Do not concur – the reviewer has misconstrued the definition of variable in the HEP context. To address this concern, the term variable has been added to the glossary.
	Pg. 113	3	" ... variable per cover type" I am still a bit confused about what you mean by variable – maybe category of cover type?	Refer to response immediately above.
Andy Casper	Pg 129	4	" ... function (i.e., quality)" I am not sure these two concepts are synonymous	Do not concur – in index-based assessments (e.g. HGM and HEP, function is measured using indices that provide the "quality" measurement of the unit output (Quantity x Quality). No change in text was made.

Review Comments				
Project:	Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP) Analyses, Results and Documentation		Review Focus: Assessment Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)	
Reviewer	Page/ Para	Chapter	Reviewer Comments	Response
Todd Caplan	Throughout the doc	NA	Suggest re-naming the cover types to remove ageclass descriptions (Mature, Immature, etc.). Also suggest changing photos and removing height descriptions..	Do not concur. The cover types utilized by this report were agreed upon by the E-Team early in the process and are not subject to change at this point. This information was obtained from past documentation, and it is important to maintain a stable description from the preceding studies, and into future studies.
	References	References	Missing or references included that were not cited in text.	Concur and rectified.
	Page 18	Introduction	“Historically, the Rio Grande . . . “ This is true of the Middle and portions of the lower Rio Grande, but not across the board. You should qualify this statement or simply say "Historically, the Middle Rio Grande in central New Mexico was considered....."	Concur and corrected throughout document.
	Page 21	Introduction	“ . . . (*Tamarix ramosissina*) . . . . , and Bermuda granss (Cynodon dactylon) . . .” It's actually T. chinensis, not ramosissima. . . . and bermuda grass is not nearly as invasive/pervasive as Kochia (Bassia scoparium). There are also several other grasses that are more invasive than bermuda grass, so I would cross this one out because its not really a big problem in the MRG	Concur and corrected.
	Page 67	Methods	“ . . . . have greatly reduced the acreage of Type I, III, and V woodlands. . . . . .” Is it true that their thinning has reduced stands of type 5 vegetation?	This information was provided to ERDC by the District – please refer these questions to their POC (Ondrea Hummel).

Table E2. External technical review form for HEP analysis.

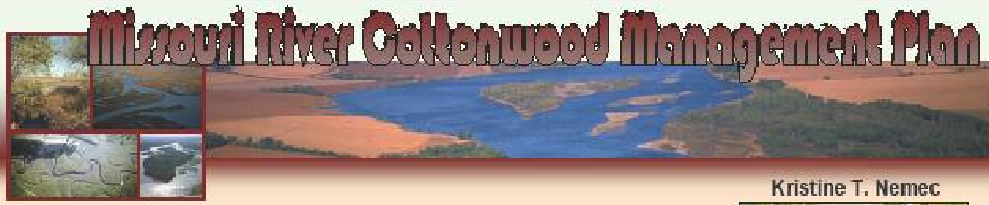
Checklist to Review HEP Assessment Reports	Peer Reviewers					
	Kristine Nemec		Andrew Casper		Todd Caplan	
General Issues	Yes	No	Yes	No	Yes	No
Were the project objectives clearly defined?	X		X		X	
Were the HEP objectives clearly defined?	X		X		X	
Was a team approach used?	X		X		X	
Were the objectives achieved?	X		X		X	
Study Delineation	Yes	No	Yes	No	Yes	No
Did the assessment consider direct and indirect effects of project alternatives?	X		X		X	
Did the assessment consider changes in land use?	X		X		X	
Did the assessment consider migration routes for fish and wildlife?	X		NA	NA	NA	NA
Did the assessment consider recreation?	X		X		X	
Did the assessment consider species home ranges?	NA	NA	NA	NA	NA	NA
Did the assessment consider cumulative effects?	X			X	X	
Cover Typing	Yes	No	Yes	No	Yes	No
Were cover types appropriate for the region?	X		X		X	
Were aerial photos used?	X		X		X	
Was ground truthing used to supplement aerial photos?	X		X		X	
Were critical cover types delineated? Note: This action may result in masking effects or increased collection costs!	X		X		X	
Model Selection	Yes	No	Yes	No	Yes	No
Were assumptions and criteria for model selection provided? Note: The use of too few or too many species could mask the overall impacts!	X		X		X	
Were regional resource priorities considered in model selection?	X		NA	NA	NA	NA

