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System-Wide Water Resources Program

Clear Creek Watershed Flood Risk Management Habitat Assessments Using Habitat Evaluation Procedures (HEP)

Analyses, Results and Documentation

Kelly A. Burks-Copes and Antisa C. Webb

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Habitat Based Ecological Response Models

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Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under System-Wide Water Resources Program - Habitat Based Ecological Response Models

Monitored by Environmental Laboratory
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Abstract

The cumulative effects of urban development along the Clear Creek (southern Texas) over the last 100 years has led to substantial increases in flooding. The flooding can be directly attributed to both the narrowing of the floodplain and the construction of buildings and infrastructure in the region's flood-prone areas. In 1999, the USACE Galveston District initiated a feasibility study to revise past efforts and formulate new solutions to address the Clear Creek problems and contacted the U.S. Army Engineer Research and Development Center's Environmental Laboratory (ERDC-EL) in 2003 for assistance. The District is preparing an Environmental Impact Statement (EIS), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the impacts of proposed flood risk management measures in the watershed. 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 studies; (4) evaluate potential impacts; and (5) recommend and evaluate potential mitigation measures. Between 2003 and 2008, this team designed, calibrated, and applied a landscape-level community-based index model for the system's floodplain forests using standard Habitat Evaluation Procedures (HEP). One hundred and one floodplain forest Average Annual Habitat Units (AAHUs) were lost due to the proposed flood risk management measures. Twelve individual mitigation plans were evaluated to offset the impacts detailed in the NED plan. The outputs for the various mitigation scenarios ranged from 9-180 AAHUs for the forests' communities. The results of both the impact and mitigation assessments are provided herein. The intent of this document is to provide details of the HEP application (for both the impact and the mitigation assessments) for the Clear Creek project. Readers interested in the scientific basis upon which the models were developed should refer to the authors' second report entitled, *Floodplain Forest Community Index Model for the Clear Creek Watershed, Texas* (Burks-Copes and Webb in preparation).

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Preface

This report provides the documentation to support a Habitat Evaluation Procedures application evaluating the effects of both flood risk management activities and proposed mitigation plans to address flooding issues in the Clear Creek watershed south of Houston, Texas.

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

Many people contributed to the overall success of the model documentation's production. The authors wish to thank the following people for their hard work and persistence during the intensive months over which the project was assessed: Jennifer Emerson (Bowhead Information Technology Services), Andrea Catanzaro and Seth Jones (Galveston District). The authors also wish to thank Dr. Andrew Casper (ERDC), Elizabeth Brandreth (Philadelphia District), Richard Stiehl (Independent consultant, Arizona), Tom Cuba (Delta Seven, Inc., Florida), Bradford Wilcox (Texas A&M, Texas), and William Espey (Espey Consultants, Inc., Texas) for their comprehensive review of the report.

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

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

1 Introduction

Background

The cumulative effects of rapid urban development along the Clear Creek (southern Texas) over the last 100 years has led to substantial increases in flooding. The flooding can be directly attributed to both the narrowing of the floodplain and the construction of buildings and infrastructure in the region's flood-prone areas (U.S. Army Corps of Engineers (USACE) 1999; 2002, 2010) (Figures 1 and 2).

In 1999, the USACE Galveston District initiated a feasibility study to revise past efforts and formulate new solutions to address the Clear Creek problems, and contacted the U.S. Army Engineer Research and Development Center's Environmental Laboratory (ERDC-EL) in 2003 for assistance. The Clear Creek study documentation identified effective, affordable and environmentally sensitive flood risk management features throughout the Clear Creek watershed (USACE 2010). The authors' 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.

Figure 1. Flooding in the Clear Creek study area just after Tropical Storm Allison in June of 2001 (photo of Green Tee Terrace provided by Galveston District).

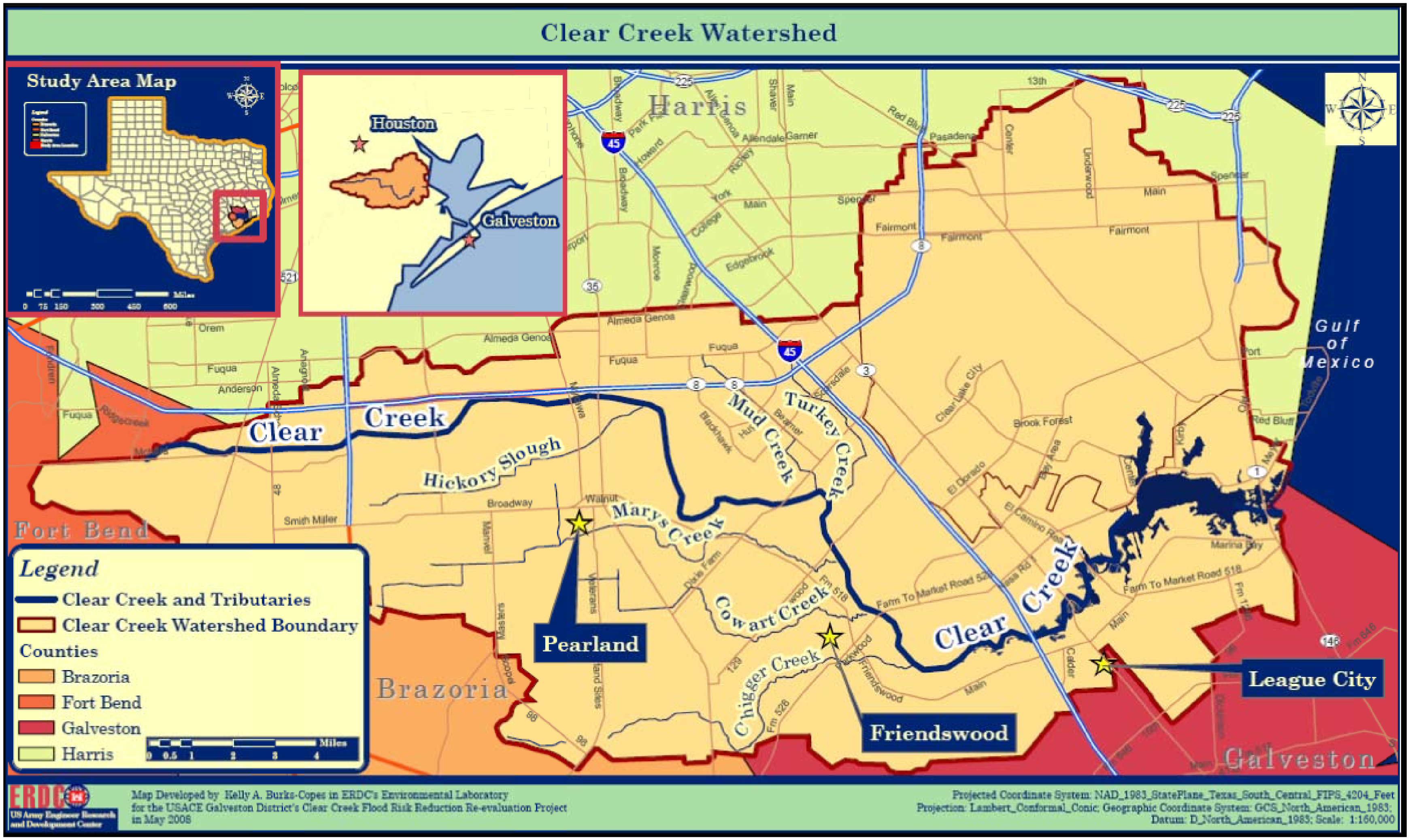

Figure 2. Study location – Clear Creek watershed.

The District is preparing an Environmental Impact Statement (EIS), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the impacts of proposed flood control measures in the watershed (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 studies; (4) evaluate potential impacts; and (5) recommend and evaluate potential mitigation measures.

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, a multi-agency Ecosystem Assessment Team (E-Team) was convened. Representatives from the Galveston District, U.S. Fish and Wildlife Service (USFWS), U. S. Environmental Protection Agency (USEPA), National Marine Fisheries Service (NMFS), and National Resources Conservation Service (NRCS), Texas Commission on

Environmental Quality (TCEQ), the Texas General Land Office (TGLO), the Texas Parks and Wildlife Department (TPWD), the Galveston Bay National Estuary Program (GBNEP), the Harris County Flood Control District (HCFCD), Brazoria County Drainage District No. 4 (BCDD), and Galveston County actively participated in the assessment process. Scientists from the U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL) facilitated the ecological evaluations undertaken by the E-Team. The planning process is described in great detail in the various Clear Creek planning and NEPA documents (USACE 1999; 2002, 2010). For purposes of this report, the authors 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 between 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 between 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 3).

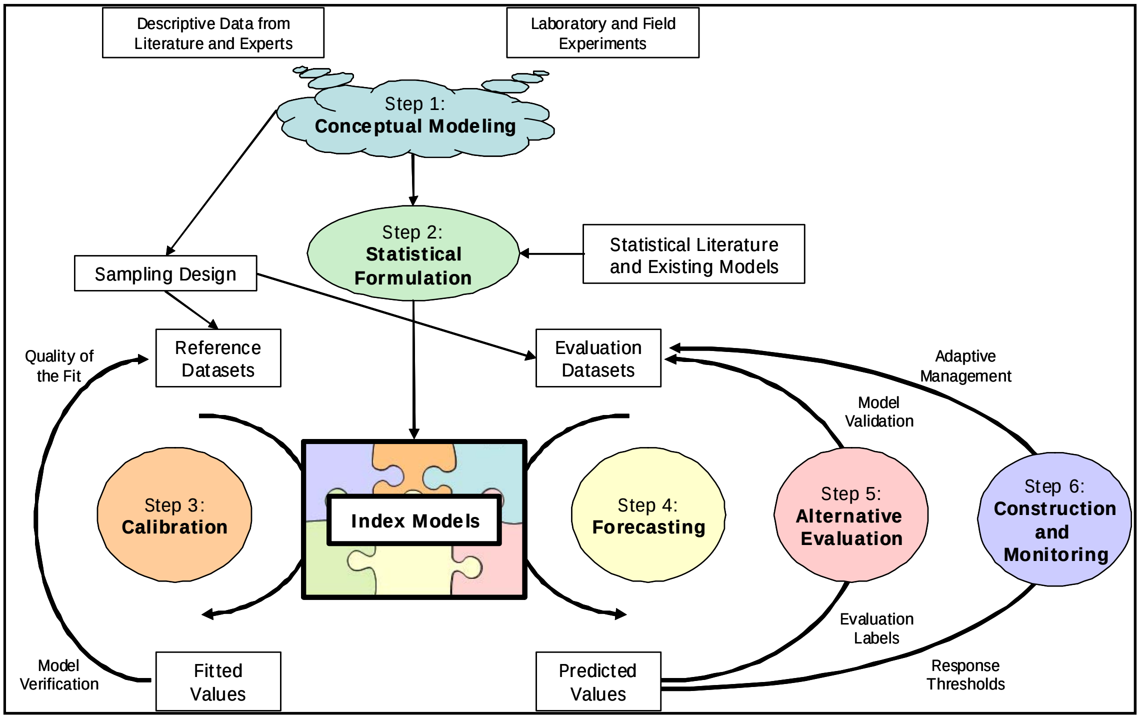

Figure 3. Overview of the successive steps (1-6) of the community-based index model building and application process for ecosystem restoration, where two data sets (one for calibration and one for alternative evaluations) are used (adapted from Guisan and Zimmerman 2000).

Under this 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 and generate response

[1] The authors 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 characteristics of the reference, such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning." The authors expand upon this definition by including Dale and Beyeler (2001) descriptions which refer to "system wholeness, including the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes."

thresholds to trigger adaptive management under the indicated feedback mechanism.

There were several advantages to using this approach that were readily apparent. First, it provided a logically consistent ordering of relations between planning steps. Second, the relationships between 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 Ecosystem Response

To evaluate the ecological impacts of proposed flood risk management plans, and to assess the veracity of proposed mitigation plans formulated to offset these potential impacts, 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 ecosystems (Figure 4).

Figure 4. At stake are the dwindling floodplain forests situated along the Clear Creek channel and its tributaries.

In 1980, the USFWS published quantifiable procedures to assess planning initiatives as they relate to change of fish and wildlife habitats (USFWS 1980a,b,and 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 or mitigation 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 Clear Creek study team made the decision to assess ecosystem impacts and mitigation using HEP and two[1] community-based functional HSI models (Burks-Copes and Webb in preparation) therein. The remainder of this document focuses on the E-Team's HEP assessment methodology and results.

Planning Model Certification

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

[1] It is important to note that a third model was initially developed under this effort to evaluate tidal marshes within the Clear Creek watershed. However, further investigation of the problems and opportunities surrounding both the proposed flood control plans and their subsequent mitigation requirements indicated tidal marsh would not be affected.

Clearly, the community-based HSI model developed for the study must be either certified or approved for one-time use. The Galveston District initiated this review in 2009 and is awaiting a memo from the USACE Eco-PCX granting one-time-use approval.[1] Information necessary to facilitate model certification/one-time-use approval is outlined in Table 2 of the EC 1105-2-407 (pages 9-11).

For purposes of model certification, 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. 2012) to automate the calculation of habitat units for the study. This software is not a "shortcut" to HEP modeling, or a model in and of itself; rather, it is a series of computer-based programming modules that accept the input of mathematical details and data comprising the index model. Through the applications of these data in the HEP or the Hydrogeomorphic Wetland Assessment (HGM) processes, the model 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 currently pursuing certification through a

[1] For a detailed copy of the independent model review report and the District's response for issue resolution, contact the District.

separate initiative, and hope to have this tool through the process in the next year, barring unforeseen financial and institutional problems.

The authors used IWR Planning Suite[1] to run the cost analyses for the restoration plans in the study which was certified in 2008.

Report Objectives and Structure

Between 2003 and 2008, the E-Team designed, calibrated, and applied a landscape-level community-based index model for the system's floodplain forests using field and spatial data gathered from watershed reference sample sites (Burks-Copes and Webb in preparation). Five individual conveyance/detention measures were combined to generate the National Economic Development (NED) plan (including mitigation). Twelve individual mitigation plans were evaluated to offset the impacts detailed in the NED plan. 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 habitat community affected by the proposed flood risk management plans;
2. Describe the methods used to assess the proposed NED plan (and the subsequent mitigation plans therein);
3. Present the HEP results for both evaluations; and
4. Present the cost analysis that will facilitate the District's selection of recommended mitigation to complete the NED 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, including 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 Habitat Units (HUs) for the models. *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 impacts of the NED plan (i.e., the With-project (WP) Condition). *Chapter 6* details the evaluation of the proposed mitigation plans and documents the cost analyses of these alternatives. *Chapter 7* summarizes the findings of the previous chapters and offers conclusions.

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

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 model). *Appendix D* has been included to facilitate review of this document. A separate report has been developed by ERDC-EL presenting the community-based HSI model (Burks-Copes and Webb in preparation) developed for this study. The model's characteristics, limiting factors (i.e., variables and habitat suitability indices), supporting mathematical equations, and significant literature references are documented therein.

2 Methods

Those responsible for 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 USACE Districts to evaluate the effects of proposed flood risk management 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 impacts are justified and can be offset with mitigation effectively. To ensure effectiveness, these methods must include the ecosystem elements necessary for linking impacts 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 impacts and mitigation. To assure plan acceptance, the models and other decision-support methods have to comply with institutional constraints and influential public opinion (both technically and politically). The main problem addressed in the search for appropriate decision-support methods, is how to evaluate the relative impacts of non-monetary environmental services and their compensation through mitigation. Once non-monetary services are characterized in fundable measures, they can be compared to other proposed projects, and independent estimates of monetized service benefits and costs in a public forum. With key stakeholders involved, the monetized opportunity costs incurred by impacts and mitigation of non-monetary service values can be weighed against the opportunity costs among other inputs.

Types of Ecosystem Evaluation Methodologies

USACE planning studies depend on non-monetary evaluation methodologies to quantify inherent ecological processes, 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.

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 2003). 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 2003). They have proven to be invaluable tools in the development and evaluation of restoration alternatives (Williams 1988, Brown et al. 2000, Store and Kangas 2001, Kapustka 2003, Store and Jokimaki 2003, Gillenwater et al. 2006, Schluter et al. 2006, Shifley et al. 2006), managing refuges and nature preserves (Brown et al. 2000, Ortigosa et al. 2000, Store and Kangas 2001, Felix et al. 2004, Ray and Burgman 2006, Van der Lee et al. 2006 and others), and mitigating the effects of human activities on wildlife species (Burgman et al. 2001, 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. And as such, most HSI models should be seen as quantitative expressions of the best understanding of the relations between easily measured environmental variables and habitat quality. Habitat suitability models then, are a compromise between ecological realism and limited data and time (Radeloff et al. 1999, Vospernik et al. 2007).

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 measure-able 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 the relationship between quality and carrying capacity for the site.

Most communities are examined inaccurately by using the single formula model 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. Multiple Formula Models require more extensive processing to evaluate habitat conditions.

Habitat units in HEP

HSI models can be tailored to a particular situation or application and adapted to meet the level of effort desired by the user. Thus, a single model (or a series of interrelated 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. 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 Clear Creek Study: 12 Steps

Twelve steps were completed in the assessment of the study's proposed flood risk management (and mitigation) 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. Collecting data;
6. Performing data management and statistical analyses;
7. Calculating baseline conditions;
8. Setting goals and objectives, and defining project life and Target Years (TYs);
9. Generating Without-project (WOP) conditions and calculating outputs;
10. Generating With-project (WP) conditions and calculating outputs;
11. Performing trade-offs; and
12. Reporting the results of the analyses.

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

Step 1: The Clear Creek Ecosystem Evaluation Team

In HEP, a multi-agency 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, USEPA, USFWS, NRCS, state fish and game offices, and other federal, state, and local governments as well as tribes as is 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 Clear Creek multidisciplinary ecosystem evaluation team (E-Team) was convened in 2003 to develop the community index models and conduct the HEP evaluations for the study. The multi-disciplinary, multi-agency team included various interests and technical expertise. A complete list of Clear Creek's E-Team members can be found in Table 1 below.

Table 1. The Clear Creek study's E-Team members.

E-Team Members	Agency	Phone	Email Address
Catanzaro, Andrea	USACE	409-766-6346	Andrea.Catanzaro@usace.army.mil
Easley, Greg	TCEQ	512-239-4539	geasley@tceq.state.tx.us
Jeff DallaRosa	TCEQ – GBNEP	281 486-1242	jdallaro@tceq.state.tx.us
Heinly, Bob	USACE	409-766-3992	Robert.W.Heinly@.usace.army.mil
Hunt, Shane	Bureau of Reclamation, Sacramento, CA (formerly with USACE–Galveston TX)	559-487-5138	shunt@mp.usbr.gov
Jones, Seth	USACE	409-766-3068	Seth.W.Jones@usace.army.mil
Labay, Andrew	PBS&J	512-342-3382	aalabay@pbsj.com
Murphy, Carolyn	USACE	409-766-3044	Carolyn.E.Murphy@usace.army.mil
Rosen, David	Lee Community College, Baytown, TX (formerly with USFWS)	281-427-5611	
Belton, Moni	USFWS	281-286-8288	moni_belton@fws.gov
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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 both the names of original participants as well as replacements and additions here as well.

Step 2: Defining the Clear Creek 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 1999; 2002, 2010)

Lead District

The Clear Creek study falls under the purview of the U.S. Army Corps of Engineers, Galveston District, Galveston, TX (Figure 5).[1]

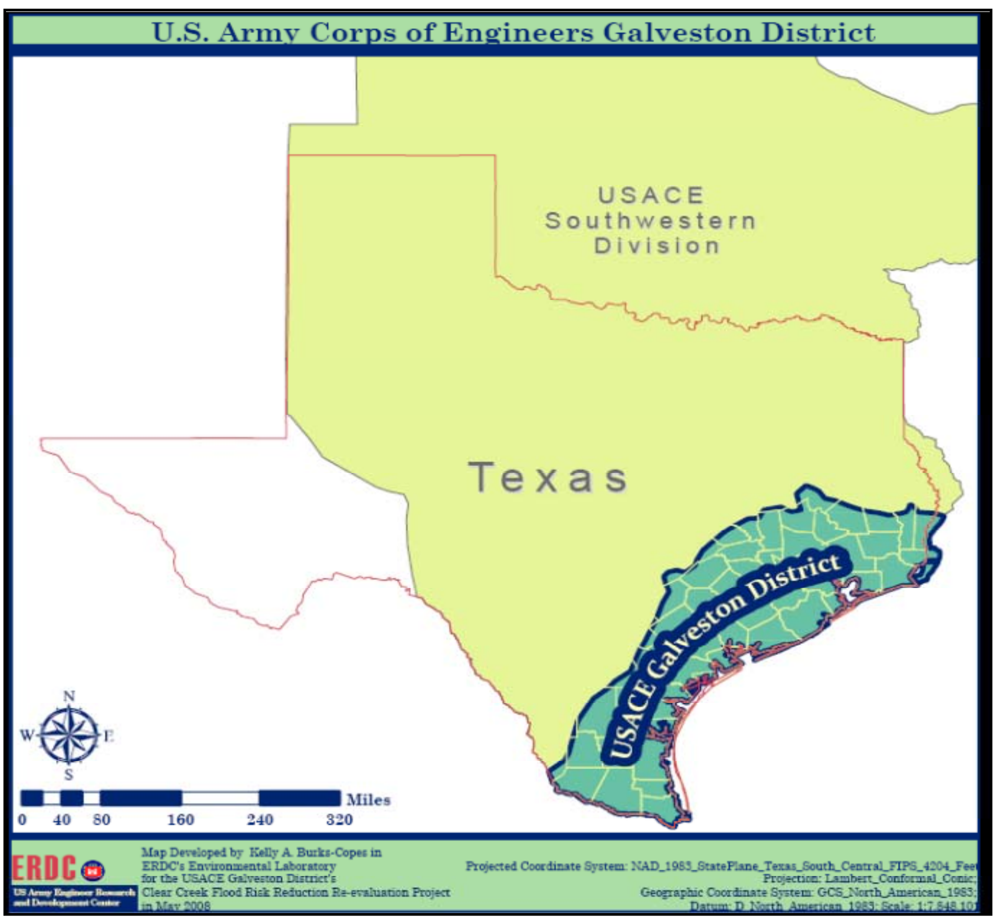

Figure 5. Galveston District boundaries.

[1] http://www.swg.usace.army.mil/ (APR 2008).

The District is one of four districts that make up the USACE Southwestern Division.[1] The Galveston District is an operating component of the Southwestern Division, responsible for providing support along an arc of the Texas Gulf Coast, approximately 150 miles in width, extending from the Texas-Louisiana border on the northeast, to the Mexican border on the southwest. With its rich heritage of history, the District performs its civil works mission throughout the Texas Gulf Coast, contributing to the area's multifaceted metropolitan and rural life, a congenial mixture of industry and natural environment, abundant wildlife, and coastal attractions. The District serves the vital Texas petrochemical refining industry, plus commercial and sports fishing. Waterborne commerce on the 1,000 miles of deep and shallow draft channels totals 300 million tons annually. The District was established in 1880 to conduct river and harbor improvements along the Texas Gulf Coast, including construction of jetties to make Galveston Channel navigable. The District is almost entirely coastal in nature, encompassing the entire Texas coast from Louisiana to Mexico - 50,000 square miles. Its length, measured along the coast, is about 400 miles and it extends inland about 150 miles, including the major metropolitan area of the fourth largest city in the U.S. – Houston, TX. With its 370 dedicated professionals and an annual budget of $200 million, the District works to carry out its missions of navigation, flood control and hurricane-flood protection, while its regulatory office works to protect the nation's wetlands and navigation channels. In addition, the District has a major real estate responsibility including acquisition of real estate for the National Park Service's Big Thicket Preserve in East Texas. The project manager for the Clear Creek study was Mr. Bob Heinly (CESWG-PE-PL), and the study manager/planner/lead biologist was Ms. Andrea Catanzaro (CESWG-PE-RB).

Project Location

The Clear Creek watershed is located south of the City of Houston and includes parts of Harris, Galveston, Brazoria, and Fort Bend Counties (Figure 6).

The Clear Creek watershed covers approximately 250 square miles and is partly inclusive of the City of Houston. There are an additional 16 cities that are at least partially within the watershed including Pearland, Friendswood, and League City. Clear Creek flows from west to east and

[1] http://www.swd.usace.army.mil/ (APR 2008).

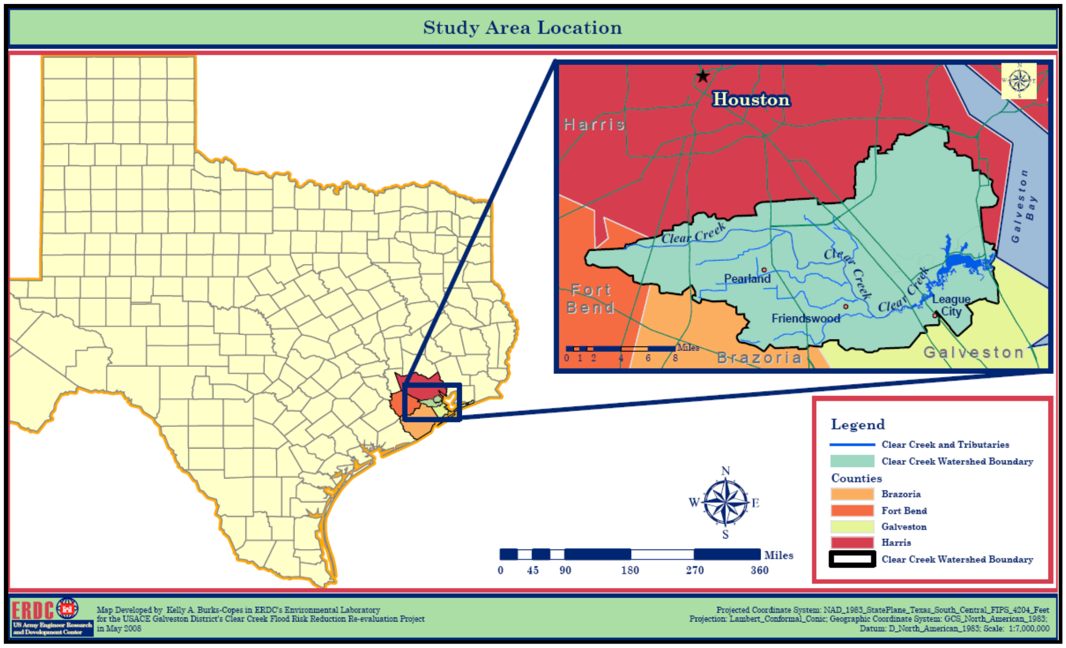

Figure 6. Clear Creek study area location.

drains into western Galveston Bay at Seabrook. Armand and Taylor Bayous are two of the larger tributaries (i.e., identified as separate subwatersheds) flowing into Clear Lake from the north.

The watershed is approximately 45 miles long and is relatively flat - exemplifying the Gulf Coast Plains (Figure 7). Elevations vary from less than 5 feet above mean sea level (msl) near Clear Lake to approximately 75 feet above msl at the western end.

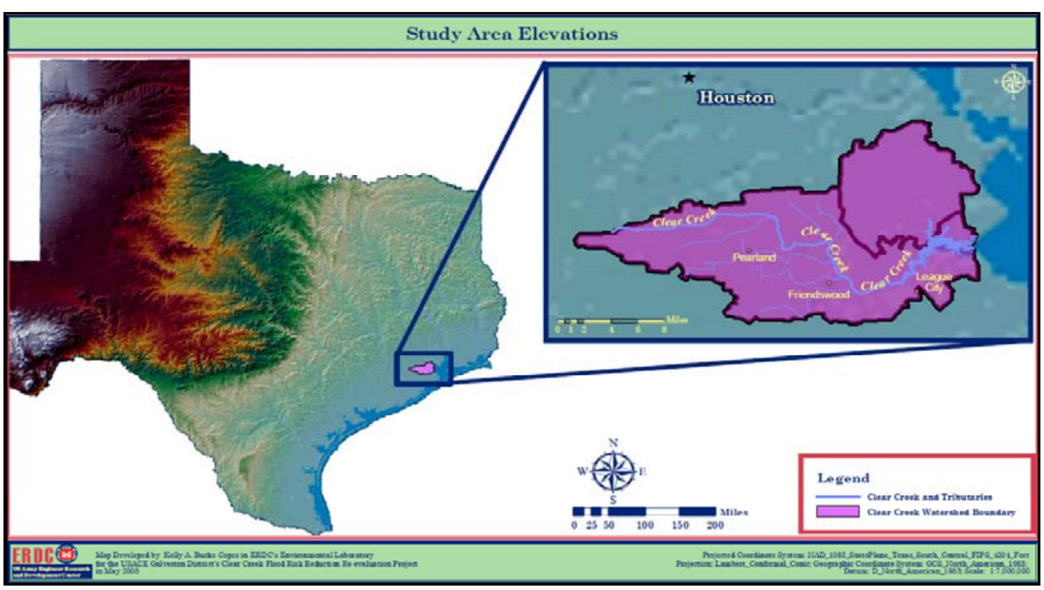

Figure 7. Clear Creek study area elevations.

The floodplain is much wider and shallower in the upstream extents. It narrows and deepens as it moves downstream into Clear Lake. The only significant irregularities in the slope are the valleys cut by the creek and its tributaries.

The Clear Creek watershed encompasses approximately 166,900 acres – 49 percent (81,650 acres) held in Harris County alone (Figure 8).

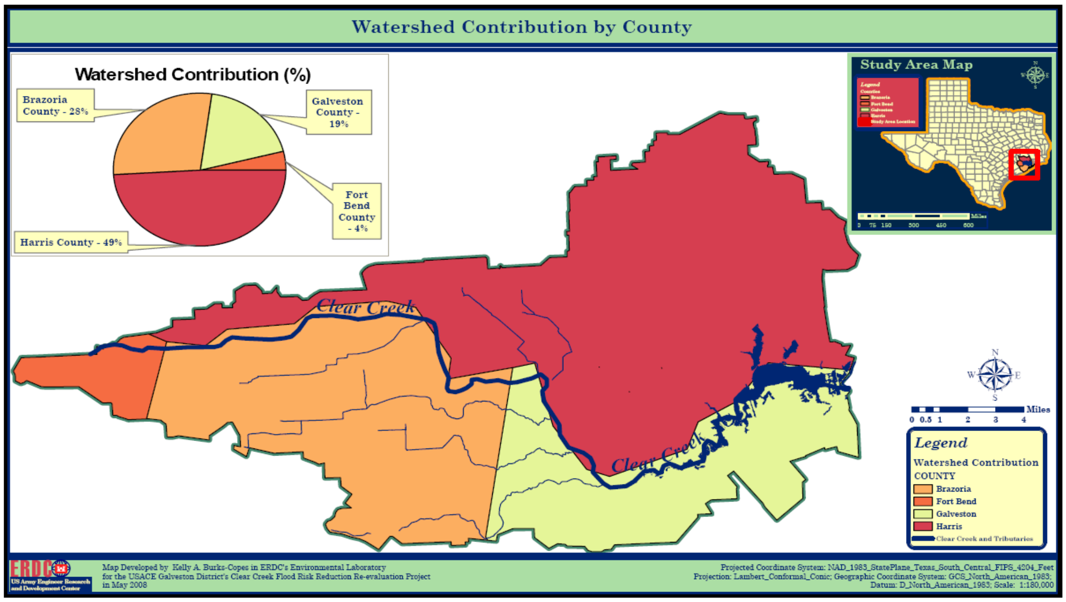

Figure 8. Distribution of acreages across the four counties in the Clear Creek watershed.

Brazoria and Galveston Counties contribute another 28 and 19 percent (47,468 and 31,771 acres). The remaining four percent comes from the Fort Bend County at the western end of the watershed (6,010 acres). A myriad of land covers/land uses have been identified within the watershed (Figure 9).

For purposes of the this analysis, the District chose to take a floodplain-level approach toward flood risk management planning, and as such, made the decision to focus all activities inside the 500-year floodplain (Figure 10).

It is important to note that the community HSI model was intentionally developed with an emphasis on evaluating landscape-level functions, and as such, was designed for applications at the "alternative" level rather than at the feature, action, or treatment level.[1] It is the collective and/or

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

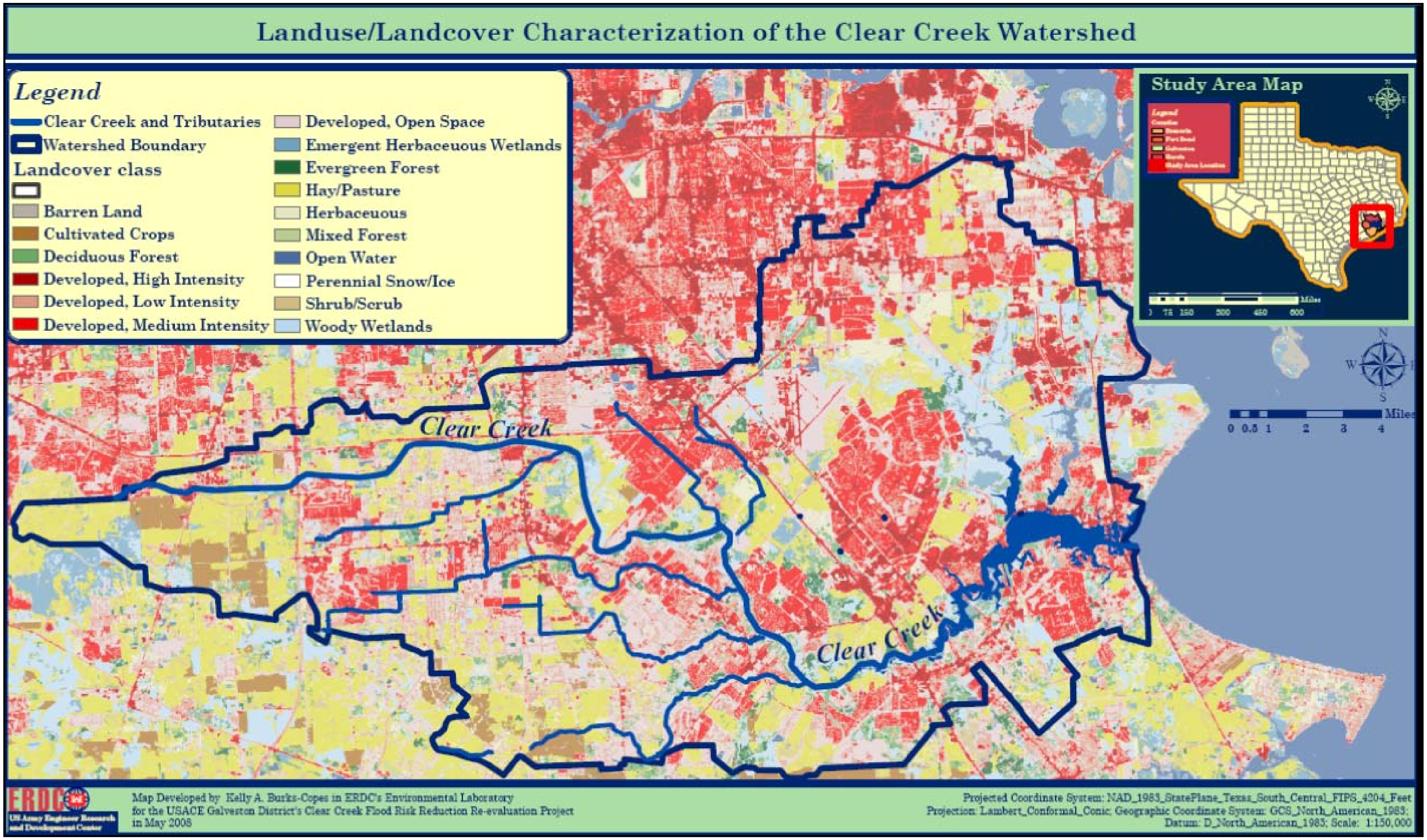

Figure 9. Landuse/landcover (LULC) classes present in the Clear Creek watershed.[1]

cascading effects of the combination of management measures (comprised of features, actions, and/or treatments) that together formulate an alternative that the model was designed to assess (Figure 11).

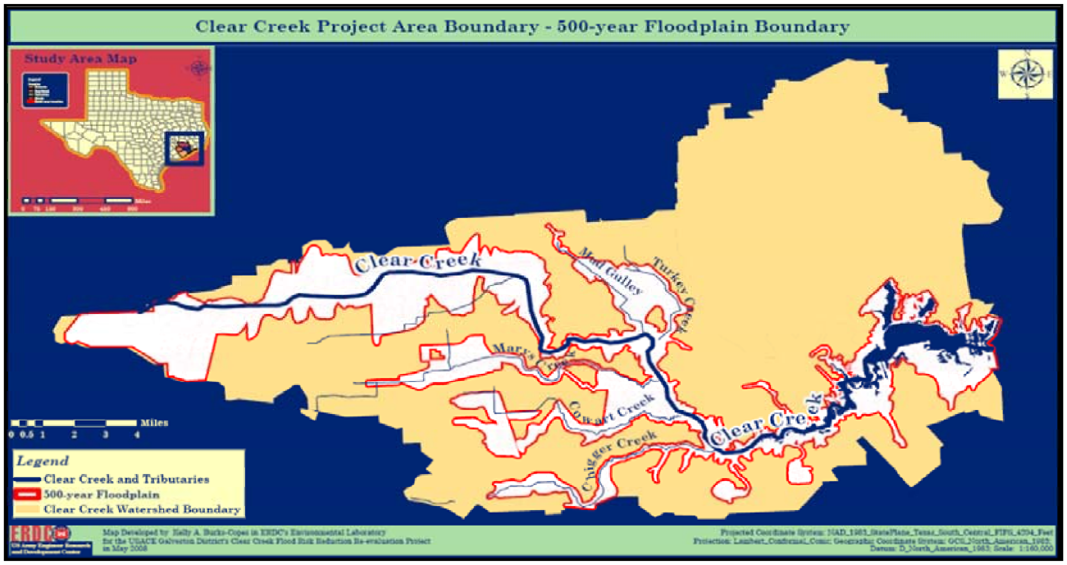

Figure 10. 500-year floodplain delineation defines the boundaries of the Clear Creek study.

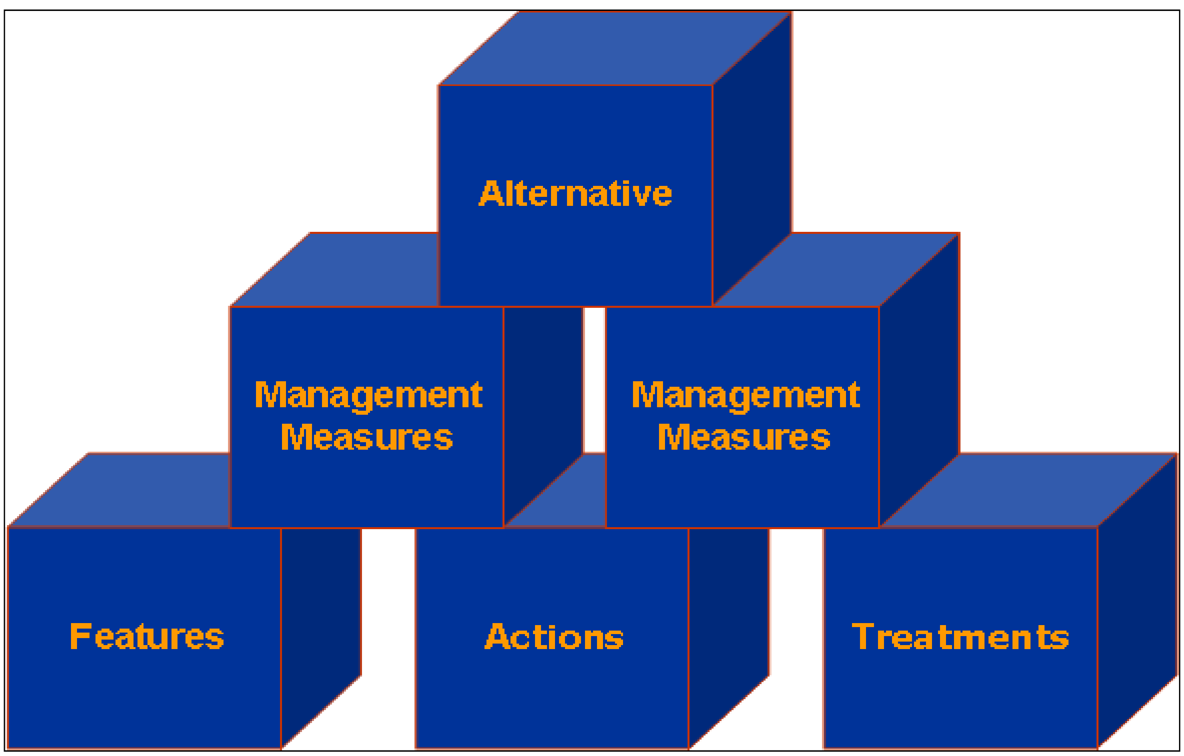

Figure 11. By definition, the Clear Creek Floodplain forest community model was designed to assess alternatives – not individual features, actions or treatments. The components of an alternative that may or may not be separable actions that can be taken to affect environmental variables and produce environmental outputs are often referred to as "management measures" in USACE planning studies. As such, management measures are typically made up of one or more features, activities or treatments at a site.

Only applications at this scale can comprehensively address watershed-level planning activities where critical landscape-level processes must be measured via patch dynamic-sensitive metrics. Since the E-Team was concerned with the potential masking of impacts when operating at this scale, the decision was made to break the system down into smaller, more manageable units or "ecological reaches" that could still be said to function at the landscape scale, but that could be assessed somewhat independently with a greater degree of resolution. The District used criteria such as degree of human disturbance, land use, stream morphology (stream width, bank characteristics, sinuosity, and water depth) as well as past channelization activities to delineate unique reach settings across the watershed. All told, seven individual "ecological reaches" were defined (Figure 12).

Eco Eco-Reach 1: Clear Lake from its mouth at Galveston Bay upstream to I-45

The lower two-thirds of Eco-Reach 1 (ER 1) includes the relatively broad, shallow, open-water area known as Clear Lake, which covers about 2 square miles. Farther upstream, the creek narrows to about 180 feet in width with a meandering channel. This reach is moderately developed with more than 60 percent of the adjacent land made up of urban development and pasture, mostly in the lower two-thirds of Clear Lake. Shores are gently sloped throughout much of the reach. The remaining undeveloped areas of riparian corridor along Clear Creek occur mostly in the upstream portion, and these areas are typically forested with small areas of tidal fringe marsh occurring intermittently within small cove-like features. The waterway remains relatively unaltered by channelization except for a very short section connecting Clear Lake to Galveston Bay. Important tributaries include Taylor Lake and Armand Bayou. The entire reach is tidally influenced, and vegetation must be able to tolerate exposure to saltier estuarine waters. ER1 includes 490 acres of floodplain forest and 255 acres of tidal marsh. These two types of land cover made up about 9 percent of the study area in ER 1. Areas of tidal marsh are populated by *Spartina*, *Juncus*, *Sagittaria*, and in some cases the submerged aquatic *Ruppia*. Some floodplain forest is located along the upper portion of this reach and in the Armand Bayou portion of the reach. Willow oak is common in these forest areas.

Eco-Reach 2: Clear Creek Tidal from I-45 Upstream to FM 528

Chigger Creek is about 10 miles long and Clear Creek is about 8 miles long in Eco-Reach 2 (ER2). ER 2 has experienced low to moderate development. Almost 50 percent of land cover in the study area is pasture followed by

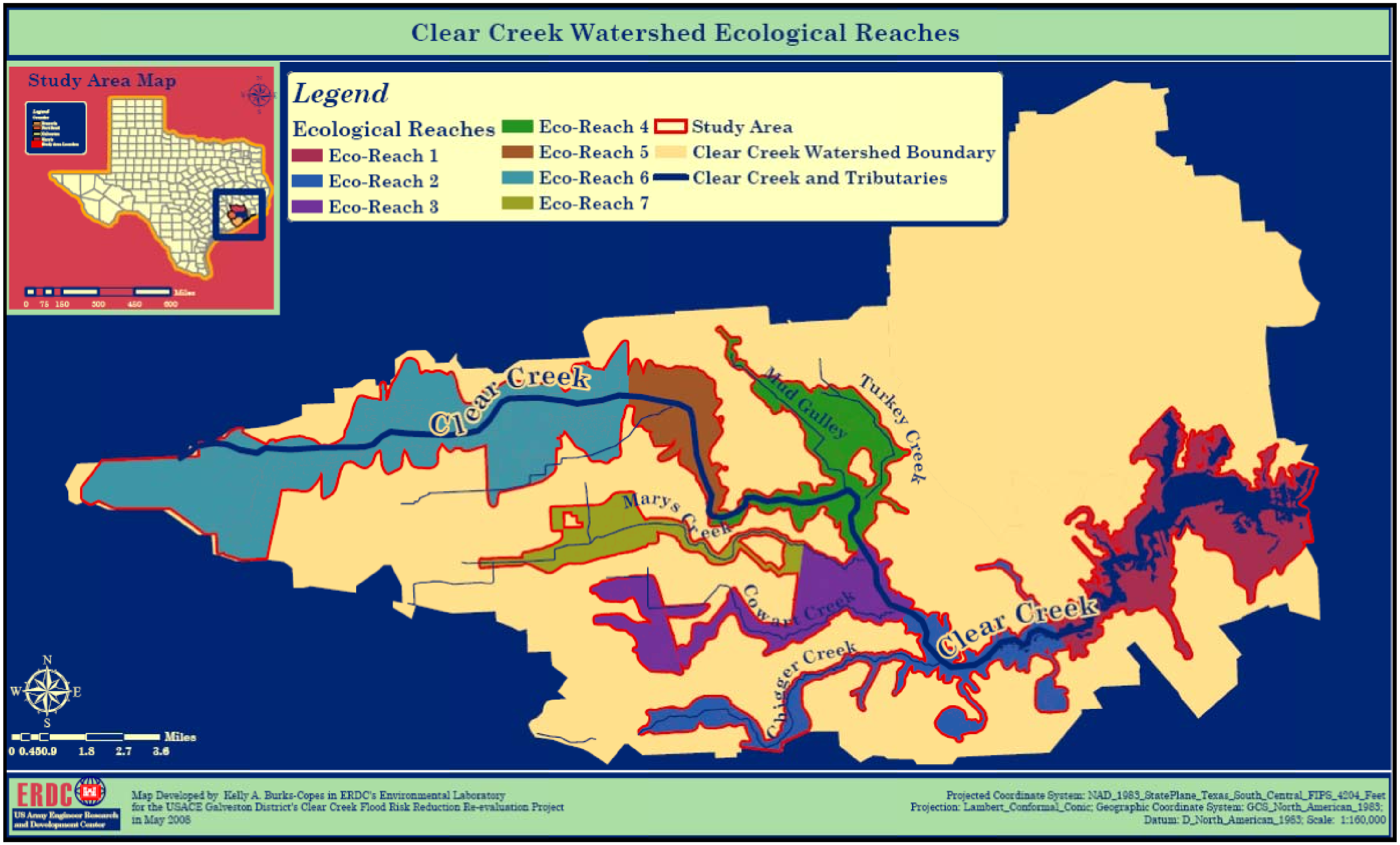

Figure 12. Reaches delineated for the baseline assessment of the Clear Creek watershed.

floodplain forest (27 percent) and urban development (19 percent). Clear Creek is about 180 feet wide just upstream of I-45, narrowing to around 90 feet in width at FM 528. Creek banks are gently sloped throughout, and some small areas of tidal marsh are still present in the lower 0.5 mile of the reach, totaling only 2 percent of the land cover in this reach. Clear Creek has not been channelized in ER 2 and retains its natural meanders and much of its riparian forest. The local drainage district performs some light clearing and snagging of trees along the water's edge.

Clear Creek is tidally influenced in this Eco-Reach, and there is some exposure to estuarine waters in the lower 5 miles of this reach. Eco-Reaches upstream of ER 2 are considered perennially fresh and should rarely, if ever, be exposed to salty estuarine waters. Chigger Creek is as an intermittent stream with perennial pools for much of its length. Floodplain forest is found along the lower 3 miles of Chigger Creek. This reach of Clear Creek includes the healthiest and most extensive stands of floodplain forest in the study area, with 1,095 acres of floodplain forest. Willow oak and cedar elm are common (Figure 13).

Figure 13. Tidally influenced marsh on the north bank of Clear Creek upstream of I-45 aptly illustrates the unique ecosystem setting in Eco-Reach 2.

Eco-Reach 3: Clear Creek from FM 528 Upstream to FM 2351 for a Distance of about 4 miles, and Cowarts Creek

Eco-Reach 3 (ER 3) includes the mainstem of Clear Creek and its tributary, Cowarts Creek. This reach has a high degree of development, with more than 90 percent of the adjacent land as pasture and urban development. Clear Creek begins to narrow considerably, ranging from 90 feet wide downstream to less than 30 feet wide at FM 2351. Stream banks steepen considerably in the upstream portion of the reach. Clear Creek has not been channelized and retains its natural meanders in this reach; however, a series of high-flow bypasses have been constructed at various locations in an effort to alleviate impacts of high-velocity flows during flooding. Development has reduced the floodplain forest to a comparatively narrow corridor within this reach. As a result of development, some clearing and snagging of trees along the edge of the creek has been performed by the local drainage district within the reach. Cowarts Creek, about 6.4 miles long, is the primary tributary to this reach of Clear Creek and is considered an intermittent stream with perennial pools. Floodplain forests in this reach include green ash, American elm, sugar hackberry, water oak, and water hickory. The only floodplain forest on Cowarts Creek consists of a small patch near its confluence with Clear Creek (Figure 14).

Figure 14. Clear Creek at Imperial Estates (downstream view) represents “typical” conditions along Eco-Reach 3.

Eco-Reach 4: Clear Creek from FM 2351 upstream to Country Club Drive

Eco-Reach 4 (ER4) includes about 8 miles of Clear Creek and two tributaries, Mud Gully and Turkey Creek. This reach has experienced a moderate to high degree of development with around 75 percent of the land converted to urban development or pasture. Clear Creek is relatively narrow, about 15 feet wide at the upstream limit, and has considerable meanders in this reach. Stream banks are naturally steep and nearly vertical. Bank slope has increased primarily due to erosion downstream of Dixie Farm Road and human alterations of the channel. The upstream portion of this reach from Dixie Farm Road to Country Club Drive has been shaped into a trapezoidal channel by flood control activities dating back to the 1940s. Past alterations combined with maintenance activities, including routine mowing, vegetation removal, and channel reshaping by the local drainage districts have left this portion of the creek a relatively straight, grass-lined, low-flow channel with steep slopes bordered by remnant fragmented riparian forest.

Channelization of the upstream portion of the reach also cut off many of the natural channel meanders when excavated material was mounded along the north bank. A series of forested oxbow lakes formed in the cutoff portions of the channel. While the oxbows join the creek via culverts, the water elevation at low flow in the rectified channel is too low for water exchange with oxbows except under heavy rainfall conditions. Under high-flow conditions, oxbows may fill to a level where they drain into the creek, or the flooding creek may force water through the culverts into the oxbows. With 1,053 acres of floodplain forest, this reach of Clear Creek has the second-largest area of floodplain forest, about 24 percent of the land cover.

The tributaries of Mud Gully and Turkey Creek have also been altered extensively as a result of past flood control activities, especially in the upstream areas. Each of the creeks is about 3 miles long, and both are considered perennial streams. Turkey Creek has been previously channelized and straightened in the upper half, and although some natural sinuosity in the lower half of the channel remains, little nature forested riparian habitat exists. Mud Gully has a few relatively small patches of floodplain forest along its channel near its confluence with Clear Creek (Figure 15).

Figure 15. Mud Gully downstream of Sagedowne Boulevard typifies conditions in Eco-Reach 4.

Eco-Reach 5: Clear Creek from Country Club Road upstream to SH 35

Eco-Reach 5 is a 6-mile reach of Clear Creek that has experienced low to moderate development with about 75 percent of the adjacent land covered with tallgrass prairie (including remnant prairie) and, to a lesser extent, pasture. Clear Creek ranges from approximately 15 to 20 feet in width. It has been extensively altered since the 1940s into a trapezoidal-shaped channel by past flood control activities. Continued maintenance activities over the last 10 years, including routine mowing, vegetation removal, and channel reshaping by the local drainage districts, have kept this portion of Clear Creek a relatively straight, steep-sided, grass-lined, low-flow channel with virtually no woody vegetation near the water's edge except in a few isolated locations. The floodplain forest remaining within this reach occurs mostly outside the low-flow channel and is somewhat fragmented.

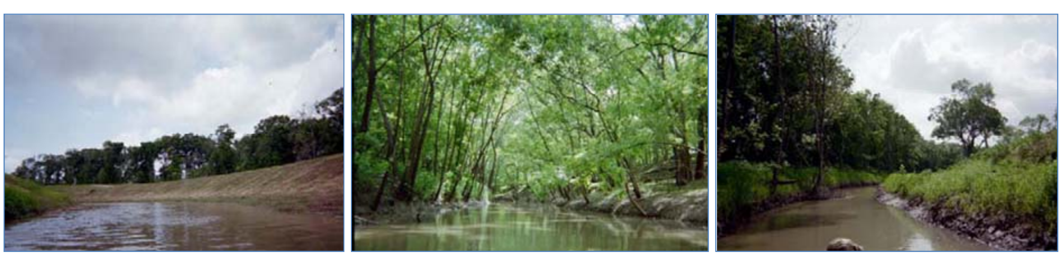

Figure 16. Sites on Clear Creek between Country Club Road and SH 35 offer examples of typical ecosystem conditions along Eco-Reach 5.

Eco-Reach 6: Clear Creek from SH 35 upstream to just past SH 288

Eco-Reach 6 (ER6) of Clear Creek has a low to moderate degree of development with coastal prairie (including remnant prairie) making up about 79 percent of the land cover and, to a lesser extent, pasture (Figure 17). The main channel of Clear Creek is very narrow, seldom exceeding 15 feet in width at low flow. Much of this reach of Clear Creek has been shaped into a trapezoidal channel by past flood control activities back to the 1940s. Channel maintenance activities (e.g., reshaping, mowing, tree removal, etc.) from approximately 1 mile downstream of Cullen Boulevard to SH 35, have kept this section relatively straight with virtually no woody vegetation along the low flow channel or its side slopes. The upstream portion of the creek in the vicinity of Tom Bass Park has not been maintained for many years allowing forested riparian habitat to return to the edges of the low-flow channel. Hickory Slough is a very small tributary (less than 8 feet wide) to Clear Creek within ER 6.

Figure 17. Sites on Clear Creek between Country Club Road and SH 35 offer insight into conditions along Eco-Reach 6.

Eco-Reach 7: Mary's Creek from its confluence with Clear Creek

Road and Sunset Meadows Road Habitat along Mary's Creek consists of a few small, isolated patches of remnant riparian forest in Brazoria County. This Eco-Reach has less floodplain forest than any other reach in the study area as a result of the extensive urban and agricultural development, totaling 83 percent of the Eco- Reach area. Floodplain forest covered about 85 acres, or 3 percent of the study area. Urbanized areas and oldfields, haylands, and pasture cover 41 and 42 percent, respectively, of the Eco-Reach. Much of the middle and upper reaches of Mary's Creek has been modified into a trapezoidal channel, concrete lined in some reaches. Riparian trees and shrubs have been removed along much of the creek (Figure 18).

Figure 18. Sites on Mary's Creek downstream of Harkey Road, Pearland, Texas and downstream of Veteran's Road illustrate conditions along Eco-Reach 7.

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. Due to the temporal and spatial variability of these factors and the sensitivity of different forms of vegetation to these factors, the watershed vegetation has been a changing mosaic of different types. The pre-settlement vegetation in southeast Texas was predominantly prairie and forest in nature (Figures 19 and 20).

Figure 19. Classic examples of floodplain forests can still be found along the main Clear Creek channel and its many tributaries (photo taken in April 2004).

Figure 20. Classic example of the wet coastal prairie community in the Clear Creek watershed (photo taken in April 2004).

The forested communities are shaped by the frequency and duration of flooding, by nutrient and sediment deposition, and by the permeability of the soil. Overbank river flooding is the primary source of water for forested wetlands. On floodplains with distinctive wetland character, flooding occurs in most years and the flooding persists for at least several weeks at a time. The wet coastal prairies, located along the coastal plain of southwestern Louisiana and south central Texas, are the southernmost tip of the tallgrass prairie ecosystem so prevalent in the Midwest. Detailed characterizations of the floodplain forest community is offered in Burks-Copes and Webb in preparation and references listed therein.

Threats to These Communities

While a significant portion of the river's banks are lined by a narrow system of relictual floodplain forest communities along its course, suburban development within the watershed has reestablsiehd a river system that has lost much of its ecological and hydrological integrity (Figure 21).

Forested wetlands are perhaps the most rapidly disappearing wetland type in the United States (Moulton, Dahl, and Dall 1997; Wagner 2004; Jacob, Moulton, and López 2003; and TPWD 2007). Agriculture and silviculture

Figure 21. Fragmentation and urban encroachment is a common problem for the riparian communities situated along Clear Creek (Clear Creek Channel between Telephone Rd and Mykawa Road).

(pine plantations) are the major continuing threats to these wetlands. The character of a forested wetland is destroyed if all of the trees are cut down, even if the hydrology is not otherwise altered, and the wetland may require a hundred or more years to recover. Many forested wetlands can be logged on a sustainable basis and still retain their major ecological functions.

Another major threat is the construction of dams and reservoirs on the rivers that supply water to these wetlands (Moulton, Dahl and Dall 1997; Wagner 2004; Jacob, Moulton and López 2003; and TPWD 2007). In addition to the clearing or drowning of forested wetlands within reservoir floodpools, there is a long-term threat that results from the flood-control function of most dams. Once annual flooding is removed, the wetlands begin to dry out and become more susceptible to development pressures. Since the mid-1950s, forested wetlands on the Texas coast have decreased in area by about 11 percent, a net loss of more than 96,000 acres (Moulton, Dahl, and Dall 1997; Wagner 2004; Jacob, Moulton, and López 2003; and TPWD 2007).

Because the proposed flood risk management activities were likely to impact vegetative communities along the streams, the impact analyses (and associated mitigation planning) focused on the floodplain forests lining their banks.

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., prairie, 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 Clear Creek Watershed study, nine unique habitat types were (i.e., cover types or CTs) were identified and mapped across the entire project study area (Table 2).

Table 2. Cover types identified and mapped for the Clear Creek watershed.

No.	Code	Cover Type (and Land Use) Description
1	AGCROP	Farms and Croplands
2	FOREST	Floodplain Forest
3	NEWFOREST	Newly Developed Floodplain Forest
4	NEWMARSH	Newly Developed Tidal Marsh
5	OPENWATER	Open Bodies of Water Deeper than 1-3m
6	PASTURES	Old Fields, Haylands and Pastures
7	PRAIRIE	Wet Coastal Prairie
8	TIDALMARSH	Tidal Marsh
9	URBAN	Existing Residential, Industrial and Transportation Avenues

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 (and ground-truthed during the 2003-2004 field seasons) (Figure 22). For details regarding the total baseline acreages and quality of these CTs, refer to *Chapter 3* of this report.