Checklist to Review HEP Assessment Reports	Peer Reviewers					
	Kristine Nemec		Andrew Casper		Todd Caplan	
Was model selection weighted in favor of economic, game, or nongame interests?		X		X	NA	NA
Do the models typify primary and secondary impacts of proposed project and alternatives?	X		NA	NA	X	
If guilding was used, do the species represent the various guild categories?	NA	NA	NA	NA	NA	NA
Were any unique or critical species, communities or habitats omitted?		X		X		X
Were any Federally listed Threatened or Endangered species selected? Note: The use of Threatened and/or Endangered species is a subject of concern and should not be used in most instances.		X		X		X
HSI Models	Yes	No	Yes	No	Yes	No
Were the sources of model(s) identified?	X		X		X	
Were the model assumptions documented?	X		X		X	
Was the model(s) verified?	X		X		X	
Describe the level of verification here: Reach level - but verification/validation was not described or defined well in the text – revisions were suggested (and incorporated in the final document).						
Was the verification level of the model(s) appropriate?	X		X		NA	NA
Were any special conditions present within study area to mandate modification of model?		X		X		X
Were the models modified and was adequate documentation provided for the modifications?		X		X	NA	NA
Did the models remain constant throughout the period of analysis?		X	X		NA	NA
Sampling Design	Yes	No	Yes	No	Yes	No
Was a sampling design documented?	X		X		X	
Was the sampling design appropriate for the cover types, species, models, and type of project examined?	X		X		NA	NA
Sampling Techniques	Yes	No	Yes	No	Yes	No

Checklist to Review HEP Assessment Reports	Peer Reviewers					
	Kristine Nemec		Andrew Casper		Todd Caplan	
Were the sampling techniques appropriate for the variables being measured?	X		X		X	
Were the sampling techniques appropriate for the region of the country being assessed?	X		X		X	
Was equipment calibrated prior to sampling?	X		NA	NA	NA	NA
Were field measurements actually made?	X		X		X	
Did results of sampling appear reasonable?	X		X		X	
HEP Accounting	Yes	No	Yes	No	Yes	No
Were Target Years identified? Note: A minimum of three Target Years are mandatory, namely "0," "1," and "n," where "n" = end of economic life of project.	X		X		X	
Did all alternatives use the same time frame (i.e., 50 years, 100 years) or was a conversion factor to make the data compatible?	X		X		X	
Were assumptions for futures provided?	X		X		X	
Checks for consistency of assumptions should be made. Note: Generally HSIs should not continue to increase if human populations are increasing within a study area over time. In addition, HSIs for aquatic species should not be static or decrease in values if water pollution control laws are assumed to be met.	X		X		X	
Were risk and uncertainty considered in making future projections?		X		X	NA	NA
Did you spot check calculations?		X		X	NA	NA
Describe any calculation errors found here.						
Were the outputs annualized correctly?	X		X		NA	NA
Trade-Off Analysis	Yes	No	Yes	No	Yes	No
Was rationale for using trade-offs provided?	NA	NA	NA	NA	NA	NA

Checklist to Review HEP Assessment Reports	Peer Reviewers					
	Kristine Nemec		Andrew Casper		Todd Caplan	
Is documentation adequate to withstand judicial review?	NA	NA	NA	NA	NA	NA
Were reasonable criteria used to develop the trade-offs?	NA	NA	NA	NA	NA	NA
Do the results appear reasonable?	NA	NA	NA	NA	NA	NA
Trade-offs are generally acceptable only for Resource Category 4 species or habitats. Were they used for any other Resource Category?	NA	NA	NA	NA	NA	NA
Mitigation	Yes	No	Yes	No	Yes	No
Was the USFWS Mitigation Policy considered?	NA	NA	NA	NA	NA	NA
Was the Mitigation type (i.e., in-kind, out-of-kind) compatible with the Resource Categories defined?	NA	NA	NA	NA	NA	NA
Were the management techniques suggested for mitigation applicable for the study area and habitat?	NA	NA	NA	NA	NA	NA
Was compensation area recommended consistent with the losses that would result from the project?	NA	NA	NA	NA	NA	NA
Did mitigation measures appear reasonable?	NA	NA	NA	NA	NA	NA
Data Presentation	Yes	No	Yes	No	Yes	No
Were outputs converted to other terms when appropriate (i.e., % changes, relationships of HU data to populations, acreage, habitat)?	X		X		X	
Were the outputs presented in terms of achieving HEP objectives?	X		X		X	
Was the project area placed in perspective of regional resources?	X		X		X	

Reviewer Curriculum Vitae



Kristine T. Nemec

USACE - Omaha District
1616 Capitol Avenue
Omaha, NE 68102
402-995-2685
Kristine.t.nemec@usace.army.mil

Professional Experience

Environmental Resources Specialist, U.S. Army Corps of Engineers, Omaha District, December 2002 to present

- Prepare environmental assessments required under the National Environmental Policy Act for shallow water habitat and emergent sandbar habitat projects along the Missouri River
- Designed planting specifications for riparian forest restorations in South Sioux City, Nebraska; Sioux Falls, South Dakota; and Lower Brule Sioux Reservation, South Dakota
- Served on the South Dakota Bald Eagle Management Team, 2003-05
- Developed environmental sections of mater plan updates for Gavins Point and Oahe projects in South Dakota

Education

- **Ph.D.,** In progress
  University of Nebraska at Lincoln, Lincoln, NE
- **M.S.,** Biology, 2003
  University of Nebraska at Omaha, Omaha, NE
- **B.S.,** Environmental Studies, 1999
  University of Nebraska at Omaha, Omaha, NE
  Summa Cum Laude. University Honors Program

Research & Teaching

- Restoration ecology, agroecology, and ecological resilience
- Conducted fieldwork during the summer for research projects in forest, wetland, and grassland ecosystems in Nebraska, 1995 to present
- Taught undergraduate and graduate students in Ecology, Biology I, and Biology II labs at the University of Nebraska at Omaha

Awards/Honors

- J. E. Weaver Competitive Grant. The Nature Conservancy, 2009
- Center for Great Plains Studies Grant. Center for Great Plains Studies, 2008
- Contributed two articles to a newspaper series on Platte River water issues which received the Nebraska Wildlife Federation's Conservation Communicator award, 2006 and the Renewable Natural Resources Foundation's national Excellence in Journalism award, 2007

Selected Publications & Conference Presentations

Nemec, K. T., C. R. Allen, A. Alai, G. Clements, A. Kessler, T. Kinsell, A. Major, and B. J. Stephen. Woody invasions of urban parks and trails and the changing face of urban forests in the Great Plains, USA. (Submitted for publication, Biological Invasions).

Invited speaker for cottonwood panel discussion sponsored by the Izaak Walton League, Sioux City, Iowa, 2008.

Presented poster entitled "Lower Brule Shoreline Protection and Cottonwood Habitat Enhancement Project, Lake Sharpe, South Dakota" at the Second National Conference on Ecosystem Restoration, Kansas City, Missouri. 2007.

Delivered presentation entitled "Cottonwood Community Delineation" at the Corps of Engineers Wildlife Workshop, Omaha, Nebraska. 2006.

Presented poster entitled "Cottonwood Management and Regeneration along the Missouri River" at the First National Conference on Ecosystem Restoration, Orlando, Florida. 2004.

Other Professional Activities

- Society for Ecological Restoration
- Ecological Society of America
- Nebraska Native Plant Society
- Association for Women in Science

September 2009

US Army Corps of Engineers

U.S. ARMY

ERDC

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

Parametrix

Engineering, Planning and Environmental Science

Todd Caplan

Vegetation Ecologist - Parametrix
8901 Adams St., Suite D
Albuquerque, NM 87113
505-821-4700 • tcaplan@parametrix.com

Professional Experience

Vegetation Ecologist, Senior Scientists at Parametrix, Albuquerque, NM., 2002 to present.

- Natural Resources Director and Restoration Program Manager for Pueblo Santa Ana, Bernalillo, NM., 1996-2002
- Performs ecological assessments and develops comprehensive watershed management and habitat restoration plans
- Assists in Tribal, Federal, and local government agencies with vegetation mapping, quantifying riparian and upland habitat characteristics, measuring fire-fuel loading, developing revegetation and habitat enhancement prescriptions, and writing comprehensive restoration management documents
- Works with interdisciplinary scientific teams to address complex watershed management issues

Education

- M.S. Natural Resources Conservation, 1996
  University of Montana, MT
- B.A. Psychology, 1987
  Roanoke College, VA