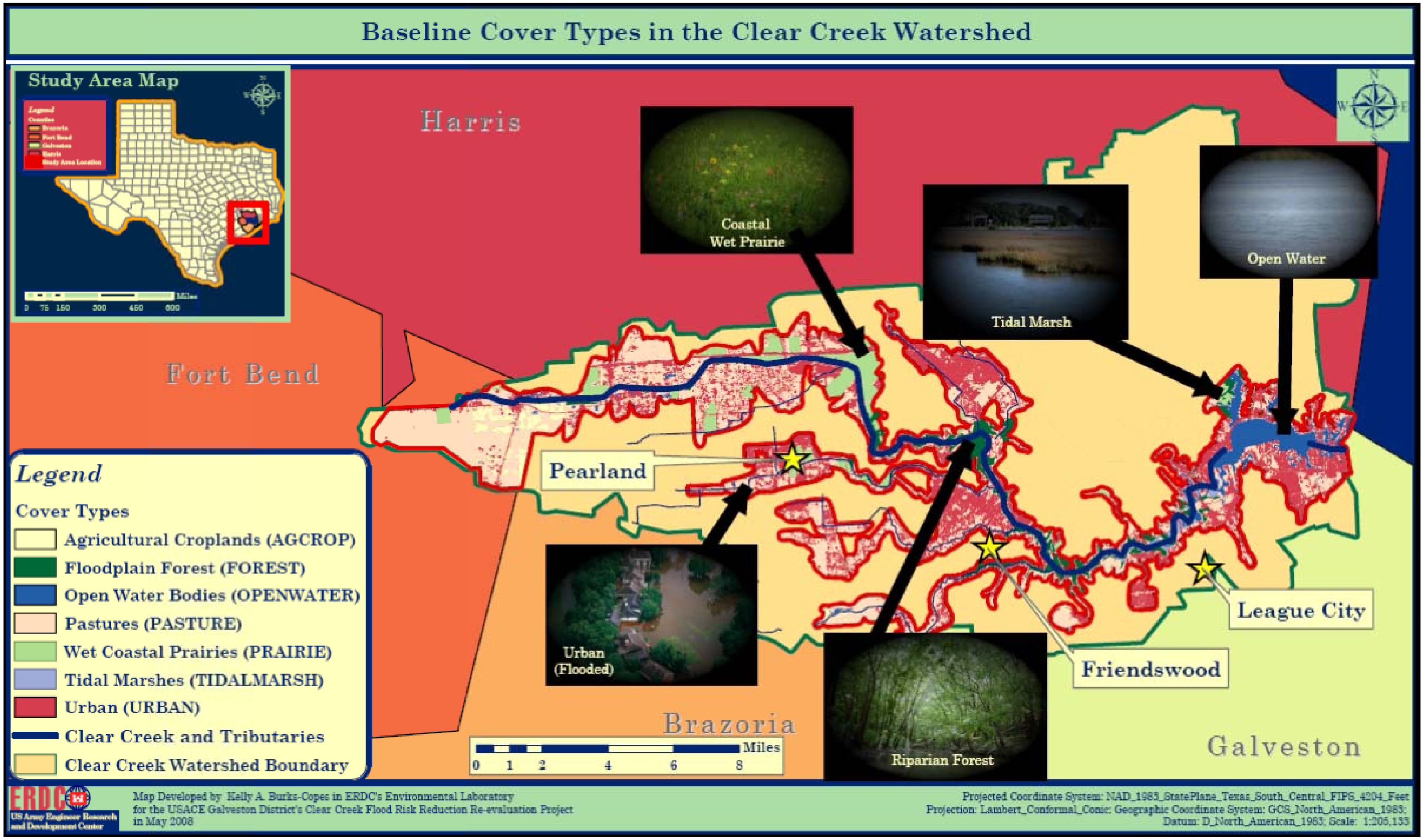

Figure 22. Baseline cover type map for the project study area.

Step 4: Developing Models for the Study

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

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

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

    b. easily measured or estimated,

    c. 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 Geographic Information Systems or GIS) and in turn, use these strategies to collect all necessary data and apply these data to the model in both the "reference" setting and on the proposed project area
4. Present the model results to an E-Team and revise/recalibrate the model based on their experiences, any additional and relevant regional data, and application directives.

5. Submit the model to both internal ERDC-EL/District review and then request review from the E-Team members 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 five years (2003-2008) to develop models and characterize baseline conditions of the study area prior to plan formulation and alternative assessment for the flood risk 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. One community-based index model was developed under this paradigm for the system's floodplain forests. Over the course of several workshops, the E-Team was able to devise three model components (i.e., Soils and Hydrology, Biotic Integrity and Structure, and Spatial Context) to characterize the key functional aspects of the system necessary to model the ecosystem integrity in Clear Creek's Floodplain forest communities. A flow diagram best illustrates the model's component relationships (Figure 23).

Variables were selected as indicators of functionality, and have been color coded here to correlate their use in specific model components (i.e., purple = hydrologic parameters, orange = soil characteristics, etc.). In essence, this diagram attempts to emulate the standard diagramming protocol adopted by the USFWS in their publications for species HSI models in the late 1980s and early 1990s. Each colored line represents the normalization of a variable (converting the raw data to a scale of 0-1 using suitability index curves). Once the scores are normalized, they are combined in a meaningful manner mathematically to characterize the existing reference conditions found in the watershed. These in turn can be used to capture the effects of change under proposed design scenarios (refer to the section below). Diamonds indicate weightings or merging of indices prior to full component calculation. The three components (i.e., ***HYDRO, BIOINTEG***, and ***SPATIAL***) are combined using a second formula to produce the final HSI result.

After successfully diagramming the relationships between the model components and the variables therein, the E-Team used their extensive natural resources expertise to translate these flow diagrams into mathematical algorithms that would capture the functional capacity of each community in a quantifiable manner. It is important to note that this

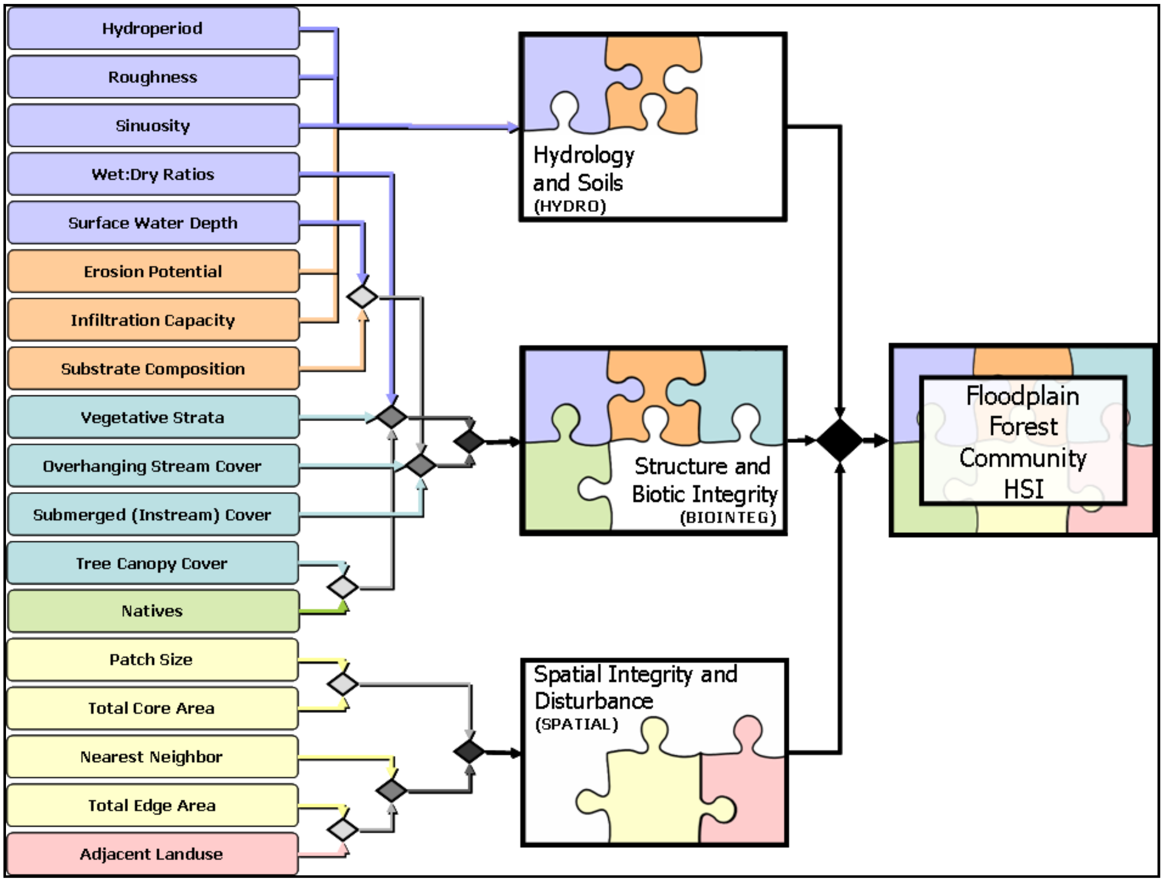

Figure 23. Flow diagram depicting combinations of model components and variables to form the Floodplain forest community index model in the Clear Creek study.

process was iterative and adaptive. Over the course of several years, the E-Team tested (verified) both the accuracy of the model to predict the suitability of known reference-based conditions[1] as well as test their utility in distinguishing between proposed restoration initiatives (Figure 24). With this information in hand, ERDC-EL used a systematic, scientifically-based, statistical protocol to calibrate the community models. Modifications to the original algorithms were incorporated into the system as indicated, and the final formulas were made ready for the Clear Creek application (Table 3). Further descriptions of the community-based index model and its calibration and verification can be found in Burks-Copes and Webb (in preparation). A general list and description of the model components and their associated variables has been included in *Appendix C* of this report.

[1] ERDC-EL assisted the Galveston District in locating a series of 28 floodplain forest 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.

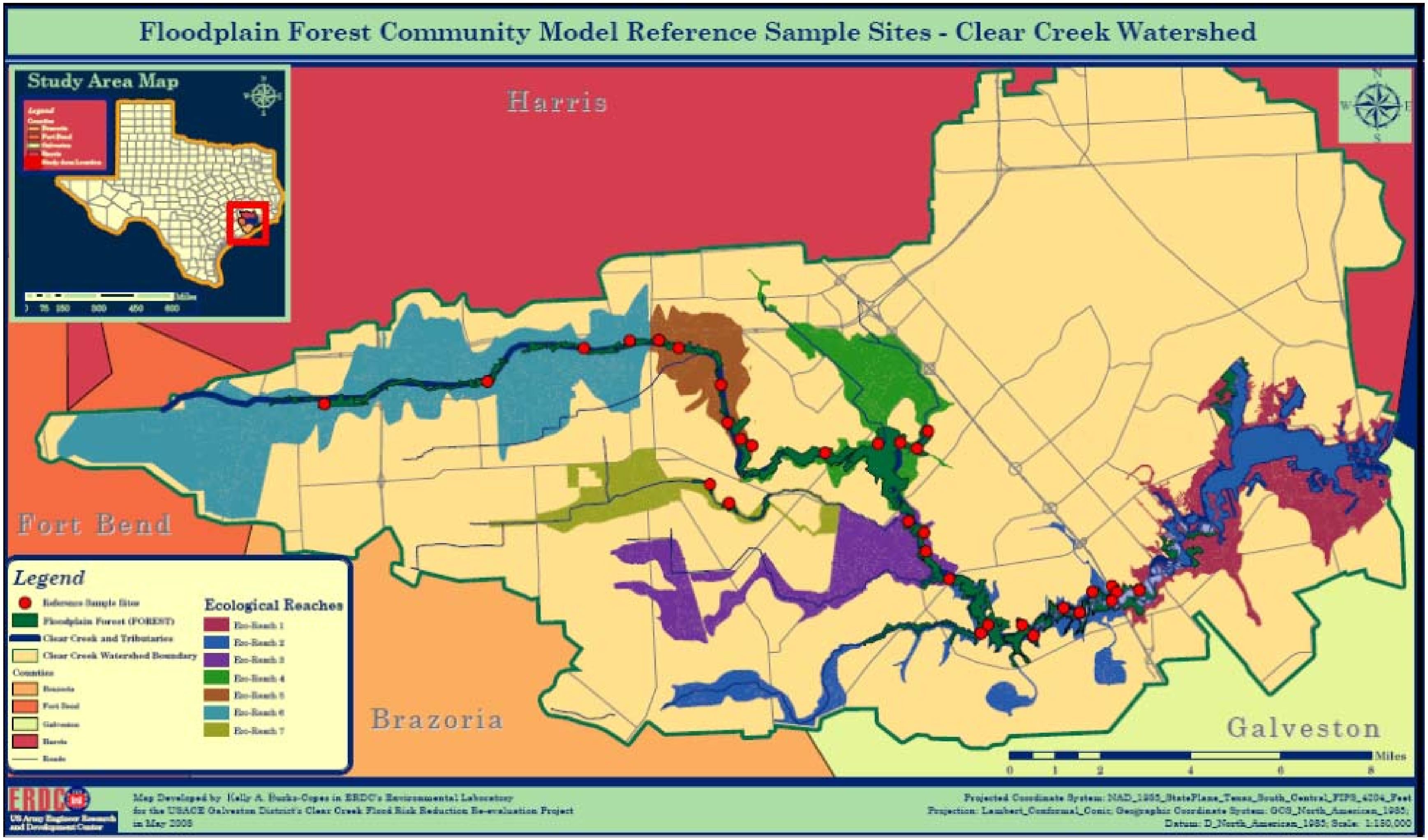

Figure 24. Floodplain forest reference sites in the Clear Creek watershed.

Table 3. Index formulas for the Clear Creek Floodplain forest community model.

<table>
<tr><th>Model Component</th><th>Variable Description</th><th>Variable Code</th><th>Formulas</th></tr>
<tr><td rowspan="5">Soils and Hydrology (HYDRO)</td><td>Hydroperiod</td><td>ALTERHYDRO</td><td rowspan="5">$$\frac{V_{ALTERHYDRO} + V_{ROUGHNESS} + V_{IMPERVIOUS} + V_{SINUOSITY} + V_{EROSION}}{5}$$</td></tr>
<tr><td>Roughness</td><td>ROUGHNESS</td></tr>
<tr><td>Infiltration Capacity</td><td>IMPERVIOUS</td></tr>
<tr><td>Sinuosity</td><td>SINUOSITY</td></tr>
<tr><td>Erosion Potential</td><td>EROSION</td></tr>
<tr><td rowspan="8">Structure and Biotic Integrity (BIOINTEG)</td><td>Tree Canopy Cover</td><td>CANTREE</td><td rowspan="8">$$\frac{\left[\frac{(V_{CANTREE} \times V_{NATIVE})^{1/2} + V_{VEGSTRATA} + V_{AREAWETDRY}}{3}\right] + \left[V_{OVRHDCOV} \times V_{INSTRMCOV} \times \left(\frac{V_{SUBSTRATE} + V_{WATERDEPTH}}{2}\right)\right]^{1/3}}{2}$$</td></tr>
<tr><td>Natives</td><td>NATIVE</td></tr>
<tr><td>Vegetative Strata</td><td>VEGSTRATA</td></tr>
<tr><td>Wet::Dry Ratios</td><td>AREAWETDRY</td></tr>
<tr><td>Overhanging Stream Cover</td><td>OVRHDCOV</td></tr>
<tr><td>Submerged (Instream) Cover</td><td>INSTRMCOV</td></tr>
<tr><td>Substrate Composition</td><td>SUBSTRATE</td></tr>
<tr><td>Surface Water Depth</td><td>WATERDEPTH</td></tr>
<tr><td rowspan="5">Spatial Integrity and Disturbance (SPATIAL)</td><td>Patch Size</td><td>PATCHSIZE</td><td rowspan="5">$$\left\{(V_{PATCHSIZE} \times V_{CORE})^{1/2} \times \left[\frac{V_{NEIGHBOR} + (V_{EDGE} \times V_{ADJLANDUSE})^{1/2}}{2}\right]\right\}^{1/2}$$</td></tr>
<tr><td>Total Core Area</td><td>CORE</td></tr>
<tr><td>Nearest Neighbor</td><td>NEIGHBOR</td></tr>
<tr><td>Total Edge Area</td><td>EDGE</td></tr>
<tr><td>Adjacent Landuse</td><td>ADJLANDUSE</td></tr>
<tr><td colspan="3">Overall Habitat Suitability Index (HSI):</td><td>$$\frac{V_{HYDRO} + V_{BIOINTEG} + V_{SPATIAL}}{3}$$</td></tr>
</table>

Step 5: Data collection

Baseline characterization of the Clear Creek watershed necessitated the collection of hydrologic, floristic, and spatially explicit data system wide. To the greatest extent possible, underlying stressors in the region were also identified. In particular, land use activities, physical habitat alterations, and indicator species were described in detail. Some of this information was geographically based and were assessed using documented protocols in a GIS environment. As part of the basic site characterization efforts, historical data on landscape-scale habitat conditions, land use characteristics, and ownership patterns were collected as well. Site- and landscape-level data were collected and analyzed between 2000 and 2008. Refer to Burks-Copes and Webb (in preparation) 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 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. For minutes/notes recorded at these meetings, contact Mrs. Andrea Catanzaro at the District office.

Step 7: Calculate Baseline Conditions

Once the baseline inventory was completed, the variable means, modes and the acreages were calculated. The baseline conditions in terms of units (HUs) were generated by multiplication. Below the mathematical protocol used to generate the units in HEP is described.

Calculating SIs in the Baseline HEP Analysis

The means/mode values for each variable were applied to the SI graphs as dictated by the models' documentation (Burks-Copes and Webb in preparation). A new SI graph was developed for each variable (per model) based on reference standards and reference site findings. The mean for each variable (per model) was then "scored" on SI 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 10 acres, the value "10" was entered into the "X-axis" on the SI curve below, and the resultant SI score (Y-axis) was determined (SI = 0.75) (Figure 25).

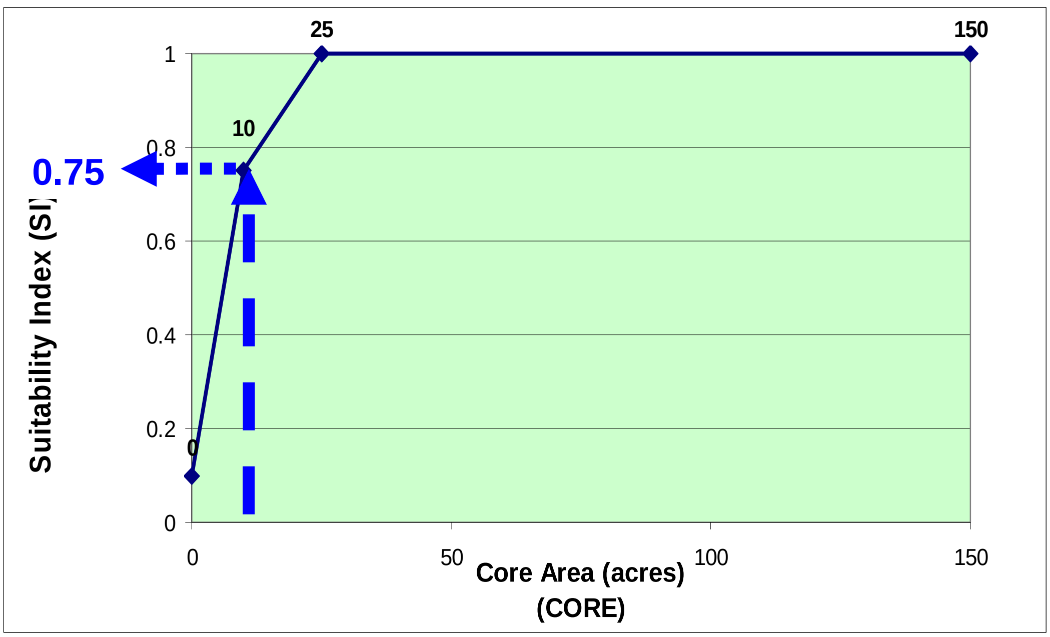

Figure 25. Example Suitability Index (SI) curve.

The process was repeated for every variable in each community's CT for each of the component (e.g., life requisite) formulas for each of the models. 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.

Calculating HSIs in the Baseline HEP Analysis

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:

$$HSI_{Model} = \sum(\text{CT HSI x RA})_X \quad (1)$$

where

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

Calculating HUs in the Baseline HEP Analysis

The final step was to multiply the HSI results (per model) 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: Clear Creek's Goals, Objectives, Project Life, and Target Years

In an attempt to generate quantifiable objectives for the study, the District began the process of establishing specific flood risk management goals, and developed a series of performance measures to assess the success of the mitigation 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 projects that would be acceptable to the public, local sponsors and USACE (USACE 1999; 2002, 2010). The Clear Creek study's objectives included:

1. Reducing flood risk for economic, social, and environmental purposes along Clear Creek and its tributaries;
2. Improving fish and wildlife resources of Clear Creek and its tributaries for the purpose of attracting more and varied species of fish and wildlife;
3. Preserving and protecting natural and cultural resources for public education and historical appreciation purposes;
4. Developing opportunities for recreation in Clear Creek and its tributaries;

5. Facilitating stabilization of the stream banks of Clear Creek and its tributaries; and
6. Improving the quantity and quality of habitat on Clear Creek and its tributaries.

The proposed mitigation efforts would be designed to mimic historic, natural conditions that harvest water, trap sediments, facilitate water absorption, and provide water to vegetation. Existing vegetation communities would be restored and rehabilitated with supplemental plantings, invasive species control, and other best management practices and strategies (e.g., restoration/rehabilitation). With the restoration of the vegetation communities, habitat structure should improve and there should be an increase in the number and diversity of wildlife species in the area. This approach to restoration, focusing on the community functions and processes via the habitat and vegetation structure, will eventually lead to more natural ecosystems, as these are signs of a healthy ecosystem and a successful ecosystem restoration.

Selection of a Project Life and TYs

With these goals and objectives in mind, the District designated a "Project Life" of 50 years for the Clear Creek 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. Five TYs were defined by the E-Team:

1. TY = "0" refers to the baseline condition, or the 2000 calendar year.
2. TY = "1" refers to the last year of construction and planting activities, or the 2020 calendar year.
3. TY = "11" was chosen to capture 10 full years of vegetative growth under the proposed with-project conditions (e.g., the 2030 calendar year).
4. TY = "36" was selected to capture 25 full years of vegetative growth under the with-project conditions (e.g., the 2055 calendar year).
5. TY = "51" was selected to capture 15 full years of vegetative growth under the with-project conditions (e.g., the 2070 calendar year).

Step 9: WOP Conditions for the Clear Creek 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 between 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 mitigation 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 action was taken. Conversely, the WOP condition is the result when no action is 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. 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 a 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 wildlife 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. 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:

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

where

$$\text{Cumulative Units } = \sum(T_2 - T_1)\left[\left(\frac{A_1I_1 + A_2I_2}{3}\right) + \left(\frac{A_2I_1 + A_1I_2}{6}\right)\right] \quad (2)$$

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

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.[1] This is equivalent to mathematical integration of the unit relationship over time, or

$$Cumulative\_Units = \int_0^T U\ dt \quad (3)$$

But U = A x I

where

A = Area 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

[1] Personal Communication. Adrian Farmer. 2003. USGS.

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,

$$\begin{aligned}\int_0^T U\,dt &\equiv \int_0^T (A_1 + m_1 t)(I_1 + m_2 t)\,dt \\ &\equiv \int_0^T A_1 I_1\,dt + \int_0^T m_1 I_1 t\,dt + \int_0^T m_2 A_1 t\,dt + \int_0^T m_1 m_2 t^2\,dt \\ &\equiv A_1 I_1 T + \frac{m_1 I_1 T^2}{2} + \frac{m_2 A_1 T^2}{2} + \frac{m_1 m_2 T^3}{3}\end{aligned} \tag{4}$$

Substitute the following equations for the slopes, m_1 and m_2

$$\begin{aligned} m_1 &= \frac{A_2 - A_1}{T} \\ m_2 &= \frac{I_2 - I_1}{T}\end{aligned} \tag{5}$$

into the above formula to generate the following:

$$\int_0^T U\,dt \equiv A_1 I_1 T + \frac{(A_2 - A_1) I_1 T}{2} + \frac{(I_2 - I_1) A_1 T}{2} + \frac{(A_2 - A_1)(I_2 - I_1) T}{3} \tag{6}$$

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

$$\int_0^T U\,dt \equiv (T_2 - T_1)\left[\left(\frac{A_1 I_1 + A_2 I_2}{3}\right) + \left(\frac{A_2 I_1 + A_1 I_2}{6}\right)\right] \tag{7}$$

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 26).

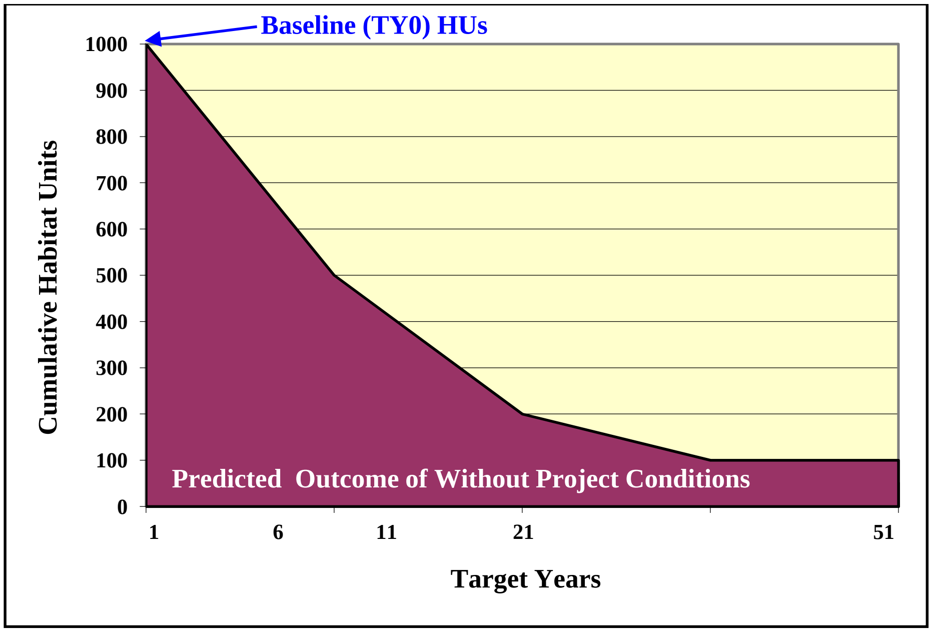

Figure 26. Example of cumulative HU availability under a without-project scenario.

The assumptions that went into the projection of future conditions at the Clear Creek 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 Clear Creek study

Between 2004 and the present, the E Team participated in several workshops to present and modify alternative designs developed by independent teams for the NED plan (including multiple mitigation scenarios). These independent teams were 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 verbal descriptions) for the 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 *Chapters 5* and *6* of this report.

Step 11: Tradeoffs in the Clear Creek Study – Not Applicable

It is important to note that tradeoffs were not necessary for this study – only a single technique (HEP) and a single community-based model were used to evaluate the NED plan's impacts. In other words, forest impacts (measured in AAHUs with the floodplain forest model) were mitigated with forest restoration/rehabilitation benefits (again measured in AAHUs with the floodplain forest model). The mitigation plans were evaluated and compared on this premise (full mitigation of all community impacts in-kind), and on the basis of cost effectiveness/incremental effectiveness (refer to the *Cost Analysis* section below and the final results presented in *Chapter 6*).

Step 12: Reporting the Results of the Analyses

The success of any evaluation lies in the planner's ability to discuss the assessment strategies and findings to 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 assure 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 assure 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 to seven chapters provided in every assessment report: *Introduction, Methods, Baseline Results, Without-project Results, and With-Project Results* (for both the impacts and the mitigation analyses), 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 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:

1. Formulate all possible combinations of alternative designs by:
    a. Displaying all outputs and costs;
    b. Identifying filters, which restrict the combination of alternative designs; and
    c. Calculating outputs and costs of combinations.
2. Complete a CEA by:
    a. Eliminating economically inefficient alternative designs; and
    b. Eliminating economically ineffective alternative designs.
3. Develop an incremental cost curve by:

   a. Calculating the average costs; and
   b. Recalculating average costs for additional outputs.
4. Complete an ICA by:
   a. Calculating incremental costs; and
   b. Comparing successive outputs and incremental costs.

In the 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 that are 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.

It is important to note that benefit-cost analysis was used to refine and hone the final NED plan. An integral part of the NED plan is inclusion of recommended mitigation. CEA/ICA was used to compare/contrast the various mitigation scenarios and ultimately facilitated the selection of the recommended mitigation plan(s) for the NED plan. *Chapter 6* of this report details the CEA/ICA analyses conducted for the Clear Creek study's mitigation plans. Specifics on cost generation for the proposed alternative mitigation designs, as well as the cost-benefit analysis for the NED plan can be found in the feasibility report (USACE 2010).

3 Baseline Analysis and Results

The baseline conditions for the Clear Creek watershed were determined on a landscape-level scale on the ecological reaches (refer back to Figure 12 on page 1). Below, the authors 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.[1]

Acreage Inputs

For the baseline analysis, the 41,566 acres were mapped and classified (i.e., cover typed) inside the study area boundaries. These, in turn, were divided among the eco-reaches for the analysis (Table 4 and Figure 27).