Project Experience

- ESA Collaborative Program-Restoration - NM
- San Acacia Reach Restoration Analysis and Recommendations
- Isleta Reach Restoration Analysis and Recommendations
- Velarde Reach Restoration Analysis and Recommendation
- Rio Grande Conceptual Restoration Plan Technical Support, Caballo Dam to American Dam, NM & TX
- River & Flood Restoration Plan - Isleta Pueblo, NM
- Bosque Wildfire Rehabilitation - Albuquerque, NM
- Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study - Albuquerque, NM
- Rio Grande Restoration Value Engineering - Albuquerque, NM
- Valencia County Bosque GIS Mapping- Albuquerque, NM
- Floodplain Forest Management Plan - Cochiti Pueblo, NM
- Master Restoration Plan Development - San Ildefonso, NM
- GIS Support Services - Albuquerque, NM
- Southwestern Willow Flycatcher Habitat Restoration Project - Cochiti Pueblo, NM
- Floodplain Habitat Restoration - Santa Ana, NM
- Rio Grande Restoration - Santa Ana, NM

Expertise

- Watershed
- Ecological Assessments
- Habitat Restoration
- Riparian Ecosystem Dynamics
- Exotic Plant Control
- Revegetation/Bioengineering
- Comprehensive Funding Strategies
- Grant Writing

Selected Publications or Conference Presentations

- Hummel, O.C. and T. Caplan. 2007. Salt cedar control and riparian restoration – be careful with generalizations. Southwest Hydrology 6(6):26-27.
- Caplan, T., McKenna, C., and L. Tear. 2005. Plant species selection for revegetating typical sites in the Albuquerque Bosque Wildfire Project. Report to the Albuquerque District, U.S. Army Corps of Engineers, Albuquerque, NM. Contract no. W912PP-04-P-F-0048. 34p.
- Caplan, T. 2002. Controlling Russian olives within cottonwood gallery forests along the Middle Rio Grande Floodplain (New Mexico). Ecological Restoration. 20 (2):138-139.
- McDaniel, K., Caplan, T. and J. Taylor. 2002. Control of Russian olive and Saltcedar re-sprouts with early and late summer herbicide applications. In: Western Society of Weed Science 2002 Research Report, Salt Lake City, Utah. March 14-17, 2002.
- Caplan T., Musslewhite, B.D., Buchanan, B.A. and J.M.H. Hendrickx. 2001. Reclaiming sodic soils following saltcedar removal on the Pueblo of Santa Ana, New Mexico. Proceedings from the Association of Surface Mining and Reclamation Conference, Albuquerque, NM; June 2001. Volume 2, pp. 332-344.

Professional Affiliations

- New Mexico Riparian Council
- Society for Ecological Restoration

December 2009

Administrative Review Status and Technical Transfer Forms

The documentation is now in senior staff and program management review. Two technology transfer forms will be completed when the document has been reviewed approved by both the senior staff and the program managers (Table E3 and Table E4).

Table E3. Internal ERDC-EL Technology Transfer Review Form.

<table>
<tr><td colspan="2">TECHNOLOGY TRANSFER STATUS SHEET</td></tr>
<tr><td colspan="2">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.</td></tr>
<tr><td colspan="2">JOB NUMBERS:

a. WORD PROCESSING SECTION ____
b. ENVIRONMENTAL INFORMATION ANALYSIS CENTER ____________________________________
c. VISUAL PRODUCTION CENTER ____</td></tr>
<tr><td>2. TITLE</td><td>3. AUTHOR(S)</td></tr>
<tr><td>4. PRESENTATION (Conference Name & Date)</td><td>5. PUBLICATION (TR, IR, MP, Journal Name, etc.)</td></tr>
<tr><td>6. SPONSOR OR PROGRAM WORK UNIT</td><td>7. DATE REQUIRED BY SPONSOR</td></tr>
<tr><td colspan="2">8. DATE DRAFT COMPLETED BY AUTHOR(S) AND AREADY FOR SECURITY OR TECHNICAL REVIEW</td></tr>
<tr><td colspan="2">9. SECURITY REVIEW (Military Projects)

a. THIS DOCUMENT HAS BEEN REVIEWED FOR SECURITY CLASSIFICATION FOLLOWING GUIDELINES SPECIFIED IN AR 380-5, DEPARTMENT OF THE ARMY INFORMAITON SECURITY PROGRAM, AND FOUND TO BE:

CLASSIFIED ___________ CONFIDENTIAL _______ SECRET __________ TOP SECRET _____
UNCLASSIFIED ________ SENSITIVE ___________ DISTRIBUTION LIMITED ________________