Table 4. Baseline acres classified and assigned to the seven eco-reaches in the Clear Creek study.

Code	Description	Baseline Acres (TY0)							Total Project Area
		Eco-Reach 1	Eco-Reach 2	Eco-Reach 3	Eco-Reach 4	Eco-Reach 5	Eco-Reach 6	Eco-Reach 7	
AGCROP	Farms and Croplands	1	97	34	2	28	1,305	12	1,479
FOREST	Floodplain Forest	490	1,095	253	1,053	337	489	85	3,802
OPENWATER	Open Bodies of Water Deeper than 1-3m	2,900	66	20	17	11	180	25	3,219
PASTURES	Old Fields, Haylands and Pastures	2,260	1,997	2,522	1,521	692	8,378	1,120	18,490
PRAIRIE	Prairie	103	33	0	26	1,094	1,077	314	2,647
TIDALMARSH	Tidal Marsh	255	64	0	0	0	0	0	319
URBAN	Existing Residential, Industrial and Transportation Avenues	2,653	763	1,869	1,753	601	2,871	1,090	11,600
	TOTALS:	8,662	4,115	4,698	4,372	2,763	14,300	2,646	41,556

[1] Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

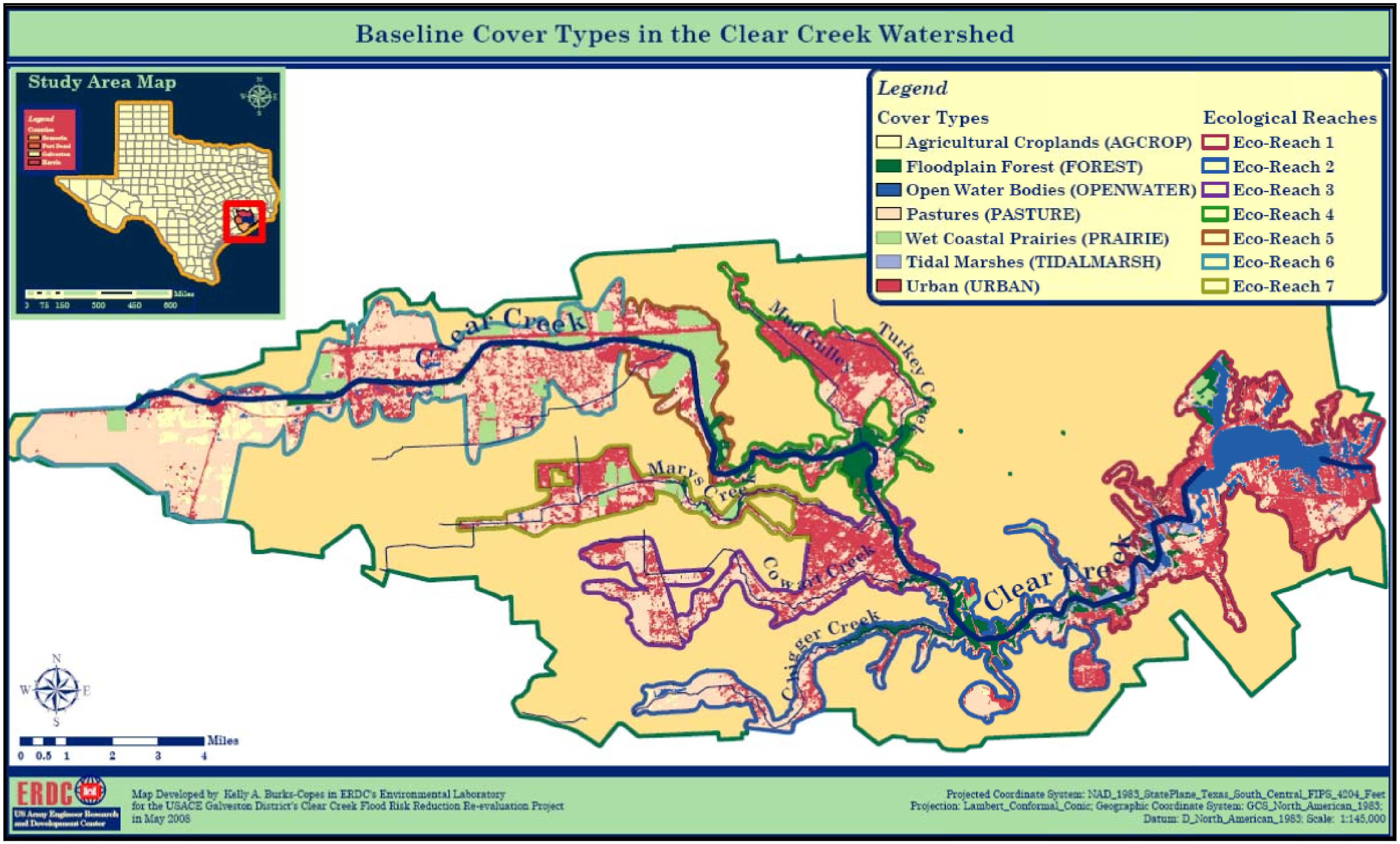

Figure 27. Map of the baseline cover types for the Clear Creek study.

Variable Data Inputs

Field data was collected in 2003 and GIS coverages (based on 2000 imagery) were compiled and analyzed on a reach-by-reach basis over the course of the next several years. Data for each variable per cover type within each community (floodplain forest and wet coastal prairie) were recorded and the variable means/modes were calculated to generate watershed baseline HSIs on a reach-by-reach basis. Eighteen floodplain forest variables and fifteen wet coastal prairie variables were measured across the seven eco-reaches following the prescribed sampling protocols detailed in Burks-Copes and Webb in preparation. The means for each variable are summarized in Table 5 below.

Table 5. Baseline data for the floodplain forest communities across reaches.

Reach	ADJLANDUSE	ALTERHYDRO	AREAWETDRY	CANTREE	CORE	EDGE	EROSION	IMPERVIOUS	INSTRMCOV	NATIVE	NEIGHBOR	OVRHDCOV	PATCHSIZE	ROUGHNESS	SINUOUSITY	SUBSTRATE	VEGSTRATA	WATERDEPTH
1	2	5	30	60	0	40	3	30	65	50	10	30	45	0	2	1	6	2
2	2	5	10	70	10	13	3	40	25	75	35	60	15	0	2	1	7	3
3	3	3	0	45	0	24	4	55	0	40	0	40	25	0	2	1	5	4
4	3	1	5	65	40	31	2	40	5	60	0	60	52	0	2	1	7	4
5	3	1	20	75	5	65	3	40	5	60	30	20	65	0	1	1	6	4
6	3	1	5	75	0	70	3	30	5	70	55	30	70	0	1	1	6	4
7	3	1	0	65	0	20	3	50	15	65	23	45	20	0	1	1	6	3

Baseline Outputs - Indices and Units

The results of the baseline HEP assessment for the reaches are summarized below. HSIs capture the quality of the acreage within the reach. Units (i.e., HUs) take this quality and apply it to the governing area through multiplication (Quality X Quantity = Units). Both HSIs and HUs are reported for each reach. Interpretations of these findings can be generalized in the following manner (Table 6).

In the majority of instances, the individual component indices (e.g., Life Requisite Suitability Indices or LRSIs) and composite HSIs scored higher than moderate values (>0.5) indicating a "moderately high" level of relative functionality in the watershed (Table 7 and Figure 28). In five out of seven of the reaches, the limiting or driving factor was the Spatial Integrity/ Disturbance component, which regularly scored lower than 0.4. The highest

Table 6. Interpretation of HSI scores resulting from HEP assessments.

HSI Score	Interpretation
0.0	Not-suitable - the community does not perform to a measurable level and will not recover through natural processes
Above 0.0 to 0.19	Extremely low or very poor relative functionality (i.e., in relation to the reference standards found in the model's domain) - the community functionality can be measured, but it cannot be recovered through natural processes
0.2 to 0 .29	Low or poor relative functionality
0.3 to 0.39	Fair to moderately low relative functionality
0.4 to 0 .49	Moderate relative functionality
0.5 to 0.59	Moderately high relative functionality
0.6 to .79	High or good relative functionality
0.8 to0.99	Very high or excellent relative functionality
1.0	Optimum relative functionality - the community performs functions at the highest level - the same level as reference standard settings

Table 7. Baseline tabular results for the floodplain forest community.

Reach Name	LRSI Code	LRSI Score	Habitat Suitability Index (HSI)	Applicable Acres	Baseline Habitat Units (HUs)
Eco-Reach 1	BIOINTEG	0.87	0.67	490	328
	HYDRO	0.88			
	SPATIAL	0.25			
Eco-Reach 2	BIOINTEG	0.87	0.84	1,095	920
	HYDRO	0.87			
	SPATIAL	0.78			
Eco-Reach 3	BIOINTEG	0.26	0.47	253	119
	HYDRO	0.62			
	SPATIAL	0.53			
Eco-Reach 4	BIOINTEG	0.67	0.74	1,053	781
	HYDRO	0.58			
	SPATIAL	0.97			
Eco-Reach 5	BIOINTEG	0.70	0.62	337	209
	HYDRO	0.66			
	SPATIAL	0.50			
Eco-Reach 6	BIOINTEG	0.66	0.56	489	275
	HYDRO	0.68			
	SPATIAL	0.34			
Eco-Reach 7	BIOINTEG	0.78	0.48	85	41
	HYDRO	0.53			
	SPATIAL	0.14			

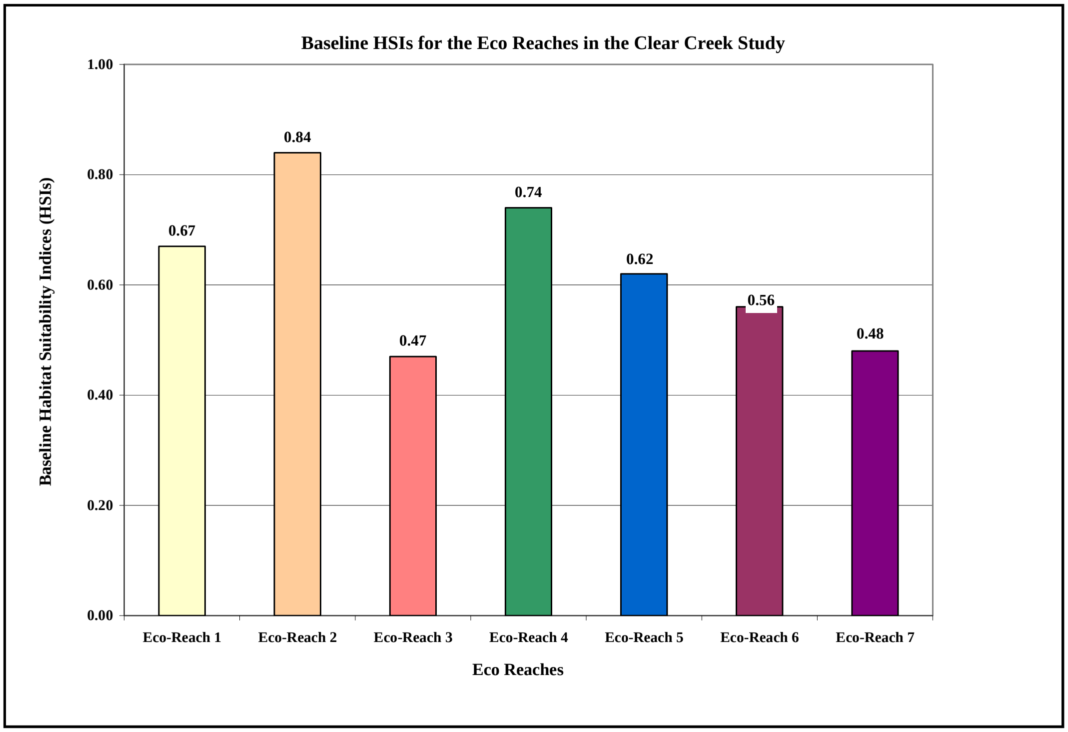

Figure 28. Baseline HSI results for the Clear Creek study's floodplain forest community.

functioning reach was Eco-Reach 2 (HSI = 0.84). This was to be expected – the last vestiges of healthy floodplain forest are found in this area. Impacts in this reach will likely incur significant levels of mitigation. Not surprisingly, Reach 3 and 7 generated the lowest HSI scores (HSI = 0.47 and 0.48 respectively). The overall lack of floodplain forest in these reaches, and the overwhelming urban encroachment they are experiencing offer insight into the lack of functioning forested communities in that tributary.

At baseline, 3,802 acres of floodplain forests were associated with the model across the entire project area (Table 7 and Figure 29). Eco-Reaches 2 and 4 held the largest numbers of forested acres (1,095 and 1,053 acres respectively). Eco-Reach 7 has the smallest forested holdings (just 85 acres).

Overall, the watershed generated 2,683 habitat units across all ecological reaches. The baseline HUs within the Eco-Reaches ranged from 41 units in Eco-Reach 7 to 920 units in Eco-Reach 2 (Table 7 and Figure 30). In HEP, the maximum HSI score possible is 1.0. Given the total number of applicable floodplain forest acres at baseline (i.e., 3,802 acres), one can derive the optimal conditions and outputs by multiplying the quantity and quality to generate the highest possible outcome (3,082 acres x 1.0 HSI = 3,802 units). By comparing the actual situation to this optimum, the E-Team can

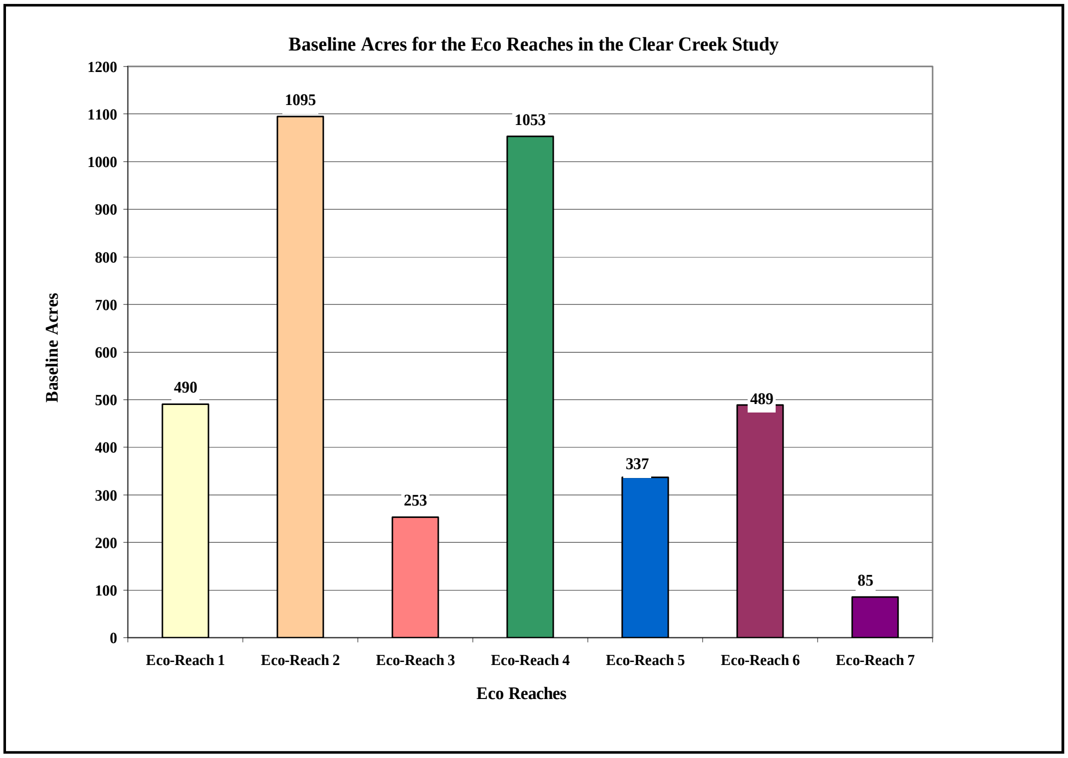

Figure 29. Baseline acre distributions for the Clear Creek study's floodplain forest community.

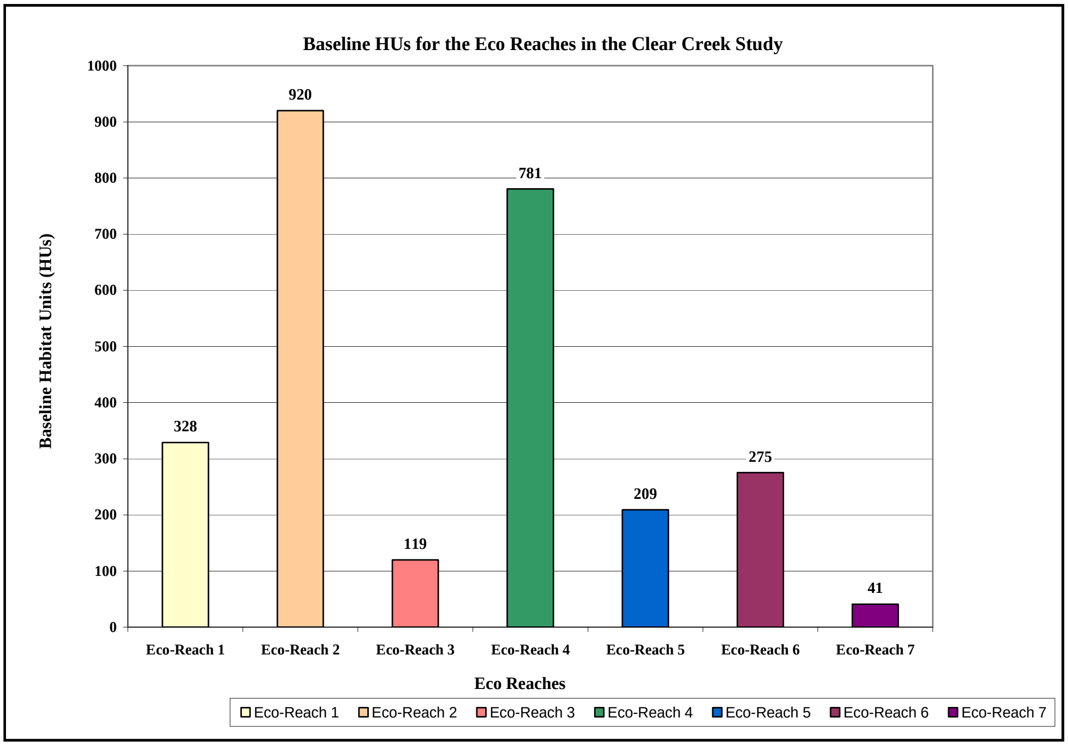

Figure 30. Baseline HU results for the Clear Creek study's floodplain forest community.

determine at what level the ecosystem is functioning. In this case, the watershed is operating at approximately 71 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 seven reaches. The individual performances ranged from 47 percent (Eco-Reach 3) to 84 percent in Eco-Reach 2. Clearly, there are opportunities for improvements (i.e., Eco-Reaches 3, 5, 6 and 7 are prime candidates for mitigation activities), and any flood risk management activities proposed in Eco-Reaches 1, 2, and 4 will likely incur the most impacts (i.e., they have more to lose).

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 community along the Texas coast point to an overall decline in ecosystem integrity (i.e., health, biodiversity, stability, sustainability, naturalness, etc.) – a finding the model can now quantify (less than optimal HSI values in all reaches). Furthermore, the results indicate an opportunity to both incur and redress impacts. There is a high likelihood that any flood risk management measures taken in Reaches 1, 2 and 4 will induce impacts to forests, and should therefore be avoided. On the other hand, there is great potential to restore forested communities in the remaining reaches, thereby meeting the demand for mitigation by implementing appropriate and sustainable activities targeting these sub-functional communities.

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 were certain to reflect losses in community function (i.e., quality) and presence (i.e., quantity) when faced with the pressures of increasing population growth and flooding. The E-Team addressed these issues in several workshops over the course of the study, and developed trends to capture both the losses of 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.[1]

Predicted WOP Acreage Trends (Quantity)

Given the study’s location and the projected growth trends for the area, forecasting suggested initial development would focus on privately held vacant and agricultural parcels.[2] Agricultural lands, pastures, wet coastal prairies, and floodplain forests near urban centers were thought to be especially vulnerable to residential conversion over the next 50 years. As privately held lands were converted to commercial and industrial park uses, adjacent publicly owned areas (forests currently considered prime candidates for preservation, creation and restoration activities) would come under increased development pressure. Real estate values would rise in response to market demand. In order to maximize development acreages in areas adjacent to Clear Creek, conventional, engineered solutions for bank protection and erosion control would likely be implemented. Over the next ~40 years, the projected population growth trends of the major cities within the watershed are staggering (Table 8).[3]

Table 8. Projected population growth trends for some cities in the Clear Creek watershed.

County	City	1990	2000	2010	2020	2030	2040	2050
Brazoria	Pearland	17,234	29,480	39,464	49,742	61,929	73,332	86,834
Harris	Friendswood	7,835	11,337	17,089	26,504	38,491	57,649	77,708
Harris	League City	133	207	237	275	298	327	358

[1] Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

[2] For more details regarding future WOP trends, refer to USACE 2010, Section 4.9.2.

[3] Population growth projections provided by the Texas Water Development Board (http://www.twdb.state.tx.us/data/popwaterdemand/2002%20Projections/populationh.htm) for the cities of Pearland, Friendswood, and League City were used as the basis for projecting populations.

In an effort to capture these significant land use changes in the Clear Creek study area, the E-Team developed a table projecting acreages per cover type on a TY basis for each Eco-Reach (Table 9).[1]

Table 9. WOP acre projections for Clear Creek watershed eco-reaches.

Eco-Reach 1						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	1	1	1	1	1
FOREST	Floodplain Forest	490	420	389	311	264
OPENWATER	Open Bodies of Water Deeper than 1-3m	2,900	2,626	2,545	2,338	2,214
PASTURES	Old Fields, Haylands and Pastures	2,260	1,834	1,684	1,314	1,092
PRAIRIE	Prairie	103	93	88	73	64
TIDALMARSH	Tidal Marsh	255	215	199	159	135
URBAN	Existing Residential, Industrial and Transportation Avenues	2,653	3,473	3,756	4,466	4,892
TOTALS:		8,662	8,662	8,662	8,662	8,662
Eco-Reach 2						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	97	94	92	86	83
FOREST	Floodplain Forest	1,095	941	869	689	581
OPENWATER	Open Bodies of Water Deeper than 1-3m	66	62	60	56	53
PASTURES	Old Fields, Haylands and Pastures	1,997	1,814	1,716	1,470	1,323
PRAIRIE	Prairie	33	28	26	20	17
TIDALMARSH	Tidal Marsh	64	55	51	42	36
URBAN	Existing Residential, Industrial and Transportation Avenues	763	1,121	1,301	1,752	2,022
TOTALS:		4,115	4,115	4,115	4,115	4,115

[1] One note to the reader - although baseline conditions for Eco-Reach 1 were assessed early on in the process, the District determined that flood risk management in that section of the watershed was not productive or feasible, and therefore the decision was made to focus planning efforts on critical river sections upstream. As such, the authors elected to omit the Eco-Reach 1 results from this document as they had no bearing on the NED plan and its recommended mitigation options.

Eco-Reach 3						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	34	31	29	25	22
FOREST	Floodplain Forest	253	206	196	171	156
OPENWATER	Open Bodies of Water Deeper than 1-3m	20	17	16	14	12
PASTURES	Old Fields, Haylands and Pastures	2,522	2,196	2,069	1,747	1,555
PRAIRIE	Prairie	0	0	0	0	0
TIDALMARSH	Tidal Marsh	0	0	0	0	0
URBAN	Existing Residential, Industrial and Transportation Avenues	1,869	2,248	2,388	2,741	2,953
TOTALS:		4,698	4,698	4,698	4,698	4,698
Eco-Reach 4						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	2	2	2	2	2
FOREST	Floodplain Forest	1,053	931	852	655	536
OPENWATER	Open Bodies of Water Deeper than 1-3m	17	15	14	12	10
PASTURES	Old Fields, Haylands and Pastures	1,521	1,370	1,271	1,019	871
PRAIRIE	Prairie	26	24	23	20	18
TIDALMARSH	Tidal Marsh	0	0	0	0	0
URBAN	Existing Residential, Industrial and Transportation Avenues	1,753	2,030	2,210	2,664	2,935
TOTALS:		4,372	4,372	4,372	4,372	4,372
Eco-Reach 5						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	28	25	24	21	20
FOREST	Floodplain Forest	337	309	295	258	236
OPENWATER	Open Bodies of Water Deeper than 1-3m	11	10	10	8	7
PASTURES	Old Fields, Haylands and Pastures	692	625	592	511	463
PRAIRIE	Prairie	1,094	988	941	826	755

TIDALMARSH	Tidal Marsh	0	0	0	0	0
URBAN	Existing Residential, Industrial and Transportation Avenues	601	806	901	1139	1282
TOTALS:		2,763	2,763	2,763	2,763	2,763
Eco-Reach 6						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	1,305	1,219	1,166	1,032	951
FOREST	Floodplain Forest	489	448	426	368	334
OPENWATER	Open Bodies of Water Deeper than 1-3m	180	163	154	132	119
PASTURES	Old Fields, Haylands and Pastures	8,378	7,814	7,527	6,811	6,381
PRAIRIE	Prairie	1,077	982	928	792	711
TIDALMARSH	Tidal Marsh	0	0	0	0	0
URBAN	Existing Residential, Industrial and Transportation Avenues	2,871	3,674	4,099	5,165	5,804
TOTALS:		14,300	14,300	14,300	14,300	14,300
Eco-Reach 7						
		Calendar Year and Target Year				
		2000	2020	2030	2055	2070
Code	Description	TY0	TY1	TY11	TY36	TY51
AGCROP	Farms and Croplands	12	10	9	6	4
FOREST	Floodplain Forest	85	71	65	51	43
OPENWATER	Open Bodies of Water Deeper than 1-3m	25	20	18	11	7
PASTURES	Old Fields, Haylands and Pastures	1,120	900	796	540	385
PRAIRIE	Prairie	314	256	228	156	113
TIDALMARSH	Tidal Marsh	0	0	0	0	0
URBAN	Existing Residential, Industrial and Transportation Avenues	1,090	1,389	1,530	1,882	2,094
TOTALS:		2,646	2,646	2,646	2,646	2,646

As these tables indicate, urban areas (residential, commercial, industrial and infrastructure such as roads) would increase in coverage, while over 1,650 acres of surrounding natural vegetative communities (e.g., floodplain forests) would be eliminated. The existing narrow band of riparian habitat supported by current hydrologic regime would decline over time in response to altered hydroregime. The loss of terrestrial and wetland communities that serve as habitat for a myriad of wildlife species is significant. Interestingly, the floodplain forest communities will not be the only “losers” under this scenario. The majority of the agricultural croplands, pastures and prairies would be consumed in the wave of urban growth (more than 6,815 acres lost).

Predicted WOP Variable Trends (Quality)

Future conditions under the “No Action” alternative were based on the development assumptions used in the rainfall and hydraulic analyses of engineering study (USACE 2010). The “No Action” alternative assumes the Clear Creek’s current configuration will be maintained, and that no locally constructed channel rectifications would occur. Future forecasts were based on urban development trends (percent land urbanization) within the watershed’s subbasins, and assumed that as population increased the area would be converted to an urban drainage system with increasing impervious percentages and associated runoff. Year 2000 population counts were coupled with the development area acreage within census tracts to compute the population/developed area ratio, and Census tract population projections from years 2010 and 2060 were used to estimate weighted future urban development conditions (percent land urbanization) within each subbasin.

As a direct result of growth, it was assumed that impervious cover would increase, thereby reducing both available areas for native vegetative communities and infiltration of runoff. Increased runoff associated with the predicted urban development would cause increased flows resulting in increases in water elevation sufficient to cause flooding in many areas. It was further assumed that urban development would occur along the edge of the creek’s banks (in those areas permitting such activities) resulting in the loss of native riparian vegetation communities. Continued urban encroachment was assumed to cause extensive losses of native riparian vegetation, and the environmental value (i.e., ecosystem function) associated with the remaining relictual communities was assumed to continue to decline. Within these remaining patches, the authors would expect to see riparian vegetation removed from within and along streams (clearing and snagging practices are common in this area, and thus the authors assumed this activity would continue). This loss of vegetative cover will lead to reduced friction and improved flow. However, the result of these actions will yield a highly fragmented landscape (i.e., smaller patches, less core area, more edge, greater distances between patches, etc.) and the forests' buffering functions would therefore be lost entirely. As the stabilizing function of native riparian plans is lost, and as further development occurs, artificial bank stabilization measures (namely armoring) would likely be employed to reduce potential erosion. With the disappearance and declining quality of the native vegetation, the authors would also expect to see a decline in community-dependent species of wildlife. Water quality (temperature, dissolved oxygen, turbidity and salinity) too will degrade significantly in the absence of the riparian vegetative community, as the shading and sediment stabilizing effects of trees and associated vegetation in and adjacent to the creek disappear. Noxious and/or exotic species will likely be introduced and proliferate rapidly into homogenous stands of undesirable vegetation choking out the native remnants in the forests. As the stabilizing function of native remnants (Table 10 – 16).

Table 10. WOP variable projections for Eco-Reach 1.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	5	2	2	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	30	30	30	40	45
	ROUGHNESS	0.11	0.070	0.07	0.07	0.07
	SINUOSITY	1.55	1.55	1.55	1.55	1.55
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	20	45	50	60	65
Structure and Biotic Integrity (BIOINTEG)	CANTREE	60	60	60	60	60
	INSTRMCOV	65	40	40	40	40
	NATIVE	50	45	40	30	25
	OVRHDCOV	30	20	20	20	20
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	2	6	6	8	9
	AREAWETDRY	30	24	20	15	10
	CORE	0	0	0	0	0
	EDGE	40	35	35	25	20
	NEIGHBOR	100	115	125	155	175
	PATCHSIZE	45	40	35	25	20

Table 11. WOP variable projections for Eco-Reach 2.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	5	2	2	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	40	40	45	55	65
	ROUGHNESS	0.1	0.070	0.07	0.07	0.07
	SINUOSITY	1.57	1.57	1.57	1.57	1.57
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	30	55	60	70	75
Structure and Biotic Integrity (BIOINTEG)	CANTREE	70	70	70	70	70
	INSTRMCOV	25	15	15	15	15
	NATIVE	75	70	65	50	40
	OVRHDCOV	60	35	35	35	35
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	2	7	7	8	8
	AREAWETDRY	10	10	9	7	6
	CORE	10	10	10	5	5
	EDGE	135	125	115	90	75
	NEIGHBOR	35	35	35	45	50
	PATCHSIZE	155	140	130	100	85

Table 12. WOP variable projections for Eco-Reach 3.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	3	2	2	1	1
	EROSION	4	4	4	5	5
	IMPERVIOUS	55	70	70	80	90
	ROUGHNESS	0.11	0.070	0.07	0.07	0.07
	SINUOSITY	1.64	1.64	1.64	1.64	1.64
	SUBSTRATE	1	1.00	1	1	1
	WATERDEPTH	40	65	70	80	85
Structure and Biotic Integrity (BIOINTEG)	CANTREE	45	45	45	45	45
	INSTRMCOV	0	0	0	0	0
	NATIVE	40	35	35	25	20
	OVRHDCOV	40	25	25	25	25

	VEGSTRATA	5	5	5	5	5
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	0	0	0	0	0
	CORE	0	0	0	0	0
	EDGE	240	195	185	165	150
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	255	205	195	170	150

Table 13. WOP variable projections for Eco-Reach 4.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	2	2	1	1
	EROSION	2	4	4	5	5
	IMPERVIOUS	40	40	45	55	65
	ROUGHNESS	0.11	0.070	0.07	0.07	0.07
	SINUOSITY	1.74	1.74	1.74	1.74	1.74
	SUBSTRATE	1	1.00	1	1	1
	WATERDEPTH	45	70	75	85	90
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	65	65
	INSTRMCOV	5	5	5	5	5
	NATIVE	60	55	50	40	35
	OVRHDCOV	60	35	35	35	35
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	5	5	4	2	1
	CORE	40	34	30	25	20
	EDGE	310	265	245	190	160
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	525	450	415	325	270

Table 14. WOP variable projections for Eco-Reach 5.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	40	40	40	50	55

	ROUGHNESS	0.11	0.110	0.11	0.11	0.11
	SINUOSITY	1.23	1.23	1.23	1.23	1.23
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	70	75	85	90
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	75	75
	INSTRMCOV	5	5	5	5	5
	NATIVE	60	55	55	45	40
	OVRHDCOV	20	10	10	10	10
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	20	18	17	15	13
	CORE	5	5	5	5	5
	EDGE	65	55	55	45	40
	NEIGHBOR	30	30	30	40	45
	PATCHSIZE	65	55	55	45	40

Table 15. WOP variable projections for Eco-Reach 6.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	30	30	30	40	45
	ROUGHNESS	0.11	0.070	0.07	0.07	0.07
	SINUOSITY	1.16	1.16	1.16	1.16	1.16
	SUBSTRATE	1	1.00	1	1	1
	WATERDEPTH	40	65	70	80	85
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	75	75
	INSTRMCOV	5	5	5	5	5
	NATIVE	70	65	60	50	45
	OVRHDCOV	30	20	20	20	20
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	5	5	4	3	3
	CORE	0	0	0	0	0
	EDGE	70	60	55	45	40
	NEIGHBOR	55	65	70	80	90
	PATCHSIZE	70	60	55	45	40

Table 16. WOP variable projections for Eco-Reach 7.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	50	60	65	75	85
	ROUGHNESS	0.11	0.070	0.07	0.07	0.07
	SINUOSITY	1.2	1.20	1.2	1.2	1.2
	SUBSTRATE	1	1.00	1	1	1
	WATERDEPTH	35	60	65	75	80
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	65	65
	INSTRMCOV	15	10	10	10	10
	NATIVE	65	60	55	45	40
	OVRHDCOV	45	25	25	25	25
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	1	1	1	1	1
	CORE	0	0	0	0	0
	EDGE	20	20	20	15	15
	NEIGHBOR	235	285	305	375	425
	PATCHSIZE	20	20	20	15	15

WOP Results

The changes predicted above led to considerable declines in projected community functionality across the watershed. Below, the authors detail these in terms of declines in quantity and quality captured in annualized outputs.[1]

WOP Quality

Based on the findings, the final HSI scores for the study indicate a dramatic loss in functionality over the 50-year life of the project (Table 17).

Under the current forecasted without-project condition, urban encroachment and flooding ensues, and the ecosystem functionality of the remnant communities plummet (final HSI scores ranged 0.35 to 0.61 across the

[1] Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

Table 17. Projected WOP results for the Clear Creek study under the WOP scenario.

Reach	Final WOP HSI	WOP TY 51 Acres	Net Change in HSIs	Net Change in Acres
Eco-Reach 1	0.49	264	-0.2	-226
Eco-Reach 2	0.61	581	-0.2	-514
Eco-Reach 3	0.35	156	-0.1	-97
Eco-Reach 4	0.61	536	-0.1	-517
Eco-Reach 5	0.52	236	-0.1	-101
Eco-Reach 6	0.47	334	-0.1	-155
Eco-Reach 7	0.37	43	-0.1	-42

eco-reaches). 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 2070 (TY51), the baseline HSI scores fell approximately 20 percent (from HSI = 0.68 on average to HSI = 0.49 on average). The loss in function and suitability was quite dramatic as was the case in Eco-Reach 1 and 2's floodplain forests (HSI dropped by 0.2 points in both cases). In the end, most of the reach scores hovered near the HSI midpoint (average HSI = 0.48, 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 31).

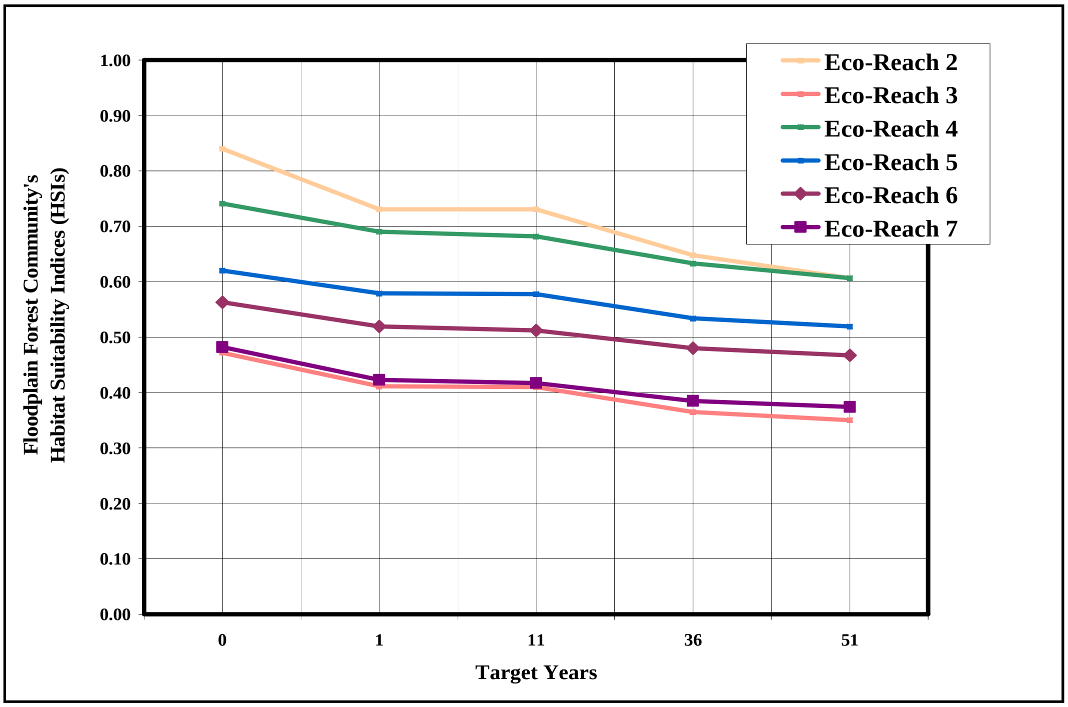

Figure 31. Cumulative changes in HSI values under the WOP scenario.

WOP Quantity

At baseline, 3,802 acres were associated with the floodplain forest model. By 2070 (TY51), this number plummets to 2,150 (a 43 percent reduction in available habitat) (Table 18 and Figure 32).

WOP Outputs (Quality x Quantity)

When the loss of quality described above is combined with the resultant loss in wetland acreage across the study area, the projected future conditions are disastrous (Figure 33).

Clearly, by 2070 (TY51) 57 percent of the forest community's baseline functionality is lost (Table 19).

Table 18. Predicted losses for the Clear Creek study area under the WOP scenario.

	Calendar Years and Target Years					
	2000	2020	2030	2055	2070	
Code	TY0	TY1	TY11	TY36	TY51	Net Change
AGCROP	1,479	1,382	1,323	1,173	1,083	-396
FOREST	3,802	3,326	3,092	2,503	2,150	-1,652
OPENWATER	3,219	2,913	2,817	2,571	2,422	-797
PASTURES	18,490	16,553	15,655	13,412	12,070	-6,420
PRAIRIE	2,647	2,371	2,234	1,887	1,678	-969
TIDALMARSH	319	270	250	201	171	-148
URBAN	11,600	14,741	16,185	19,809	21,982	10,382
TOTALS:	41,556	41,556	41,556	41,556	41,556	

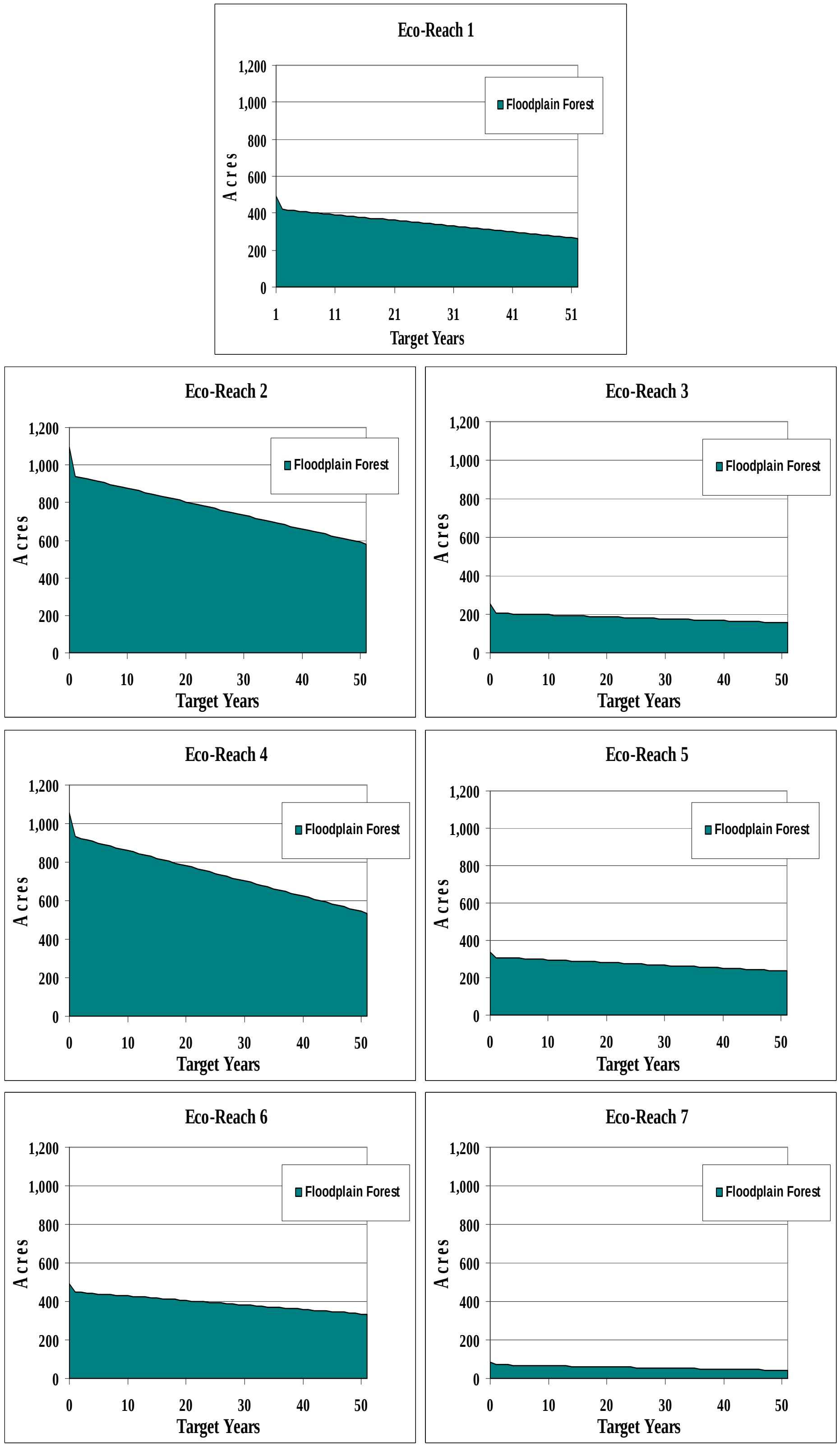

Figure 32. Predicted cumulative losses of habitat for eco-reaches in the Clear Creek watershed under the WOP scenario.

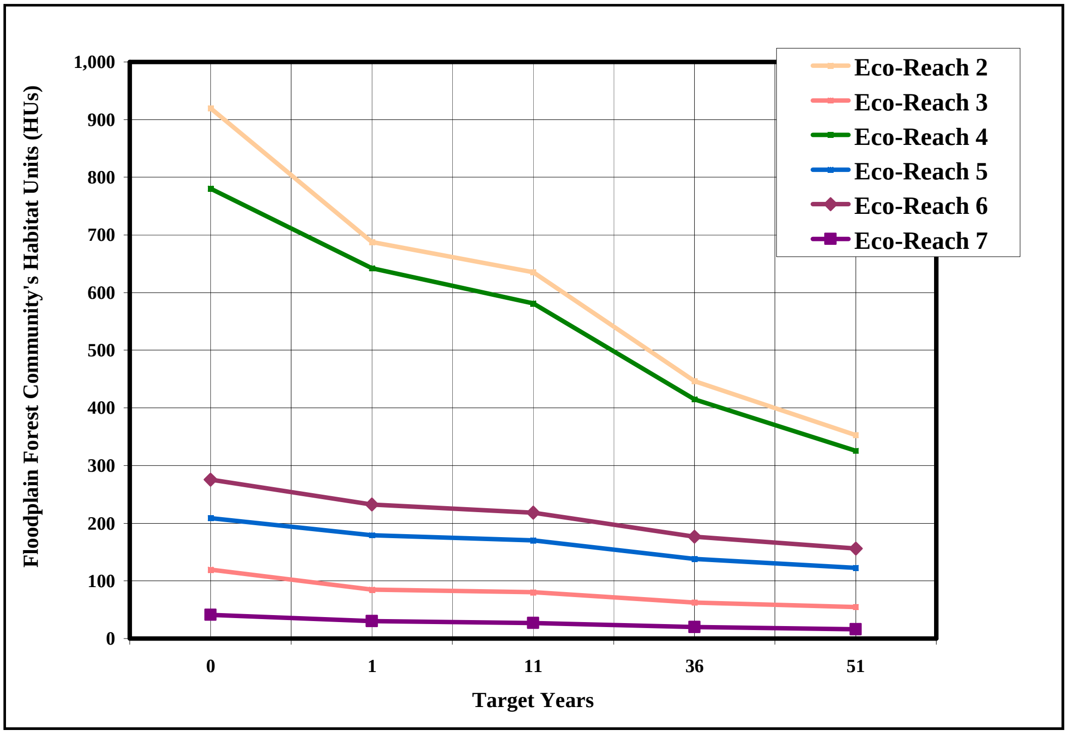

Figure 33. Cumulative changes in HUs under the WOP scenario.

Table 19. Predicted losses for the Clear Creek study under the WOP scenario.

Reach	Baseline Hus	TY 51 WOP HUs	Net Change in HUs (TY51-TY0)	Percent Loss of HUs	WOP AAHUs
Eco-Reach 1	328	130	-198	60	193
Eco-Reach 2	920	353	-567	62	527
Eco-Reach 3	119	55	-65	54	70
Eco-Reach 4	780	325	-455	58	486
Eco-Reach 5	209	122	-86	41	152
Eco-Reach 6	275	156	-119	43	195
Eco-Reach 7	41	16	-25	61	23
TOTALS	2,673	1,158	-1,515	57	1,646

5 With-Project (WP) Analysis and Results

For reasons detailed in the District's planning documentation (USACE 2010), the District's Project Delivery Team (PDT) implemented a proactive strategy to formulate flood risk management features, measures, and alternatives – an approach specifically tailored to focus on flood-prone areas (identified by stakeholders and the public).[1] A series of 72 structural and non-structural features were combined to generate 24 measures that addressed the four planning criteria (i.e., completeness, efficiency, effectiveness, and acceptability). Three sizes of each of these measures were then carried forward into detailed hydraulic, economic, and environmental analyses. Each measure was evaluated on a stand-alone basis for its potential impact on the entire watershed and its capability for reduction of flood damages (Figure 34).

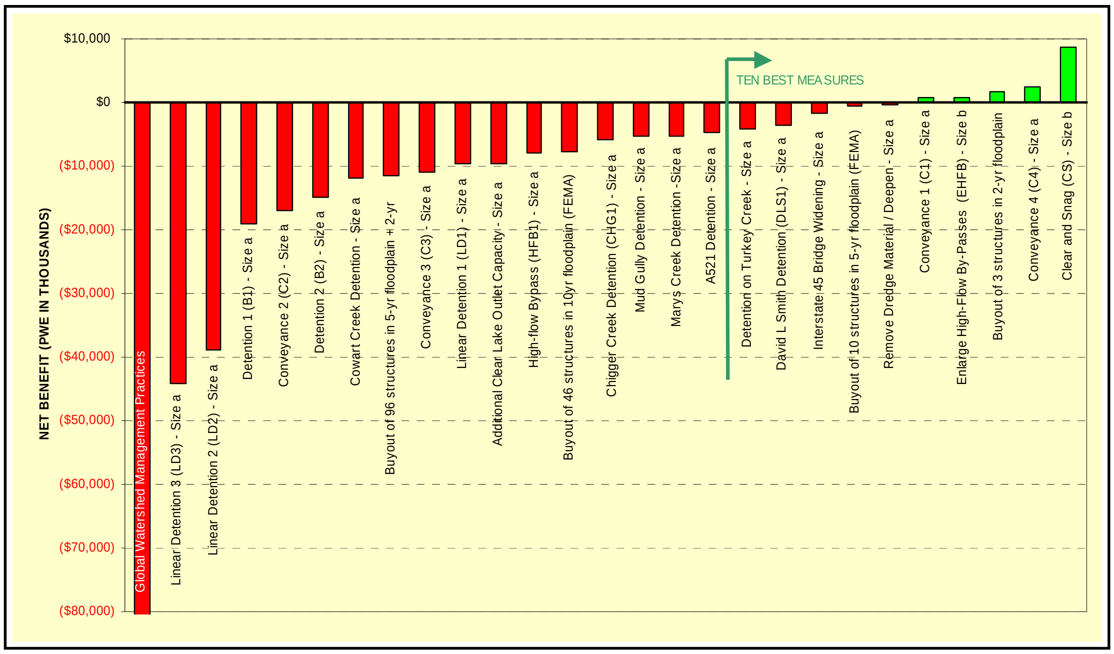

Figure 34. "First-added" results of the WP planning process on the Clear Creek study – the top 10 measures were carried forward into the "second-added" analysis.[2]

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[1] The WP analyses generated the NED plan (aka the General Reevaluation Plan, or GRP Alternative). All other plans (Sponsor's Alternative, the Authorized Plan, Non-Structural Plan) have not been analyzed with the HSI models to date.

[2] Graphic from USACE 2010.

Detailed descriptions of each measure as well as determinations of costs, net excess benefits, and Benefit-Cost Ratios (BCRs) for each of these measures can be found in the *First Added Notebook* (USACE 2010). The team then concentrated on the more successful measures from the first-added analysis - refining them, modifying their designs where appropriate, and testing combinations of these measures to produce the most effective NED Plan. To form these combinations, the decision was made to begin with upstream measures that would reduce damages in the "hardest hit" reaches, then incrementally add productive downstream measures in a "systems" approach to produce the final plan accepted NED plan. Although preliminary (iterative) HEP analyses were performed throughout the process, the authors present only the HEP assessment of the final NED plan here.[1]

NED Plan Components - Conveyance

It is important to grasp the iterative process that eventually led to the NED plan presented herein. The "second added" analysis focused predominantly on conveyance measures - detention was not considered initially due to its poor performance in the first added analysis. Thus, five "conveyance" type measures were drafted as a preliminary NED plan and presented to sponsors for consideration (Figure 35):

1. Clear Creek Mainstem-Upstream Conveyance (*Super C*);
2. Clear Creek Mainstem-Downstream Conveyance [*C5(d)*];
3. Turkey Creek Conveyance (*TKC1d*);
4. Mary's Creek Conveyance (*MaC2a*); and
5. Mud Gulley Conveyance (*MudG1b*).

A synopsis of these measures is provided in the sections below. Refer to the *Predicted WP Acreage Trends (Quantity)* and the *Predicted WP Variable Trends (Quality)* sections below that to review the analysis assumptions that went into the HEP assessment of impacts for these measures.[2]

1 - Clear Creek Mainstem-Upstream Conveyance (*Super C*)

The *Super C* measure was designed to provide conveyance improvement on Clear Creek's mainstem (upstream) running from State Highway (SH) 288 to 4,000 feet downstream of Bennie Kate Road, in Harris and Brazoria

[1] Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

[2] For further details regarding these designs, refer to USACE 2010 (Section 4.9.3).

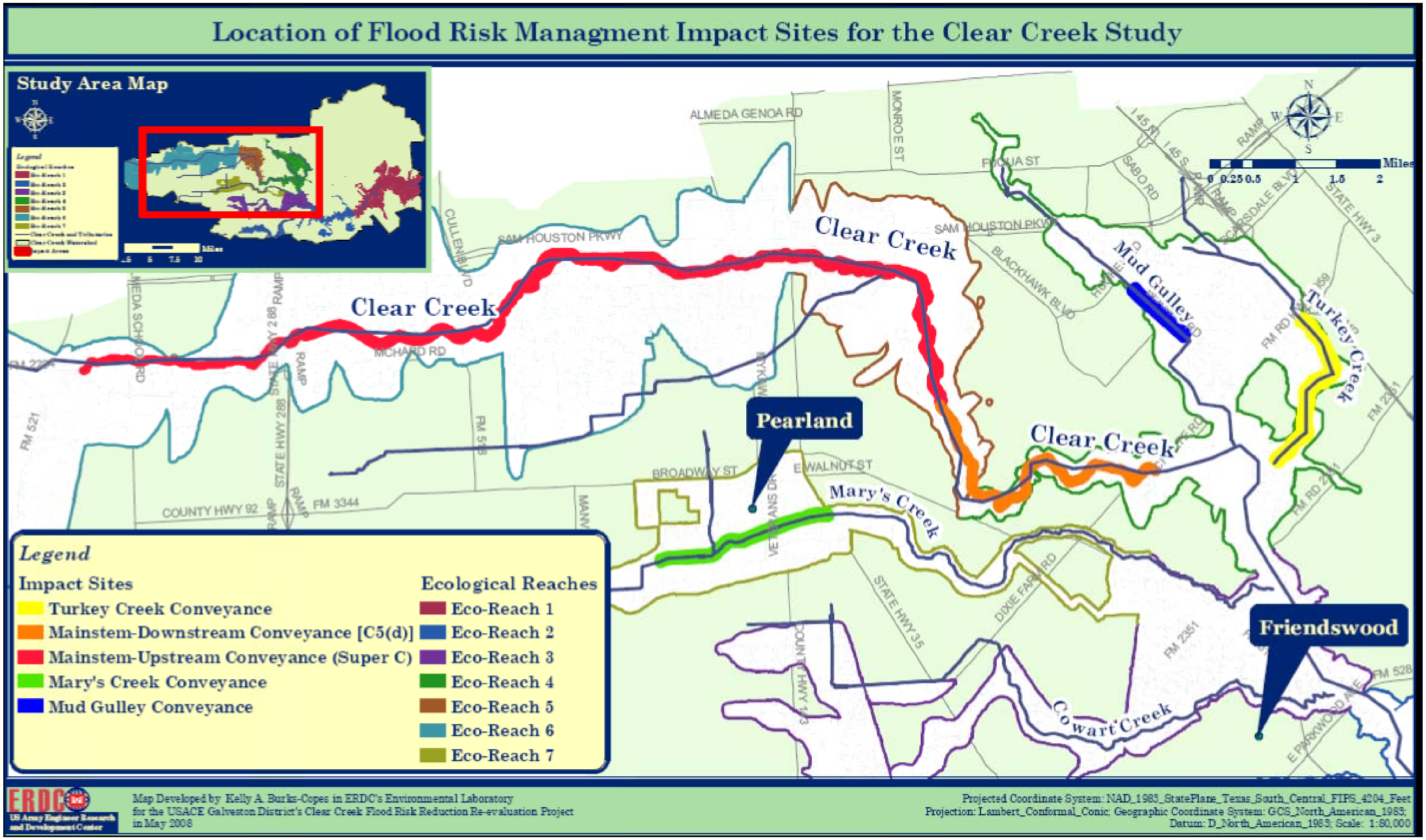

Figure 35. Final proposed NED plan for the Clear Creek study .

Counties, Texas (Eco-Reaches 5 and 6) (refer to Figure 38 on the next page). The measure involved the construction of 10.8 miles of 240-foot-wide high flow channel. The high flow channel would be reestablished by constructing a shallow, wide flood bench that, generally, straddled the existing channel. The existing channel would be preserved to convey low flows. The 240-foot-wide flood bench would have a total bottom width of 200 feet with 20-foot-wide side slopes on either side (Figure 36).

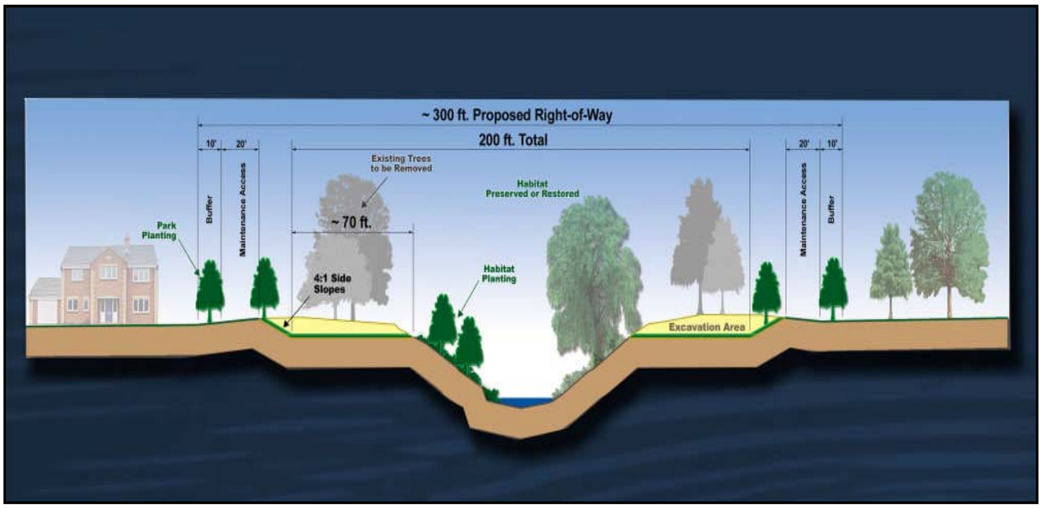

Figure 36. Illustration depicting on-the-ground designs for the Clear Creek *Mainstem-Upstream Conveyance* measure (*Super C*).

The bench would be designed with 1:4 (V:H) side slopes. The bench areas would be grassy, park-like areas that would be routinely mowed. Trees would be planted on the side slopes at a density of 14 trees per acre. An additional 25 feet of right-of-way (ROW) would be required outside of and on both sides of the high flow bench. This ROW would be used to construct several 15-foot-wide backslope drains to prevent erosion caused from sheet flows into the high flow channel. The remaining 10 feet of the ROW on each side would become a buffer that preserved, restored and rehabilitated existing floodplain forest or reestablished/restored existing floodplain forest where the land was undeveloped pasture or cropland. One hundred and eighty-six acres of floodplain forest would be lost with the implementation of this design.

In-line Detention – One Final Modification to the Clear Creek Mainstem-Upstream Conveyance (*Super C*)

As a final adjustment to the suit of measures that when combined formed the NED plan, "in-line" detention was added to the *Super C* measure

(Figure 37). In essence, this additional feature was designed to provide detention for approximately 485 acre feet of water within limited segments of the currently proposed footprint of the Clear Creek Conveyance measure (detailed above). This measure would consist of deepening the high flow channel in areas where the high flow channel diverges from the low flow channel.