CLASSIFICATION WAS BASED ON THE ____
SECURITY CLASSIFICATION GUIDE DATED ____</td></tr>
<tr><td>10. AUTHOR</td><td>11. DATE</td></tr>
<tr><td>12. GROUP/DIVISION CHIEF</td><td>13. DATE</td></tr>
<tr><td colspan="2">14. IN-HOUSE TECHNICAL REVIEW (To be completed by two or more reviewers who are GS-12 or Above, Expert, or Contractor)
a. ____________________ _______________________ _________________ ____________________
DATE TO REVIEWER DATE RETURN REQUESTED DATE RETURNED TECHNICAL REVIEWER

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

b. ____________________ _______________________ _________________ ____________________
DATE TO REVIEWER DATE RETURN REQUESTED DATE RETURNED TECHNICAL REVIEWER

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

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.</td></tr>
</table>

ERDC FORM 2378
R OCT 89 PREVIOUS EDITIONS ARE OBSOLETE. (CONTINUED ON REVERSE)

15. SUPERVISORY REVIEW

THE DOCUMENT IS TECHNICALLY SUITABLE AND REVIEWERS' COMMENTS HAVE BEEN ACKNOWLEDGED. IT IS SUBMITTED FOR EDITORIAL REVIEW AND CLEARANCE FOR PUBLICATION OR PRESENTATION AS INDICATED. THE DOCUMENT CONTAINS NO COPYRIGHTED INFORMATION.* ENG FORM 4329-R OR 4330-R HAS BEEN COMPLETED, IF REQUIRED, AND IS ATTACHED TO THE DOCUMENT.

a. ____________________ ______________________ ________________ ___________________
DATE TO GROUP CHIEF DATE RETURN REQUESTED DATE RETURNED GROUP CHIEF

b. ____________________ ______________________ ________________ ___________________
DATE TO DIVISION CHIEF DATE RETURN REQUESTED DATE RETURNED DIVISION CHIEF

16. PROGRAM MANAGER REVIEW (If Appropriate)

________________________ ______________________ ________________ ___________________
DATE TO PROGRAM MANAGER DATE RETURN REQUESTED DATE RETURNED PROGRAM MANAGER

17. COMPLETE THE FOLLOWING FOR ALL REPORTS

a. RECOMMEND TYPE OF REPORTS (TR, IR, MP, Or Other):

____

b. LEVEL OF EDITING (Type 1, 2, 3, Or 4):

____

c. IF TYPE 1 OR 2 EDITING IS INDICATED, ADD A BRIEF JUSTIFICATION:

____

____

____

____

____
SIGNATURE OF DIVISION CHIEF

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Reverse of ERDC Form 2378, R OCT 89

Table E4. Security Clearance Form for ERDC-EL reports.

<table>
<tr><td colspan="6">REQUEST FOR CLEARANCE OF MATERIAL CONCERNING CIVIL WORKS FUNCTIONS OF THE CORPS (ER 360-1-1)</td></tr>
<tr><td colspan="2">THRU</td><td colspan="2">TO

CDR, USACE
CEPA-ZM
WASH, DC 20314-1000</td><td colspan="2">FROM</td></tr>
<tr><td colspan="6">1. TITLE OF PAPER</td></tr>
<tr><td colspan="2">2. AUTHOR (NAME)</td><td colspan="4">3. OFFICIAL TITLE AND/OR MILITARY RANK</td></tr>
<tr><td colspan="6">4. THIS PAPER IS SBUMITTED FOR CLEARANCE PRIOR TO PRESENTATION OR PUBLICATION AS IT FALLS INTO THE CATEGORY (OR CATEGORIES) CHECKED BELOW:</td></tr>
<tr><td colspan="3">☐ MATERIAL THAT AFFECTS THE NATIONAL MISSION OF THE CORPS.

☐ RELATES TO CONTROVERSIAL ISSUES.</td><td colspan="3">☐ MATERIAL IS SIGNIFICANTLY WITHIN THE PURVIEW OF OTHER AGNECIES OF THE FEDERAL GOVERNMENT.

☐ PERTAINS TO MATTERS IN LITIGATION.</td></tr>
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☐ COPYRIGHTED MATERIAL USED.
☐ COPYRIGHTED MATERIAL USED HAS BEEN PREVIOUSLY CLEARED IN ACCORDANCE WITH AR 25-30 AND A COPY OF T ATTACHED.</td></tr>
<tr><td colspan="6">6. FOR PRESENTATION TO:

ORGANIZATION:

CITY AND STATE:</td></tr>
<tr><td colspan="2">7. DATE OF FUNCTION</td><td colspan="4">8. DATE CLEARED PAPER IS REQUIRED</td></tr>
<tr><td colspan="2">9. FOR PUBLICATION (Name of Publication Media)</td><td colspan="4">10. DATE CLEARED PAPER IS REQUIRED</td></tr>
<tr><td colspan="6">THIS PAPER CONTAINS NO CLASSIFIED ORIGINAL OR DERIVATIVE MATERIAL.</td></tr>
<tr><td>DATE</td><td colspan="2">NAME AND TITLE (Approving Authority)</td><td colspan="3">SIGANTURE (Approving Authority)</td></tr>
<tr><td colspan="2">THRU</td><td colspan="2">TO</td><td colspan="2">FROM
CDR, USACE
CEPA-ZM
WASH, DC 20314-1000</td></tr>
<tr><td colspan="6">1. SUBJECT MANUSCRIPT IS CLEARED FOR PRESENTATION AND PUBLICATION:

☐ WITHOUT CHANGE ☐ WITH CHANGES ANNOTATED ON THE MANUSCRIPT ☐ WITH SUGGESTED CHANGES AND/OR COMMENTS ATTACHED</td></tr>
<tr><td colspan="6">2. RETURNED WITHOUT CLEARANCE FOR THE FOLLOWING REASON(S):</td></tr>
<tr><td>DATE</td><td colspan="2">NAME AND TITLE (Approving Authority)</td><td colspan="3">SIGNATURE (Approving Authority)</td></tr>
</table>

ENG FORM 4329-R, APR 91 EDITION OF JAN 82 IS OBSOLETE. (Proponent; CEPA-I)

INSTRUCTIONS FOR SUBMISSION OF MATERIAL FOR CLEARANCE (ENG Form 4239-R)

1. An original and two copies of papers or material on civil works functions or other non-military matters requiring HQUSACE approval, will be forwarded to reach HQUSACE at least 15 days before clearance is required. Including any maps, pictures and drawings, etc., referred to in the text.

2. Technical papers containing unpublished data and information obtained by the author in connection with his/her official duties will contain the following acknowledgement when released for publication outside the US Army Corps of Engineers. The acknowledgement will identify the research program which provided resources for the paper, the agency directing the program and a statement that publication is by permission of the Chief of Engineers.

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the _______________ of (Program) the United States Army Corps of Engineers by the ____________________. Permission was granted by (Agency) the Chief of Engineers to publish this information.

3. When manuscripts are submitted for publication in THE MILITARY ENGINEER, a brief biographical sketch (100 to 150 words) of the author is required, indicating his/her background in the subject matter.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)***	**2. REPORT TYPE**	**3. DATES COVERED** ***(From - To)***
August 2012	Final report	

4. TITLE AND SUBTITLE

Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP): Analyses, Results and Documentation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Kelly A. Burks-Copes and Antisa C. Webb

5d. PROJECT NUMBER

5e. TASK NUMBER

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Vicksburg, MS 39180-6199

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14. ABSTRACT

Over the last century, the Middle Rio Grande was subjected to significant anthropogenic pressures, producing a highly degraded ecosystem that today is poised on the brink of collapse. In 2004, the U.S. Army Corps of Engineers (USACE) (Albuquerque District) initiated a feasibility study of the area and began the preparation of an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the effects of proposed ecosystem restoration alternatives on the watershed's significant resources. As part of the process, a multi-agency, multi-disciplinary evaluation team was established to formulate alternatives that would address two critical problems: 1) hydrological alterations and 2) bosque (riparian) ecosystem degradation. Between 2005 and 2008, this team designed, calibrated, and applied a community-based index model for the bosque (riparian) ecosystem using standard Habitat Evaluation Procedures (HEP) (USFWS 1980a-c). The 17-mile long study area was divided into five separate reaches; within each reach a series of 44 separate measures were formulated and combined to generate no less than 56 potential alternatives for the study (approximately 8 to 13 alternatives per reach were fully formulated and evaluated). The outputs for these alternatives ranged from 3 to 264 Average Annual Habitat Units (AAHUs). The results of these evaluations are provided herein. The intent of this document is to provide details of the HEP application for the Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study (MRGBER). Readers interested in the scientific basis upon which the model was developed should refer to the additional report produced for this study (Burks-Copes and Webb 2009).

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