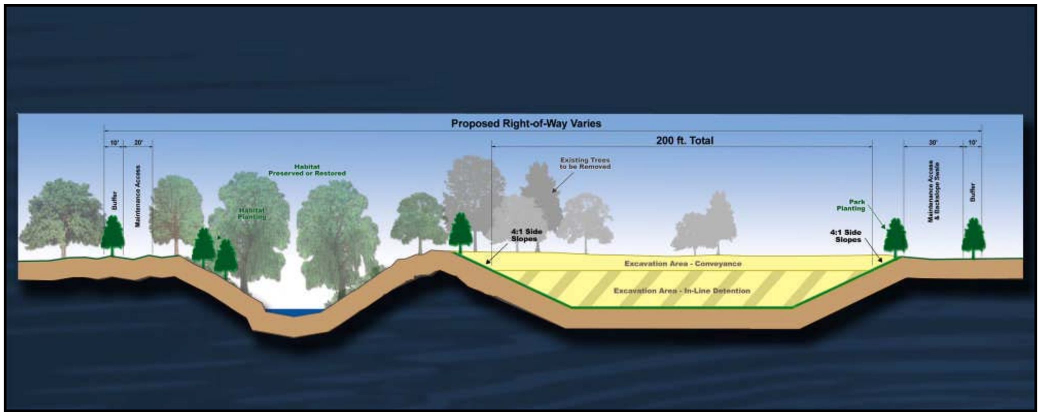

Figure 37. Illustration depicting “in-line” detention utilized in the *Clear Creek Mainstem-Upstream Conveyance* measure (*Super C*).

This would allow for additional storage with no impact to the low flow channel itself. The width of the high flow channel would remain the same as described above. The only change would be depth of excavation. Approximately 8 additional feet of excavation would be performed in the divergent high flow to reestablish storage. Gravity flow would be utilized to return temporarily stored waters to the low flow channel.

2 - Clear Creek Mainstem-Downstream Conveyance (*C5(d)*)

The *C5(d)* measure was designed to provide conveyance improvement on the Clear Creek mainstem from a point approximately 4,000 feet downstream of Bennie Kate Road downstream to Dixie Farm Road, in Harris and Brazoria Counties, Texas (Eco-Reaches 4 and 5) (refer to Figure 40 on the next page). The conveyance feature involved the construction of 4.4 miles of 130-foot-wide high flow channel. The high flow channel would be reestablished by constructing a shallow, wide flood bench that straddles the existing channel. The existing channel would be preserved to convey low flows. The 130-foot-wide flood bench would have a total bottom width of 90 feet with approximately 20-foot-wide side slopes on either side (Figure 39).

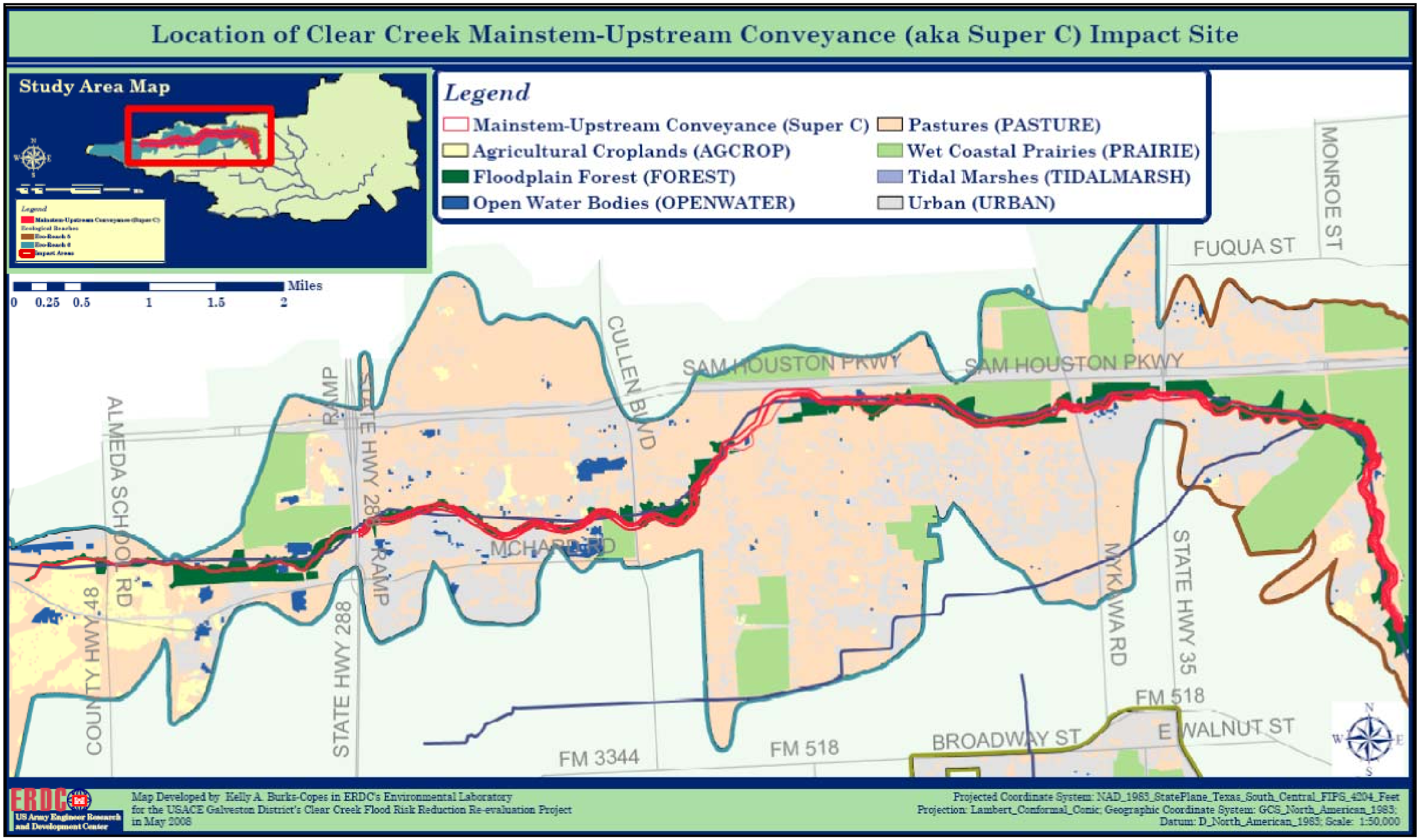

Figure 38. Cover type map of the Clear Creek Mainstem-Upstream Conveyance (*Super C*) measure.

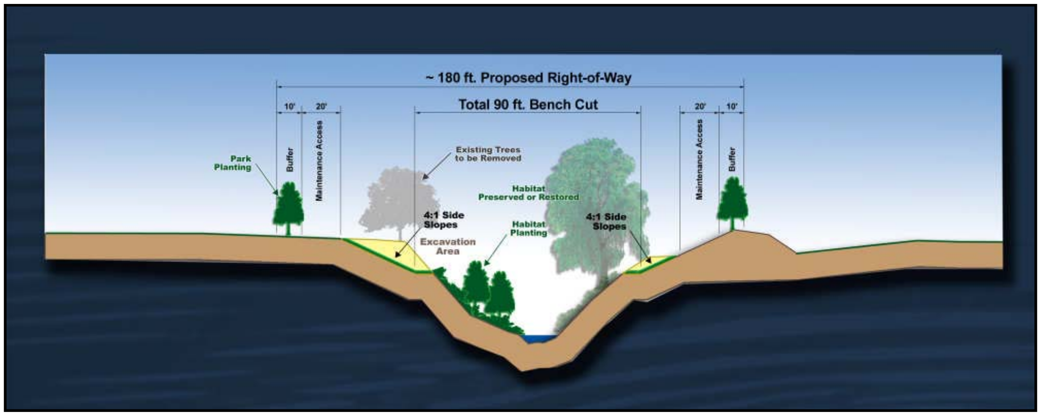

Figure 39. Illustration depicting on-the-ground designs for the Clear Creek *Mainstem-Downstream Conveyance* measure [*C5(d)*].

The channel would be designed with 1:4 (V:H) side slopes. The bench areas would be grassy, park-like areas that are routinely mowed. Trees would be planted on the side slopes at a density of 14 trees per acre. An additional 25 feet of ROW would be required outside of and on both sides of the high flow bench. This ROW would be used to construct several 15-foot-wide backslope drains to prevent erosion caused from sheet flows into the high flow channel. The remaining 10 feet of the ROW on each side would become a buffer that preserved existing floodplain forest or reestablished/restored existing floodplain forest where the land was undeveloped pasture or cropland. Seventy-two acres of floodplain forest would be lost with the implementation of this design.

3 - Turkey Creek Conveyance (*TKC1d*)

The *TKC1d* measure was designed to provide conveyance improvement through the construction of a 2.4-mile earthen, grass-lined channel on Turkey Creek from Dixie Farm Road to its confluence with Clear Creek, in Harris County, Texas (Eco-Reach 4) (refer to Figure 42 on the next page). The channel bottom width from Dixie Farm Road to 2,000 feet downstream of Well School would be 20 feet wide. The remaining length of the proposed channel would have a bottom width of 25 feet to its confluence with Clear Creek (Figure 41).

The channel be designed with 1:4 (V:H) side slopes. An additional 60 feet of ROW would be required outside of the high flow bench (30-foot ROW on each side). This ROW would be used to construct several 15-foot-wide maintenance ROWs and 15-foot-wide backslope drains on each side of the channel to prevent erosion caused from sheet flows into the high flow channel. Twenty acres of floodplain forest would be lost with the implementation of this design.

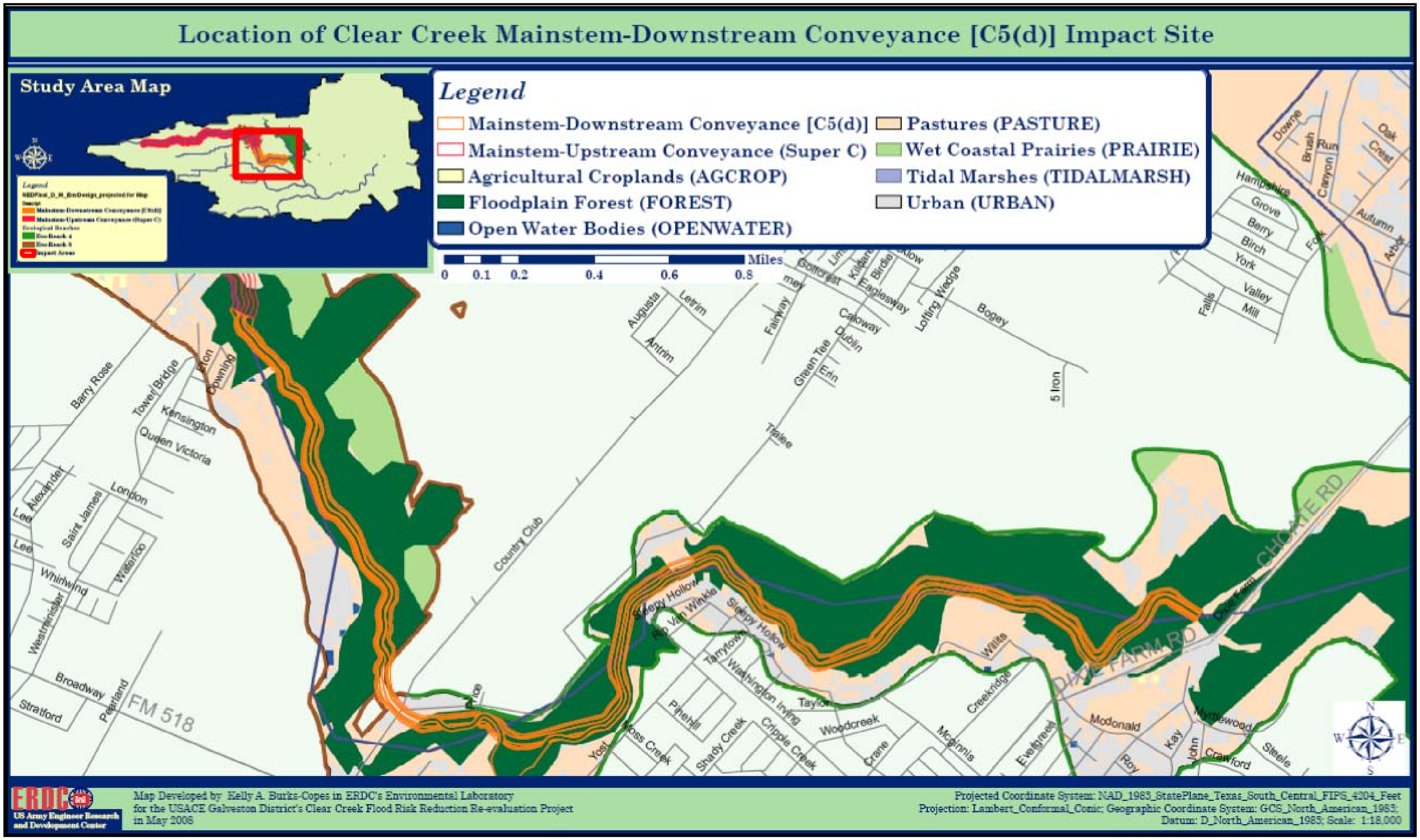

Figure 40. Cover type map of the Clear Creek Mainstem-Downstream Conveyance [*C5(d)*] measure.

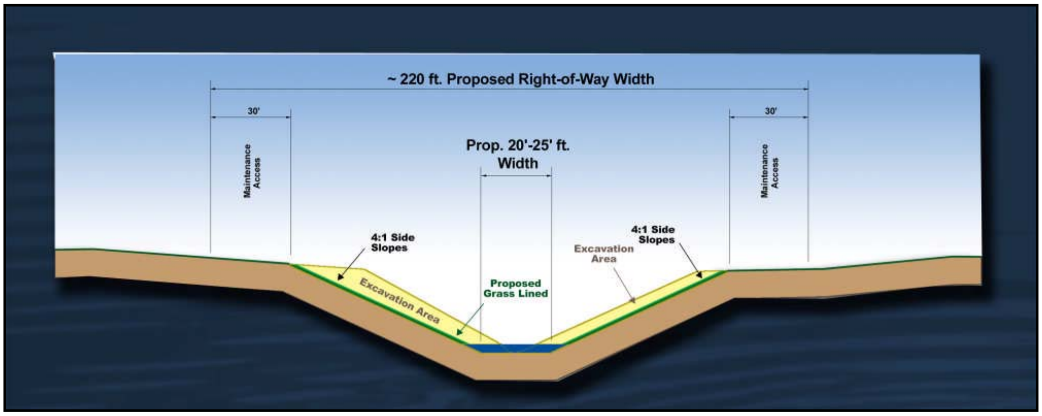

Figure 41. Illustration depicting on-the-ground designs for the Turkey Creek Conveyance measure (*TKC1d*).

4 - Mary's Creek Conveyance (*MaC2a*)

The *Mac2a* measure was designed to provide conveyance improvement through the construction of a 2.1-mile earthen, grass-lined channel on Mary's Creek from Harkey Road to State Highway 35, in Brazoria County, Texas (Eco-Reach 4) (refer to Figure 44 on the next page). The channel bottom cut will be 15 feet wide from Harkey Road to 3,940 feet upstream of McClean Road, 27.5 feet wide from 3,940 feet upstream of McClean Road to 100 feet downstream of McClean Road, and 35 feet wide from 100 feet downstream of McClean Road to State Highway 35 (Figure 43).

The channel be designed with 1:4 (V:H) side slopes. A 30-foot ROW will be required outside and on both sides of the channel. This ROW will be used to construct several 15-foot-wide maintenance ROWs and 15-foot-wide backslope drains on each side of the channel to prevent erosion caused from sheet flows into the high flow channel.

5 - Mud Gulley Conveyance (*MudG1b*)

The *MudG1b* measure was designed to provide conveyance improvement through the construction of a 0.8-mile concrete-lined channel on Mary's Creek from Sagedown to Astoria (southwest of the intersection of Beltway * and I-45) in Houston, Harris county, Texas (Eco-Reach 7) (refer to Figure 46 on the next page). The channel bottom cut will be 15 feet wide from Harkey Road to 3,940 feet upstream of McClean Road, 27.5 feet wide from 3,940 feet upstream of McClean Road to 100 feet downstream of McClean Road, and 35 feet wide from 100 feet downstream of McClean Road to State Highway 35 (Figure 45).

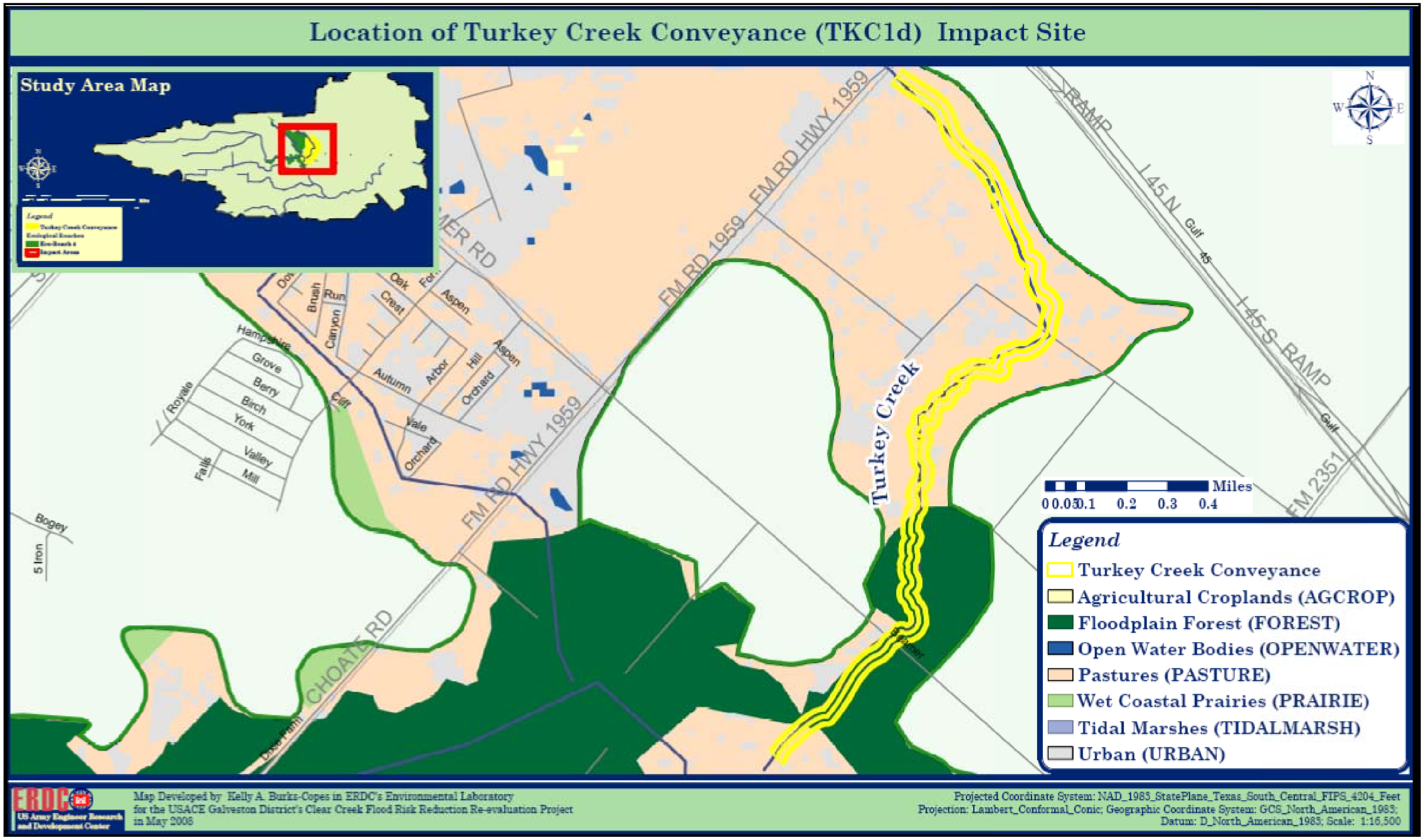

Figure 42. Cover type map of the Turkey Creek Conveyance (*TKC1d*) measure.

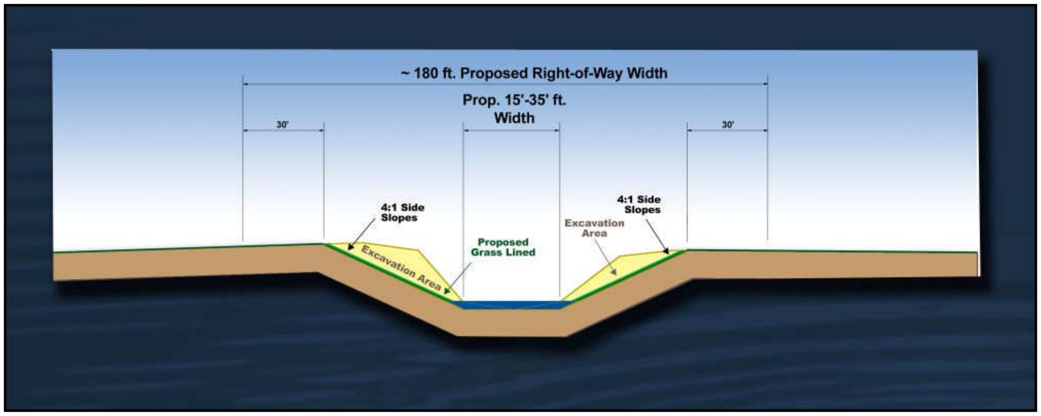

Figure 43. Illustration depicting on-the-ground designs for the Mary's Creek Conveyance measure (*MaC2a*).

The channel be designed with 1:4 (V:H) side slopes. A 30-foot ROW will be required outside and on both sides of the channel. This ROW will be used to construct several 15-foot-wide maintenance ROWs and 15-foot-wide backslope drains on each side of the channel to prevent erosion caused from sheet flows into the high flow channel. No impacts were anticipated with the implementation of this design.

To summarize, the proposed 698-acre NED footprint would include 542 acres of direct impacts (lands converted to flood risk management features) and an additional 156 acres of on-site mitigation via avoidance, minimization and restoration/rehabilitation features (Table 20).

Predicted WP Acreage Trends (Quantity)

In order to complete the HEP assessment of the NED plan, individual measures were assessed independently (per Eco-Reach), and their cumulative effects were combined to generate an estimate of total impacts and the subsequent requirements for mitigation in terms of AAHUs. The first step was to develop acreage projections over the life of the project for each plan. It should be noted that two measures (i.e., Mud Gulley Conveyance (*MudG1b*) and Mary's Creek Conveyance (*MaC2a*)) avoided impacts to the existing floodplain forest community, and as such have been omitted from the following sections. The remainder of the plans and their expected landuse trends are detailed below (Tables 21 - 25). In this manner, the E-Team was able to capture the localized affects of the various measures, yet maintain the landscape-level trends experienced across the affected eco-reaches (including the omnipresent urban encroachment).[1]

[1] Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

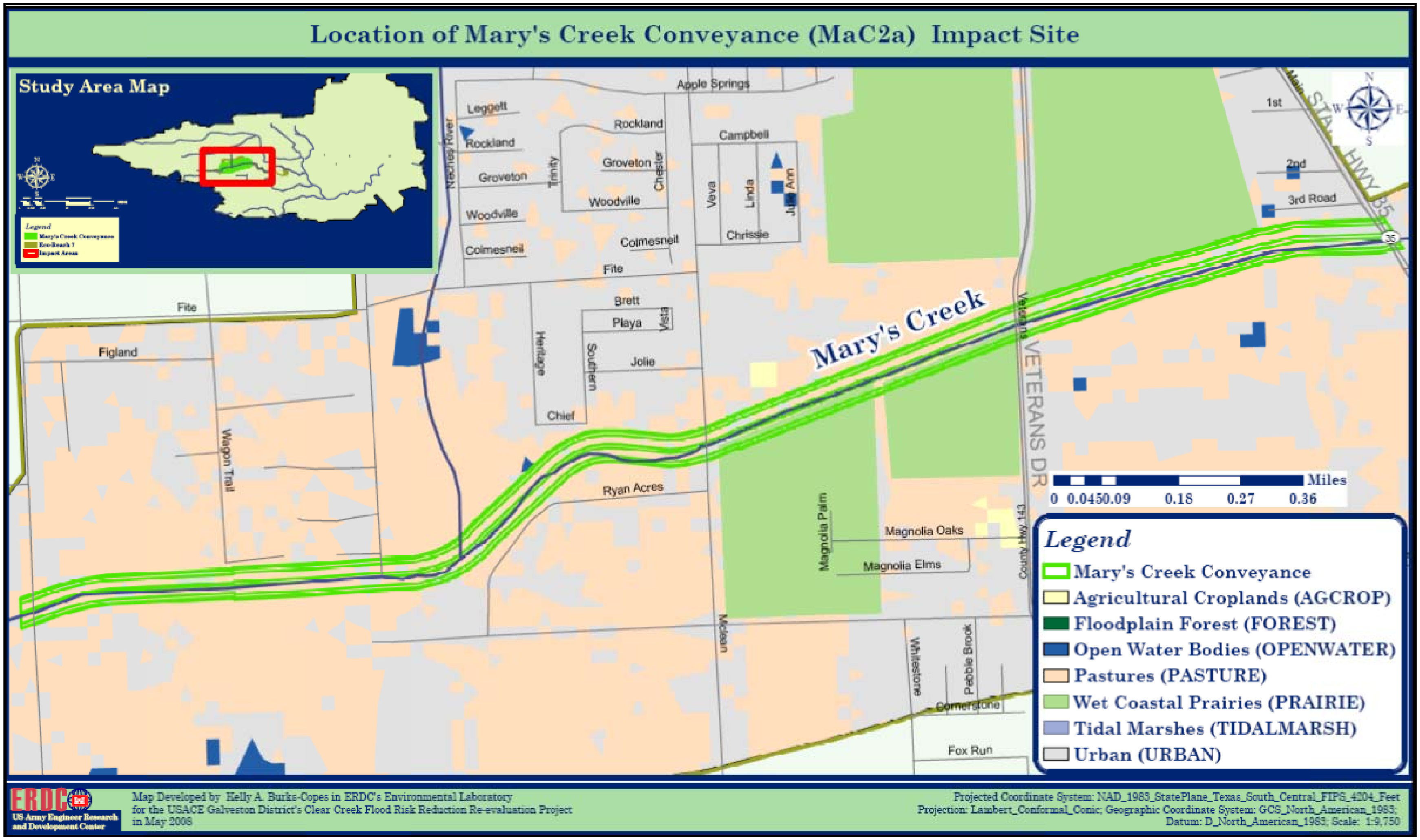

Figure 44. Cover type map of the Mary's Creek Conveyance (*MaC2a*) measure.

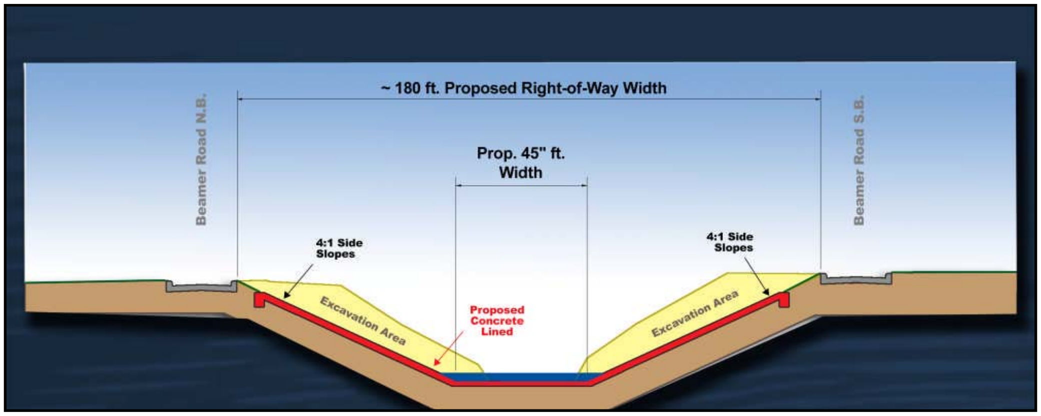

Figure 45. Illustration depicting on-the-ground designs for the Mud Gulley Conveyance measure (*MudG1b*).

> *One note here – the creation of new forest community on agricultural croplands (or any other cover type in the list) warranted the addition to the cover type classification scheme. In those instances where active restoration or creation was undertaken to address on-site mitigation activities, the acreages were tracked in categories using the "NEW" naming convention (see below – Super C in Eco-Reach 5 for example tracks the development of new floodplain forest).*

Just as they did for the WOP conditions, these tables indicating urban encroachment will continue to change the face of the Clear Creek watershed over the next 50 years regardless of the implementation of the NED plan. This time, however, the NED plan's individual measures will play a role in shaping the landscape.

Predicted WP Variable Trends (Quality)

Rather than presenting copious amounts of tables documenting variable projections here, the authors chose to provide a brief synopsis of general WP trends (and the E-Team assumptions supporting these trends).[1] Generally speaking, the E-Team surmised that the hydrologic parameters (hydroregime, sinuosity, substrates, roughness, etc.) would not be greatly affected by the proposed WP scenario – the system was already stressed and would continue as such. However, water depth would increase as a matter of design. The impacts were more acutely experienced in the vegetative and spatial arenas. The E-team assumed that fragmentation of the habitat incurred by the NED plan, when it converted forest into channelized

1 Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

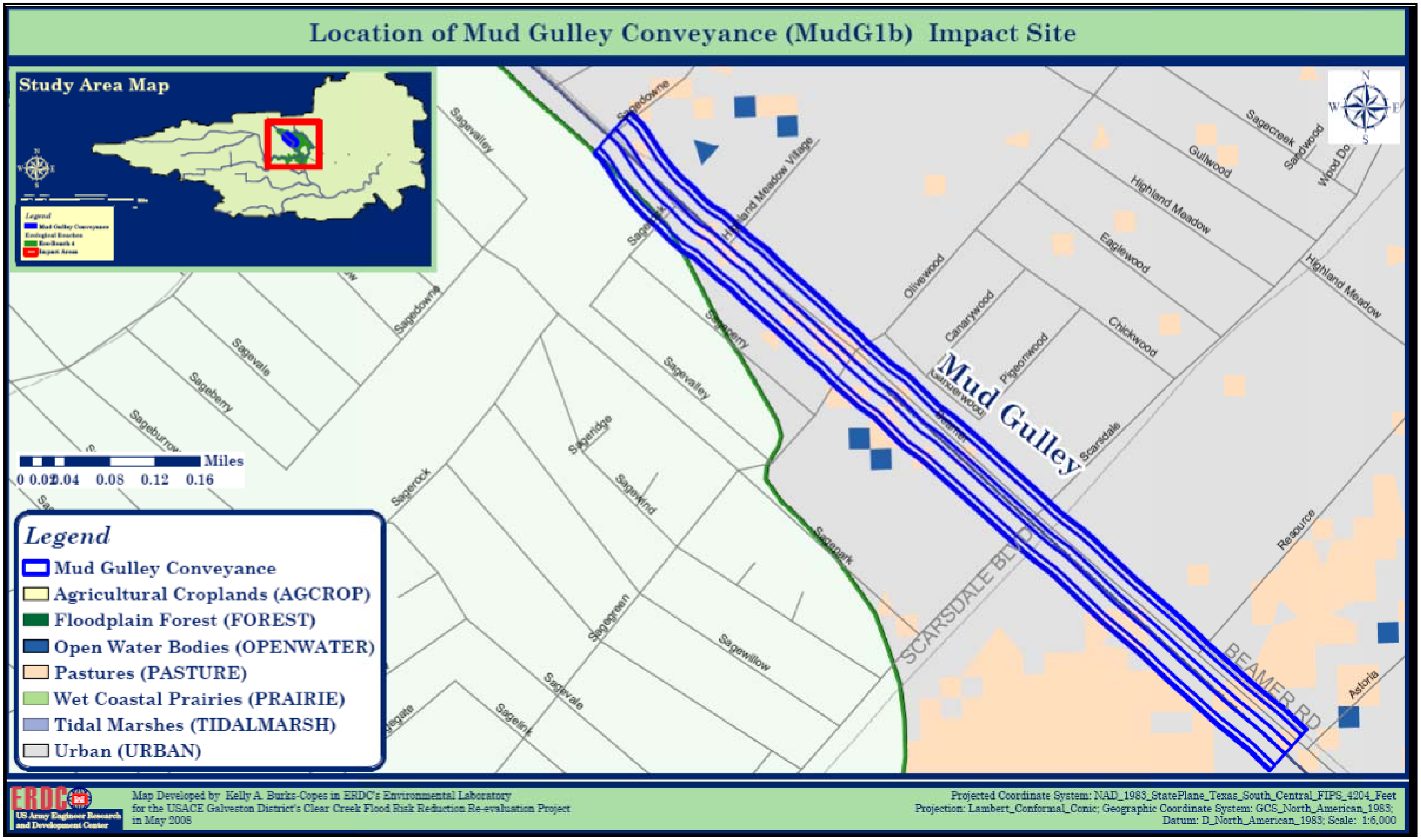

Figure 46. Cover type map of the Mud Gulley Conveyance (*MudG1b*) measure.

Table 20. Summary of the measures incorporated into the final NED plan and the conversion of habitats (floodplain forest/wet coastal prairies) and other landscape features to construct the plan.

	Footprints (Acres)	FOREST (Floodplain Forest)			PRAIRIE2	AGCROP	OPENWATER	PASTURES	URBAN
Total NED Footprint	6981	Impacted	Preserved, Restored, and Rehabilitated	Reestablished Floodplain Forest (NEWFOREST)	Coastal Prairies	Farms and Croplands	Open Bodies of Water Deeper than 1-3m	Old Fields, Haylands and Pastures	Existing Residential, Industrial and Transportation
1 Mainstem-Upstream Conveyance (Super C)	432	-186	88	33	-3	0	-1	-71	-15
Corridor	122	0	88	33	0	0	1	25	8
Bench/right-of-ways	310	-186	0	0	-3	0	-2	-96	-23
2 Mainstem-Downstream Conveyance [C5(d)]	109	-72	34	0	0	0	0	-2	-1
Corridor	34	0	34	0	0	0	0	0	0
Bench/ right-of-ways	75	-72	0	0	0	0	0	-2	-1
3 Turkey Creek Conveyance (TKC1d)	68	-20	0	0	0	0	-1	-43	-4
4 Mary's Creek Conveyance (MaC2a)	63	0	0	0	-5	0	0	-45	-13
5 Mud Gully Conveyance (MudG1b)	26	0	0	0	0	0	0	-5	-21

1 Blue values indicate combinations of features to generate the final footprints (in acres) per management measure.

2 While these few acres were lost within the impact footprint, it was assumed that they were relatively non-functioning scrubby fringe prairie patches that have been severely modified by local drainage activities. As such, the E-Team made the assumption that these losses would be more than compensated for with the proposed forest community mitigation activities.

Table 21. WP acre projections for Mainstem-Upstream Conveyance (*Super C*) – Eco-Reach 5.

Code	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2010	2030	2055	2070	2000	2020	2030	2055	2070
	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	28	25	24	21	20	28	25	24	21	20
FOREST	337	309	295	258	236	337	256	245	217	200
NEWFOREST	0	0	0	0	0	0	11	11	11	11
OPENWATER	11	10	10	8	7	11	10	10	8	7
PASTURES	692	625	592	511	463	692	585	552	471	423
PRAIRIE	1,094	988	941	826	755	1,094	985	938	823	752
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	601	806	901	1,139	1,282	601	780	872	1,101	1,239
FCPROJECT	0	0	0	0	0	0	111	111	111	111
TOTALS:	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763

Table 22. WP acre projections for Mainstem-Upstream Conveyance (*Super C*) – Eco-Reach 6.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2010	2030	2055	2070	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	1,305	1,219	1,166	1,032	951	1,305	1,219	1,166	1,032	951
FOREST	489	448	426	368	334	489	330	317	283	263
NEWFOREST	0	0	0	0	0	0	22	22	22	22
OPENWATER	180	163	154	132	119	180	161	152	130	117
PASTURES	8,378	7,814	7,527	6,811	6,381	8,378	7,740	7,453	6,737	6,307
PRAIRIE	1,077	982	928	792	711	1,077	982	928	792	711
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	2,871	3,674	4,099	5,165	5,804	2,871	3,647	4,063	5,105	5,730
FCPROJECT	0	0	0	0	0	0	199	199	199	199
TOTALS:	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300

Table 23. WP acre projections for Mainstem-Downstream Conveyance [*C5(d)*] – Eco-Reach 4.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2020	2030	2055	2070	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	2	2	2	2	2	2	2	2	2	2
FOREST	1,053	931	852	655	536	1,053	885	812	630	520
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	17	15	14	12	10	17	15	14	12	10
PASTURES	1,521	1,370	1,271	1,019	871	1,521	1,368	1,269	1,017	869
PRAIRIE	26	24	23	20	18	26	24	23	20	18
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	1,753	2,030	2,210	2,664	2,935	1,753	2,023	2,197	2,636	2,898
FCPROJECT	0	0	0	0	0	0	55	55	55	55
TOTALS:	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372

Table 24. WP acre projections for Mainstem-Downstream Conveyance [*C5(d)*] – Eco-Reach 5.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2020	2030	2055	2070	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	28	25	24	21	20	28	25	24	21	20
FOREST	337	309	295	258	236	337	291	278	244	224
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	11	10	10	8	7	11	10	10	8	7
PASTURES	692	625	592	511	463	692	625	592	511	463
PRAIRIE	1,094	988	941	826	755	1,094	988	941	826	755
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	601	806	901	1,139	1,282	601	804	898	1,133	1,274
FCPROJECT	0	0	0	0	0	0	20	20	20	20
TOTALS:	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763

Table 25. WP acre projections for Turkey Creek Conveyance (*TKC1d*) – Eco-Reach 4.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2020	2030	2055	2070	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	2	2	2	2	2	2	2	2	2	2
FOREST	1,053	931	852	655	536	1,053	913	836	643	526
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	17	15	14	12	10	17	14	13	11	9
PASTURES	1,521	1,370	1,271	1,019	871	1,521	1,331	1,232	980	832
PRAIRIE	26	24	23	20	18	26	24	23	20	18
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	1,753	2,030	2,210	2,664	2,935	1,753	2,020	2,198	2,648	2,917
FCPROJECT	0	0	0	0	0	0	68	68	68	68
TOTALS:	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372

features in conjunction with the ongoing urban growth scenario, would lead to constrictions in core areas and increases in overall edges. Urban encroachment would continue to affect patch sizes, distances between patches, and impervious surfaces – the WP scenario would simply exacerbate the problems to some extent. Increased edge would make the communities more susceptible to disease and incursions of non-native species and exotics and would lead to increased competition and a general loss of the native-based, functioning communities. The incidental loss of overhanging vegetation as the channels were constructed, and the general loss of species diversity as critical core areas disappeared would lead to the loss of vegetative structure and spatial complexity critical to ecosystem support and function.

On-site restoration activities, on the other hand, were expected to counteract these trends to some degree. Detailed (native) planting schemes and intensive 30+ year maintenance plans were predicted to generate highly functioning systems in 40 years or less. These areas contributed to the overall spatial complexity of the systems adding patches, expanding core areas, and increasing the overall connectivity of the landscape mosaic (Tables 26 - 32).

Table 26. FOREST cover type WP variable projections for Mainstem-Upstream Conveyance (Super C) – Eco-Reach 6.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	3	3	5	6
	IMPERVIOUS	30	40	40	45	45
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.16	1.16	1.16	1.16	1.16
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	40	70	75	85	90
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	75	75
	INSTRMCOV	5	5	5	5	5
	NATIVE	70	60	60	50	45
	OVRHDCOV	30	30	30	40	45
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	5	8	8	9	11
	CORE	0	1	0	0	0
	EDGE	70	5	5	5	5
	NEIGHBOR	55	25	25	30	30
	PATCHSIZE	70	5	5	5	5

Table 27. NEWFOREST cover type WP variable projections for Mainstem-Upstream Conveyance (Super C) – Eco-Reach 6.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	0	1	1	1	1
	EROSION	0	3	3	5	6
	IMPERVIOUS	0	40	40	45	45
	ROUGHNESS	0	0.11	0.11	0.11	0.11
	SINUOSITY	0	1.16	1.16	1.16	1.16
	SUBSTRATE	0	1	1	1	1
	WATERDEPTH	0	70	75	85	90
Structure and Biotic Integrity (BIOINTEG)	CANTREE	0	5	30	70	75
	INSTRMCOV	0	5	10	25	35
	NATIVE	0	100	100	100	100
	OVRHDCOV	0	60	60	65	70
	VEGSTRATA	0	2	3	5	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	0	7	7	8	8
	AREAWETDRY	0	8	8	9	11
	CORE	0	1	0	0	0
	EDGE	0	5	5	5	5
	NEIGHBOR	0	25	25	30	30
	PATCHSIZE	0	5	5	5	5

Table 28. FOREST cover type WP variable projections for Mainstem-Upstream Conveyance (Super C) – Eco-Reach 5.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	3	3	5	6
	IMPERVIOUS	40	45	45	55	60
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.23	1.23	1.23	1.23	1.23
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	75	80	90	95

Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	75	75
	INSTRMCOV	5	5	5	5	5
	NATIVE	60	60	60	50	45
	OVRHDCOV	20	20	20	30	35
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	20	18	18	16	14
	CORE	5	5	5	5	5
	EDGE	65	20	20	20	20
	NEIGHBOR	30	20	20	20	20
	PATCHSIZE	65	25	25	25	25

Table 29. NEWFOREST cover type WP variable projections for Mainstem-Upstream Conveyance (Super C) – Eco-Reach 5.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	0	1	1	1	1
	EROSION	0	3	3	5	6
	IMPERVIOUS	0	45	45	55	60
	ROUGHNESS	0	0.11	0.11	0.11	0.11
	SINUOSITY	0	1.23	1.23	1.23	1.23
	SUBSTRATE	0	1	1	1	1
	WATERDEPTH	0	75	80	90	95
Structure and Biotic Integrity (BIOINTEG)	CANTREE	0	5	30	70	75
	INSTRMCOV	0	5	10	25	35
	NATIVE	0	100	100	100	100
	OVRHDCOV	0	60	60	65	70
	VEGSTRATA	0	2	3	5	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	0	7	7	8	8
	AREAWETDRY	0	18	18	16	14
	CORE	0	5	5	5	5
	EDGE	0	20	20	20	20
	NEIGHBOR	0	20	20	20	20
	PATCHSIZE	0	25	25	25	25

Table 30. FOREST cover type WP variable projections for Mainstem-Downstream Conveyance [C5(d)] – Eco-Reach 4.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	3	3	3	3
	EROSION	2	1	1	1	1
	IMPERVIOUS	40	45	50	60	70
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.74	1.74	1.74	1.74	1.74
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	60	60	60	60
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	70	75
	INSTRMCOV	5	10	10	25	40
	NATIVE	60	55	50	40	35
	OVRHDCOV	60	60	60	60	60
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	5	3	3	3	3
	CORE	40	30	30	20	15
	EDGE	310	65	60	45	40
	NEIGHBOR	0	5	5	5	5
	PATCHSIZE	525	95	85	70	60

Table 31. FOREST cover type WP variable projections for Mainstem-Downstream Conveyance [C5(d)] – Eco-Reach 5.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	2	2	2	2
	EROSION	3	2	2	2	2
	IMPERVIOUS	40	45	45	55	60
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.23	1.23	1.23	1.23	1.23
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	50	50	50	50

Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	75	75
	INSTRMCOV	5	10	10	15	20
	NATIVE	60	55	55	45	40
	OVRHDCOV	20	20	20	25	25
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	20	18	17	15	13
	CORE	5	0	0	0	0
	EDGE	65	45	45	35	30
	NEIGHBOR	30	30	30	40	45
	PATCHSIZE	65	50	50	40	35

Table 32. FOREST cover type WP variable projections for Turkey Creek (TCK1d) – Eco-Reach 4.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	2	2	1	1
	EROSION	2	4	4	5	5
	IMPERVIOUS	40	35	35	25	20
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.74	1.74	1.74	1.74	1.74
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	70	75	85	90
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	65	65
	INSTRMCOV	5	5	5	5	5
	NATIVE	60	55	50	40	35
	OVRHDCOV	60	35	35	35	35
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	5	3	3	2	2
	CORE	40	30	30	20	15
	EDGE	310	110	100	80	65
	NEIGHBOR	0	50	55	65	75
	PATCHSIZE	525	175	160	125	105

WP Results for the Proposed NED Plan

The changes predicted above under the proposed NED plan resulted in quantifiable impacts to the floodplain forest community within the watershed (Table 33).

Table 33. Final results (Net AAHUs) of the proposed NED plan (impacts and mitigation).

		Eco-Reach 4	Eco-Reach 5	Eco-Reach 6	SUM of Net AAHUs Across Reaches
Measure Description	Code	Floodplain Forest	Floodplain Forest	Floodplain Forest	TOTALS
Mainstem-Upstream Conveyance	MS_US Conveyance		-22	-42	-64
Mainstem-Downstream Conveyance	MS_DS Conveyance	2	3		5
Turkey Creek Conveyance	TkC Conveyance	-47			-47
SUM of Net AAHUs Across Reaches		-45	-19	-42	-106

The proposed flood risk management and mitigation measures were analyzed as stand alone features to determine the ecological gains or losses attributed to each on an individual basis. This also allowed decision-makers to better determine which flood risk management measures were worth implementing or dropping from consideration due to disproportionate ecological losses requiring added mitigation. System-wide affects of flood risk management measures were determined from combining the gains and losses of stand alone measures to allow the team to make decisions regarding the best performing measure or combinations of measures with respect to ecological gains and losses. Mitigation measures were then assessed in a similar fashion. Where two or more flood risk management or mitigation measures were proposed for implementation within a particular ecological reach, the E-Team agreed to cumulatively reconcile the results of the measures to account for the system effects of the measure(s) on that reach using multiplicative factors.

A total of 106 AAHUs were lost in the floodplain forest community due to the combined proposed management measures. The greatest forest losses were experienced in Eco-Reaches 4 and 6 (i.e., 45 AAHUs and 42 AAHUs were lost respectively). The more significant impacts were felt under the Clear Creek Mainstem-Upstream Conveyance (*Super C*) management measure which generated a total loss of 64 AAHUs across Reaches 5 and 6 (Figure 47).

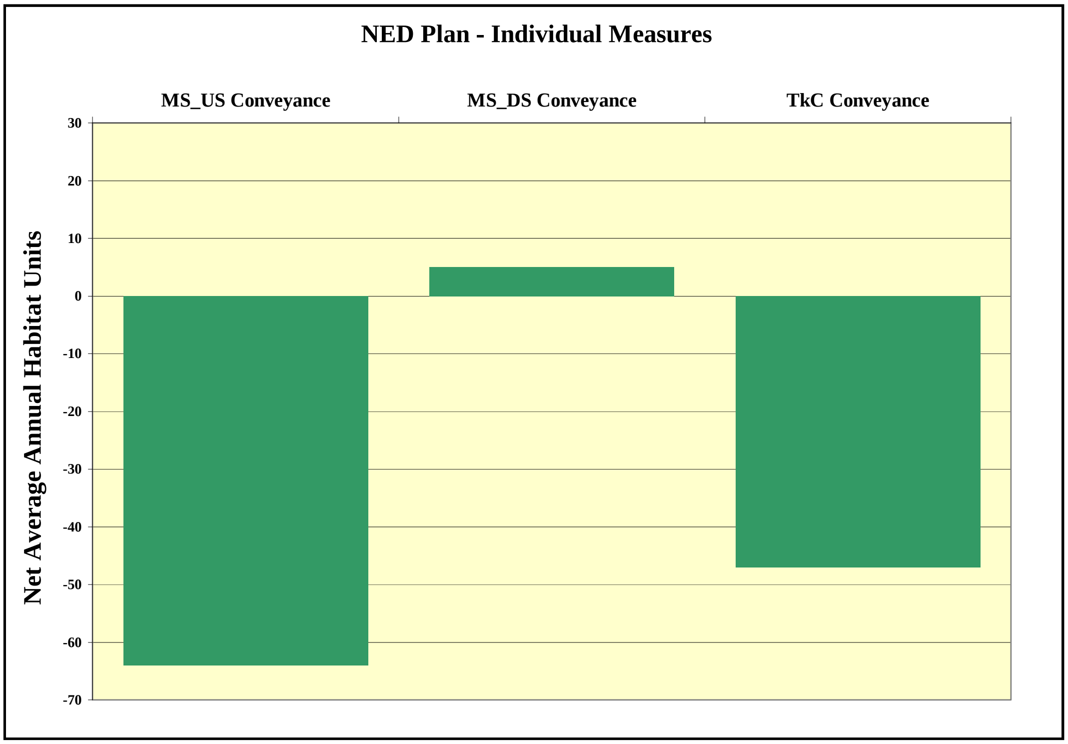

Figure 47. Results of the proposed NED plan arrayed across individual components (i.e., measures).

Based on these findings, additional mitigation of 106 AAHUs of floodplain forest must be acquired to fully compensate for the losses incurred under the proposed NED plan. Refer to *Chapter 6* for details regarding the mitigation options under consideration.

6 Mitigation Analysis and Results

In light of the potential impacts likely to be incurred as a direct result of implementing the proposed NED plan, the E-Team began an iterative plan formulation process to develop, evaluate and compare potential mitigation activities across the watershed. Below, the authors briefly describe the final set of mitigation alternatives that evolved out of this iterative formulation process. The benefits gained with the implementation of these plans are detailed here in terms of acres, quality, and ultimately AAHUs.[1]

Mitigation Measures Under Consideration

Twenty-seven mitigation measures were initially conceived and assessed with HEP at a screening-level.[2] Where possible, the E-Team devised strategies to preserve, restore, and reestablish both communities at the same locale, thereby addressing concerns of lost spatial heterogeneity and complexity while taking advantage of the cost savings of restoring both communities in the fewest possible locations. The E-Team culled measures that did not meet the in-kind mitigation requirements, did not address the spatial connectivity and complexity requirements, and/or refined plans to optimize outputs where possible. In some instances, proposed measures incorporated non-structural “buy-outs” of flood-prone structures, with the expectation of providing potential ancillary flood risk management benefits. However, these measures were dropped from consideration or were modified to remove the non-structural or “buy-out” component as they provided relatively minor economic benefits to flood risk management and would likely receive unfavorable public reception as stand-alone mitigation measures. Some measures offered less than full compensation to offset the community’s losses, but generated reasonable amounts of benefits to partially mitigate losses in the region. Since these options might serve as partial fulfillment of the mitigation requirements, and could be combined with additional measures to fully meet the demand for replacement of function, these measures were retained and included in the final comparative array. The final array included 10 management measures, spanned 4 reaches, and offered a range of AAHU outputs at varying degrees of costs sufficient to offset losses and move forward into cost effective and incremental cost caparisons (Figure 48).

[1] Details of the plan formulation process and the final selection of a recommended mitigation plan can be found the study’s planning documentation (USACE 2010).

[2] Contact the District to obtain the results of these initial screening-level analyses.

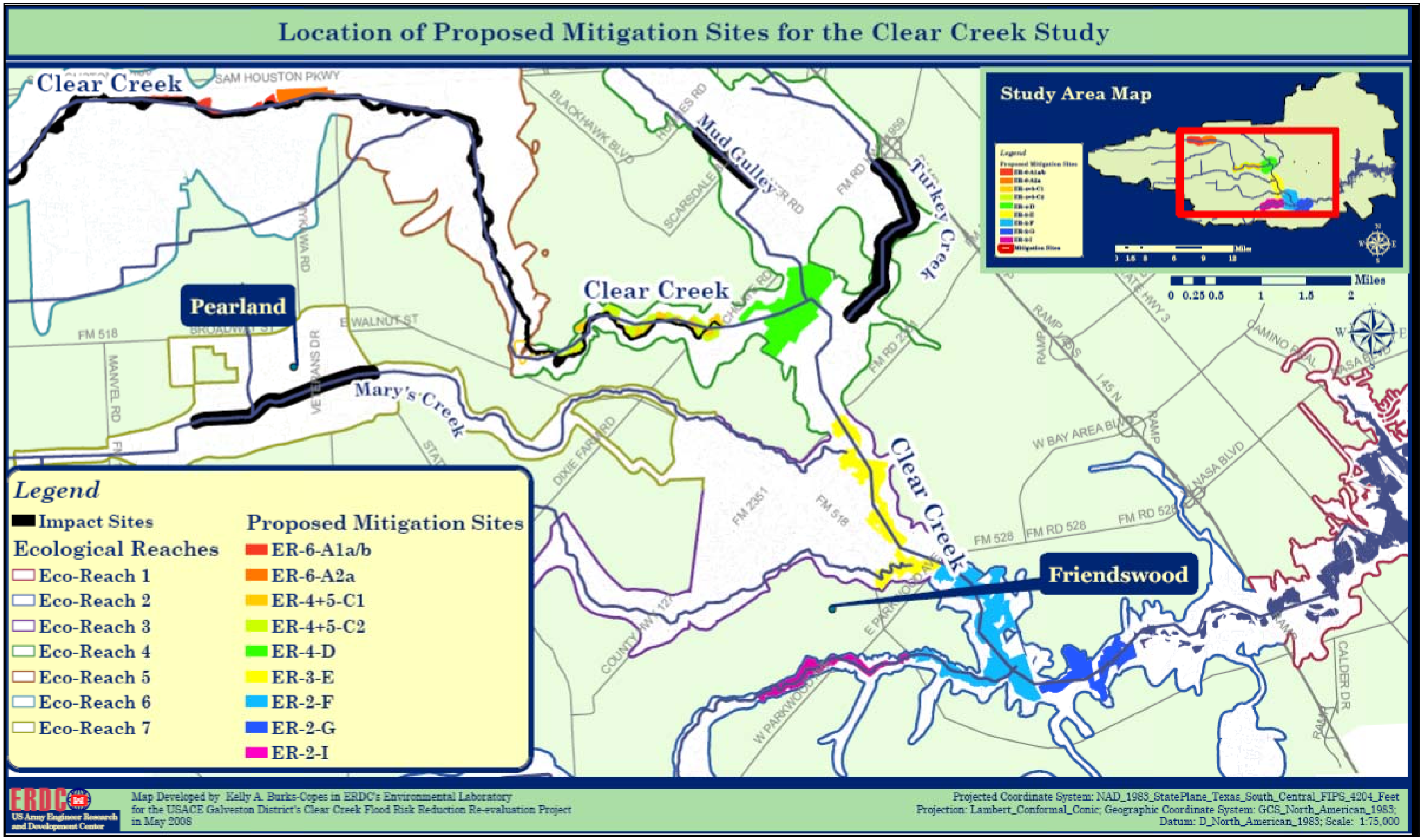

Figure 48. Proposed locations for the various mitigation measures proposed to offset losses incurred by the proffered NED plan for the Clear Creek study.

Eco-Reach (ER)-6-A1a and ER-6-A1b

The *A1* measure, located in Eco-Reach 6, proposed the preservation of 20 existing acres of floodplain forest (Figure 49). Intensive O&M (including reconnaissance, removal and foliar applications (e.g., cut-tumped method with application of herbicides) to control invasive, noxious, and exotic species) would be performed annually for 35 years. The *A1a* vs. *A1b* increments of this mitigation measure was formulated to quantify the two optional desired states: 1) and 20% wet core area (*A1a*) versus 2) a 30% wet core area (*A1b*). The measure would require the purchase of vacant land south of Beltway 8 west of Mykawa.

ER-6-A2a

The *A2a* measure (also in Eco-Reach 6) proposed the preservation of 29 existing acres of floodplain forest, and the conversion of 9 acres of urban areas and pasturelands to newly planted floodplain forest, with at least 20% of the area restored to a hydric or wetland interior (Wet:Dry Ratio of the floodplain forest would be 20%) (Figure 50). Intensive O&M (including reconnaissance, removal and foliar applications to control invasive, noxious, and exotic species) would be performed annually for 35 years. The measure would require the purchase of vacant land south of Beltway 8 east of Mykawa.

ER-4-C1 and ER-5-C1

The *C1* measure's footprint spanned two reaches (ER 4 and 5) and offered the restoration of the low flow channel to mimic the 1955 sinuosity regime of the Clear Creek mainstem by reconnecting thirteen remnant oxbows scattered throughout the system between Country Club Drive and Dixie Farm Road that were cut off as a result of past channelization activities (Figure 51). This would be accomplished by modifying portions of the existing conveyance feature, diverting water into the oxbows under low flow conditions, and maintaining high flow conditions to guarantee flood protection for the area. Dredged material stockpiled along the north bank of the creek would be removed, and the existing cleared overbank areas along the channel would be densely planted to restore the existing floodplain forest to a desired state (based on data collections by TPWD and USFWS in 2005 within the study area). Approximately 31 acres of floodplain forest would be restored.

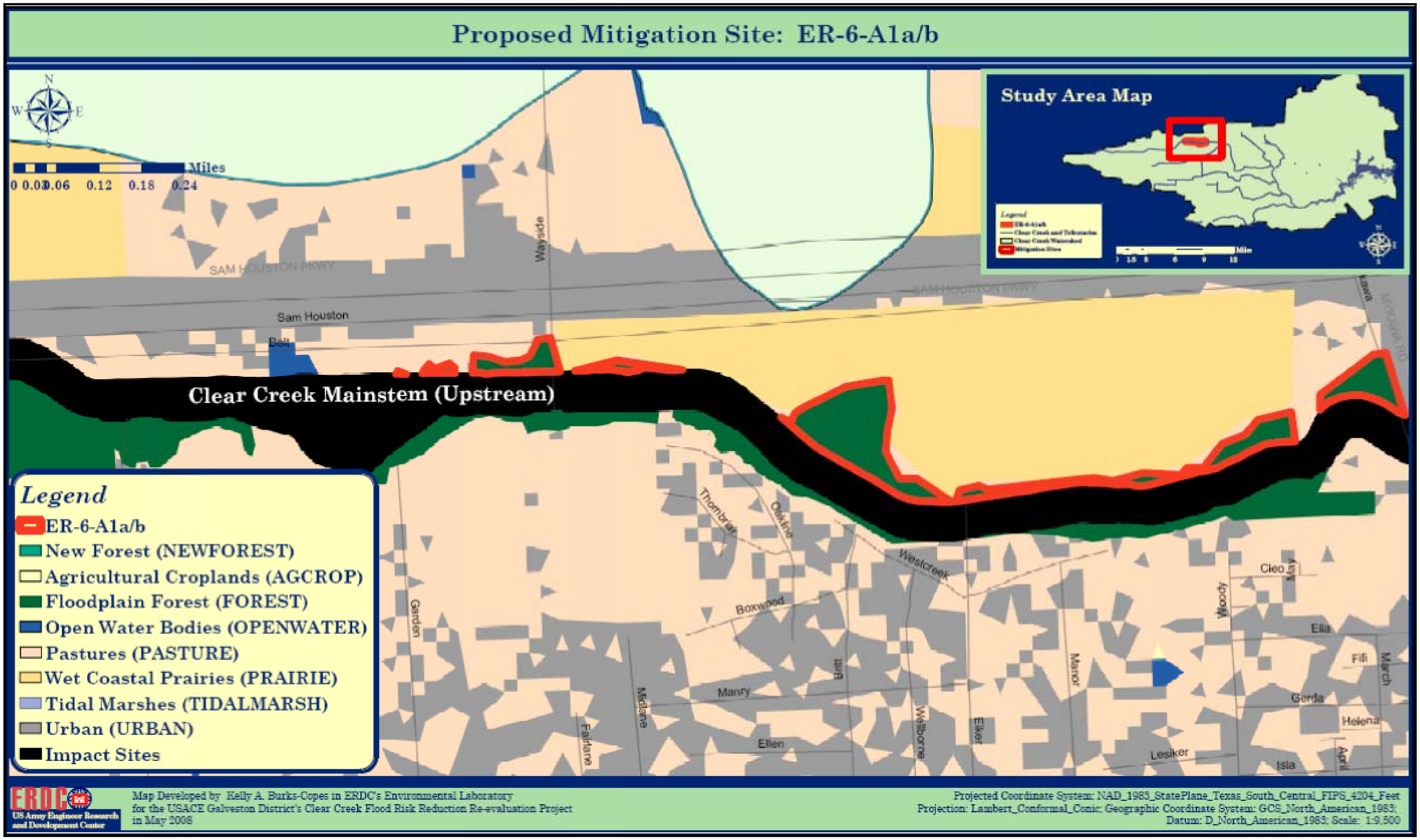

Figure 49. Cover type map of the ER-6-A1a and ER-6-A1b mitigation measures.

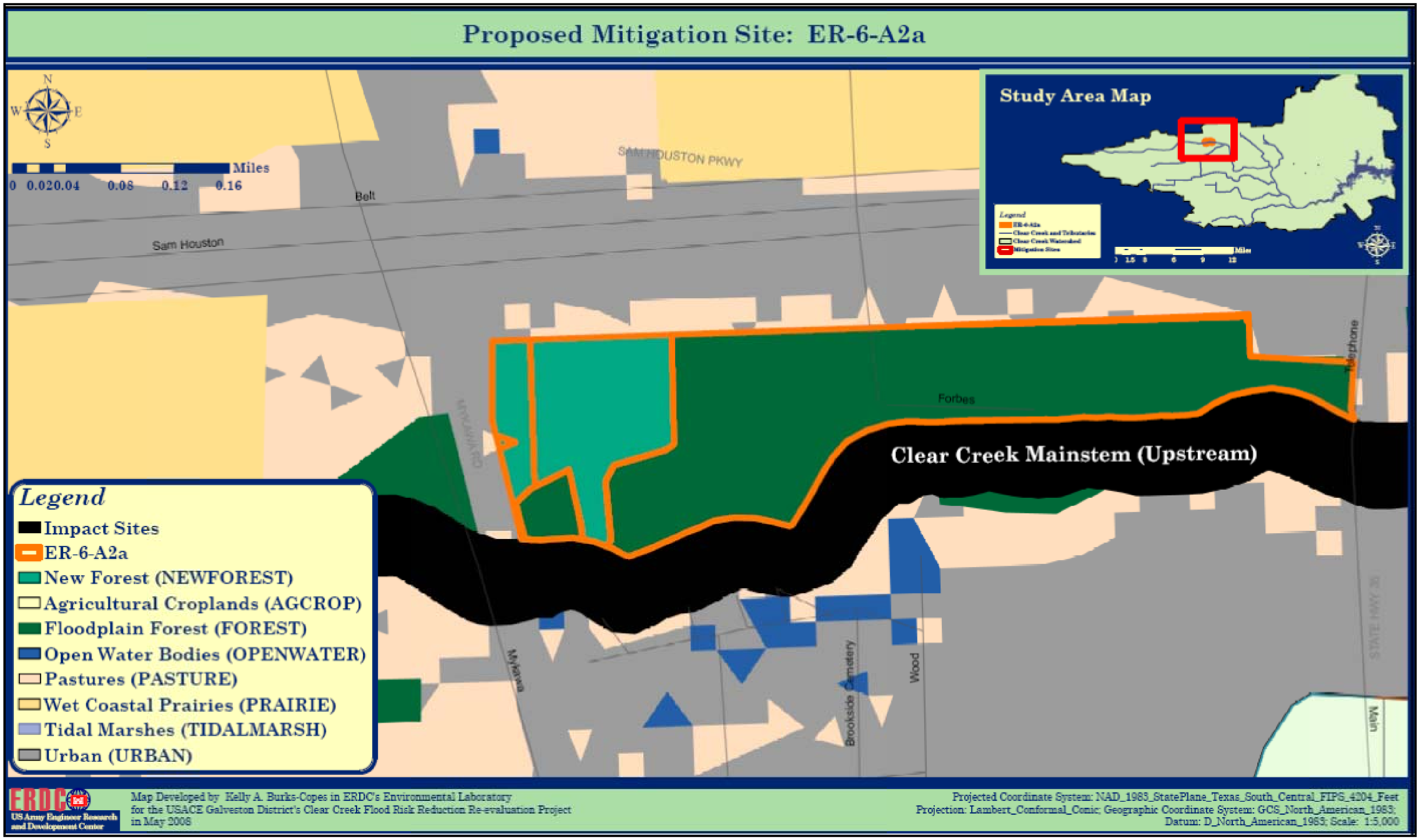

Figure 50. Cover type map of the ER-6-A2a mitigation measure.

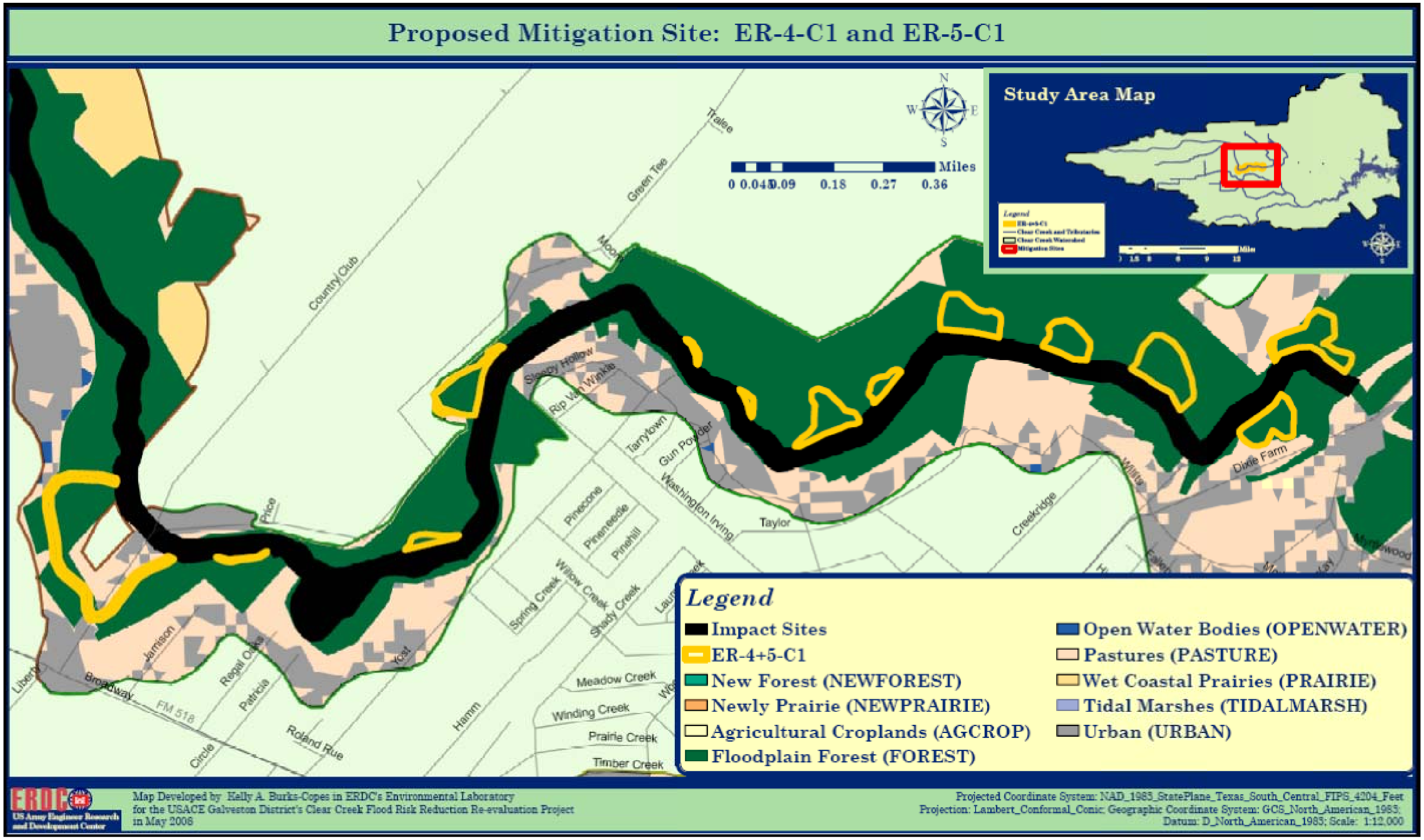

Figure 51. Cover type map of the ER-4-C1 and ER-5-C1 mitigation measure.

ER-4-C2 and ER-5-C2

The *C2* measure was a modification of the *C1* measure involving the addition of 31 acres of floodplain forest restoration via a reconnection of oxbows, and the additional preservation of 67 acres and restoration of 5 acres of floodplain forest (Figure 52).

ER-4-D

The *D* measure proposed the preservation and restoration of 272 acres of existing floodplain forest including the riparian corridor along Clear Creek in Eco-Reach 4. This measure required the purchase of vacant land around the confluence of Clear Creek and Mud Gully adjacent to, and east of, Dixie Farm Road and Choate Parks Road (Figure 53).

ER-3-E

The *E* measure proposed the preservation and restoration of 241 acres of existing floodplain forest including the riparian corridor along Clear Creek in Eco-Reach 3. This measure required the purchase of vacant land along Clear Creek between FM 2351 and FM 528 (Parkwood) (Figure 54).

ER-2-F

The *F* measure proposed the preservation and restoration of 388 acres of existing floodplain forest, including the riparian corridor along Clear Creek in Eco-Reach 2. This measure required the purchase of vacant land along Clear Creek between FM 528 and FM 518 (Figure 55).

ER-2-G

The *G* measure proposed the preservation and restoration of 144 acres of existing floodplain forest, including the riparian corridor along Clear Creek in Eco-Reach 2 as well. This measure required the purchase of vacant land along Clear Creek between FM 518 and Challenger 7 Park (Figure 56).

ER-2-I

The *I* measure proposed the preservation and restoration of 91 acres of existing floodplain forest, including the riparian corridor along Chigger Creek near its confluence with Clear Creek in Eco-Reach 2. This measure requires the purchase of vacant land along Chigger Creek from FM 518 to approximately 9,000 feet upstream (Figure 57).

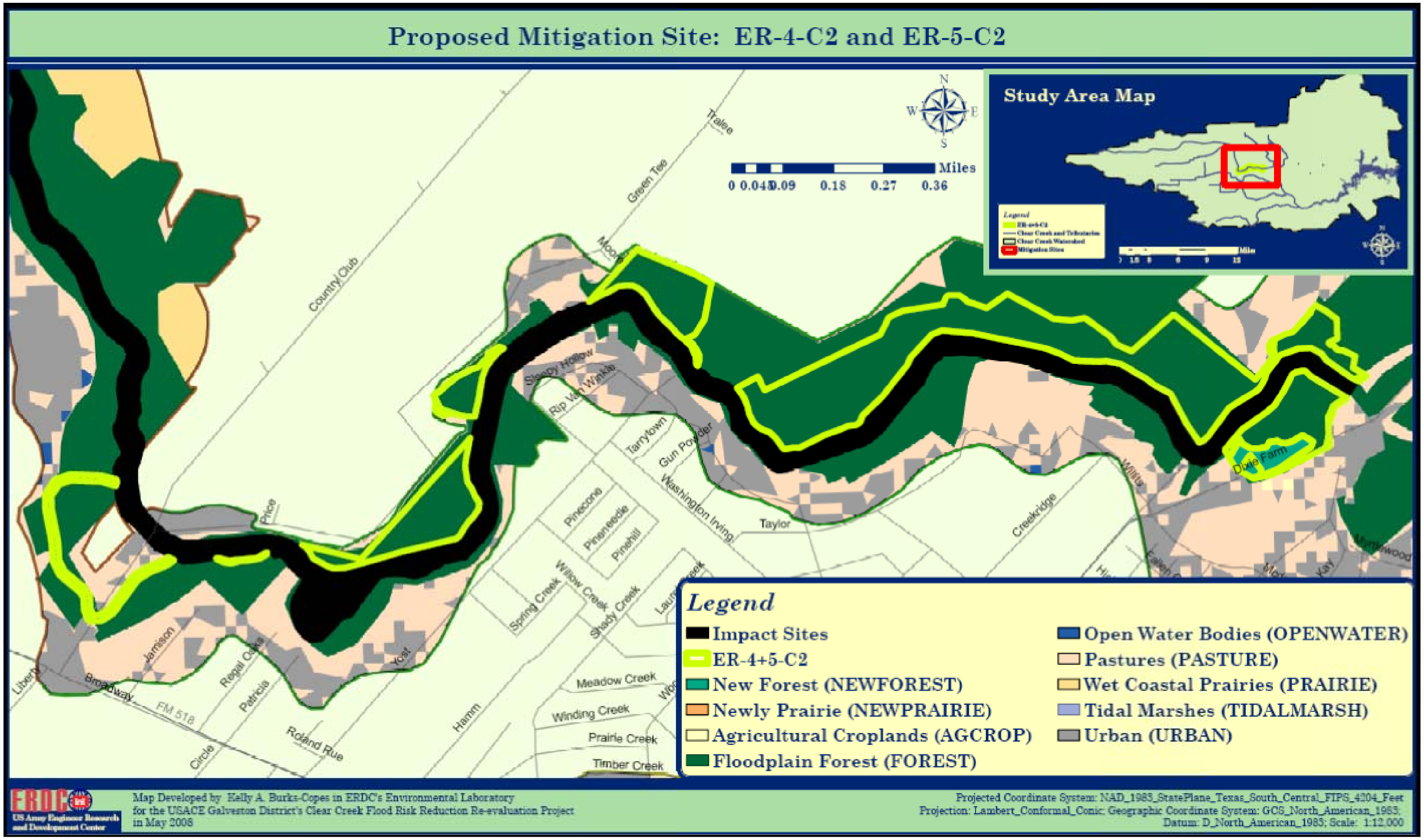

Figure 52. Cover type map of the ER-4-C2 and ER-5-C2 mitigation measure.

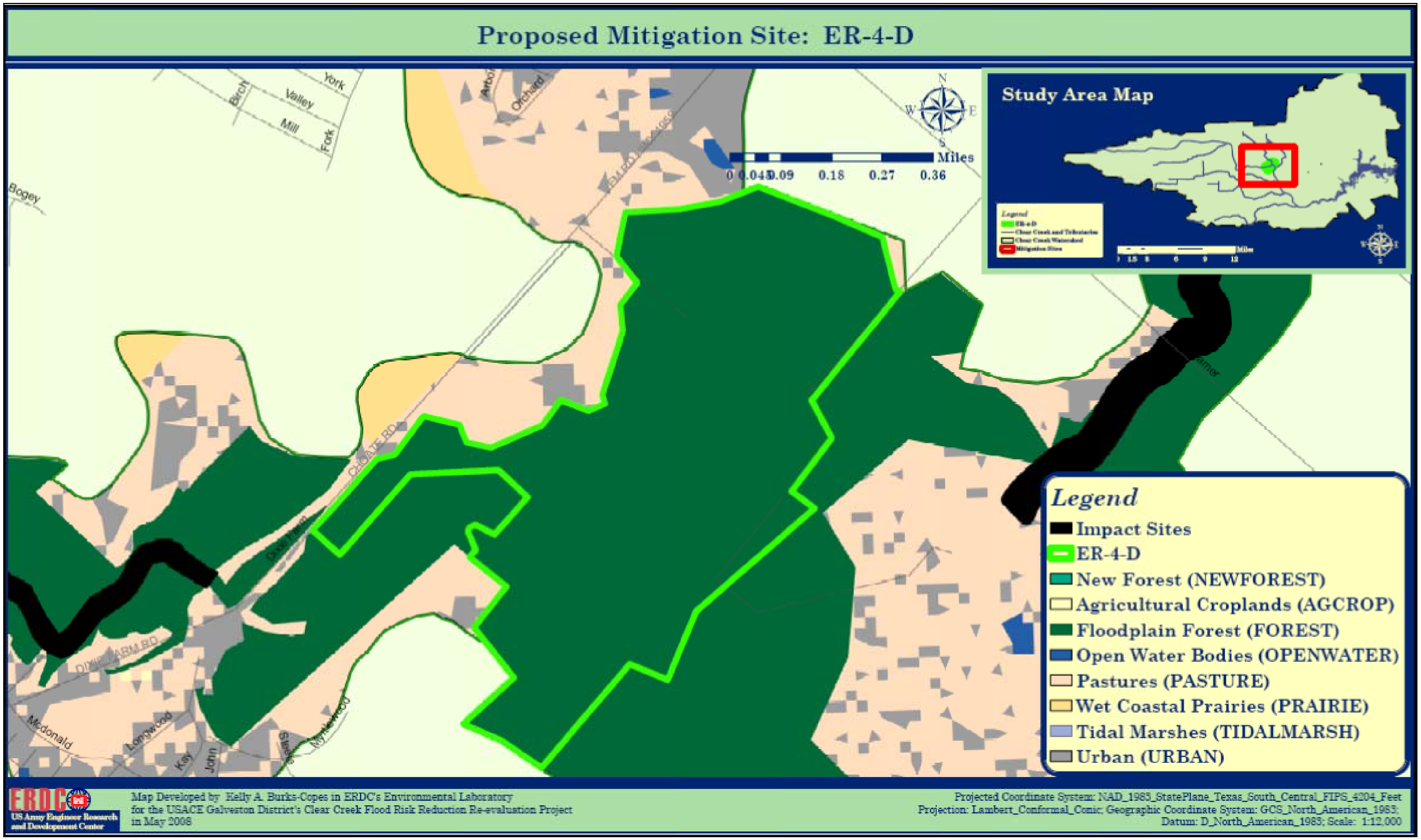

Figure 53. Cover type map of the ER-4-D mitigation measure.

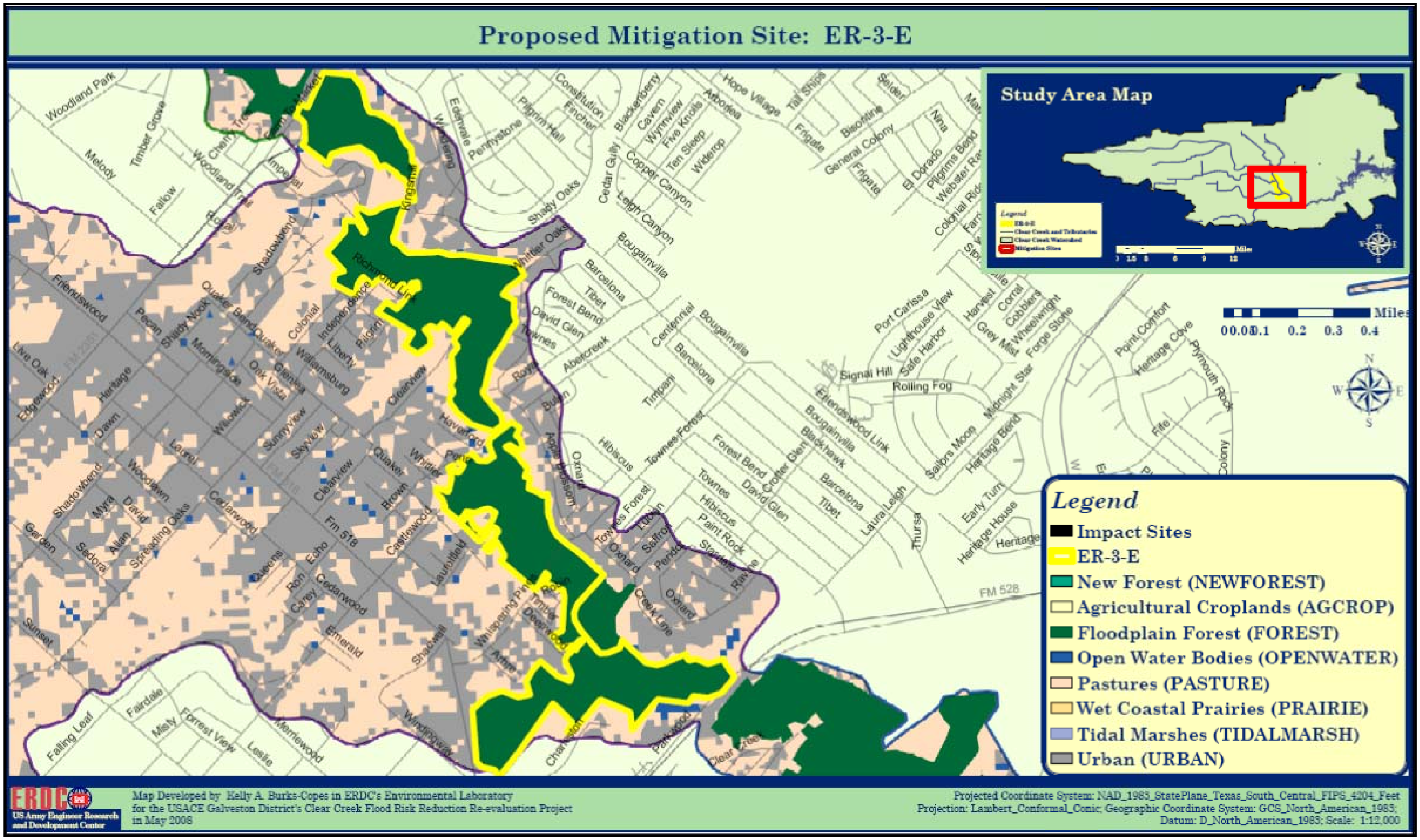

Figure 54. Cover type map of the ER-3-E mitigation measure.

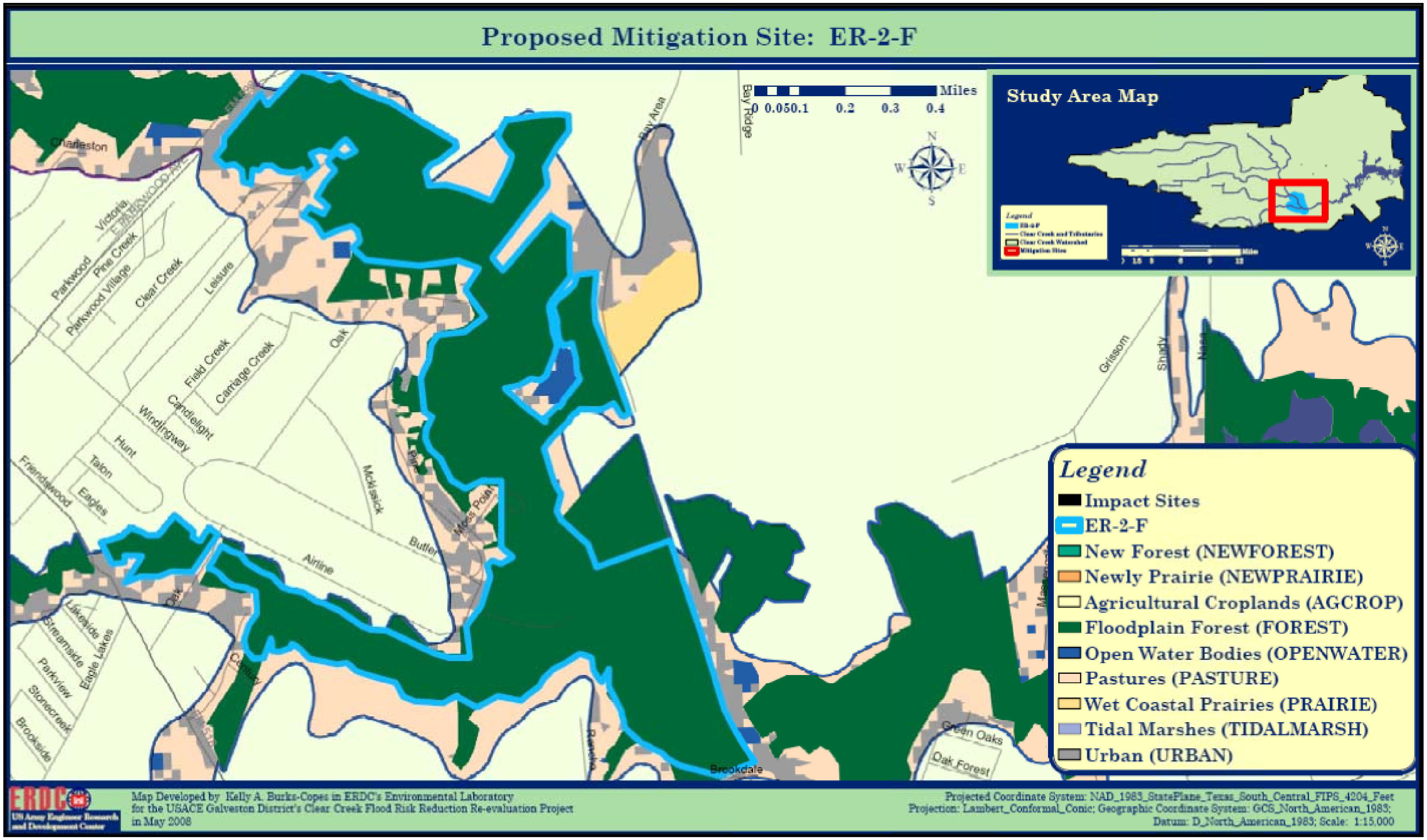

Figure 55. Cover type map of the ER-2-F mitigation measure.

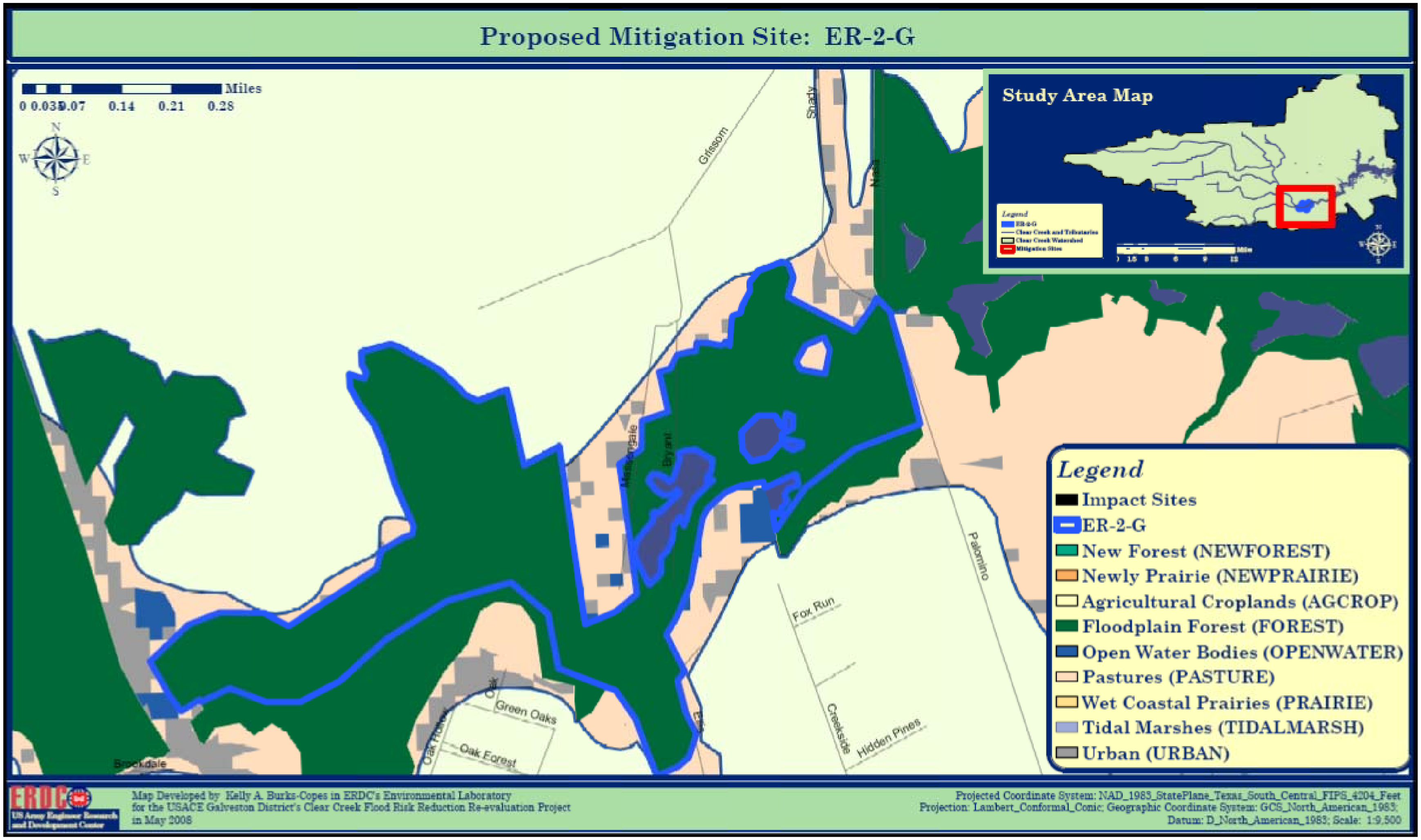

Figure 56. Cover type map of the ER-2-G mitigation measure.

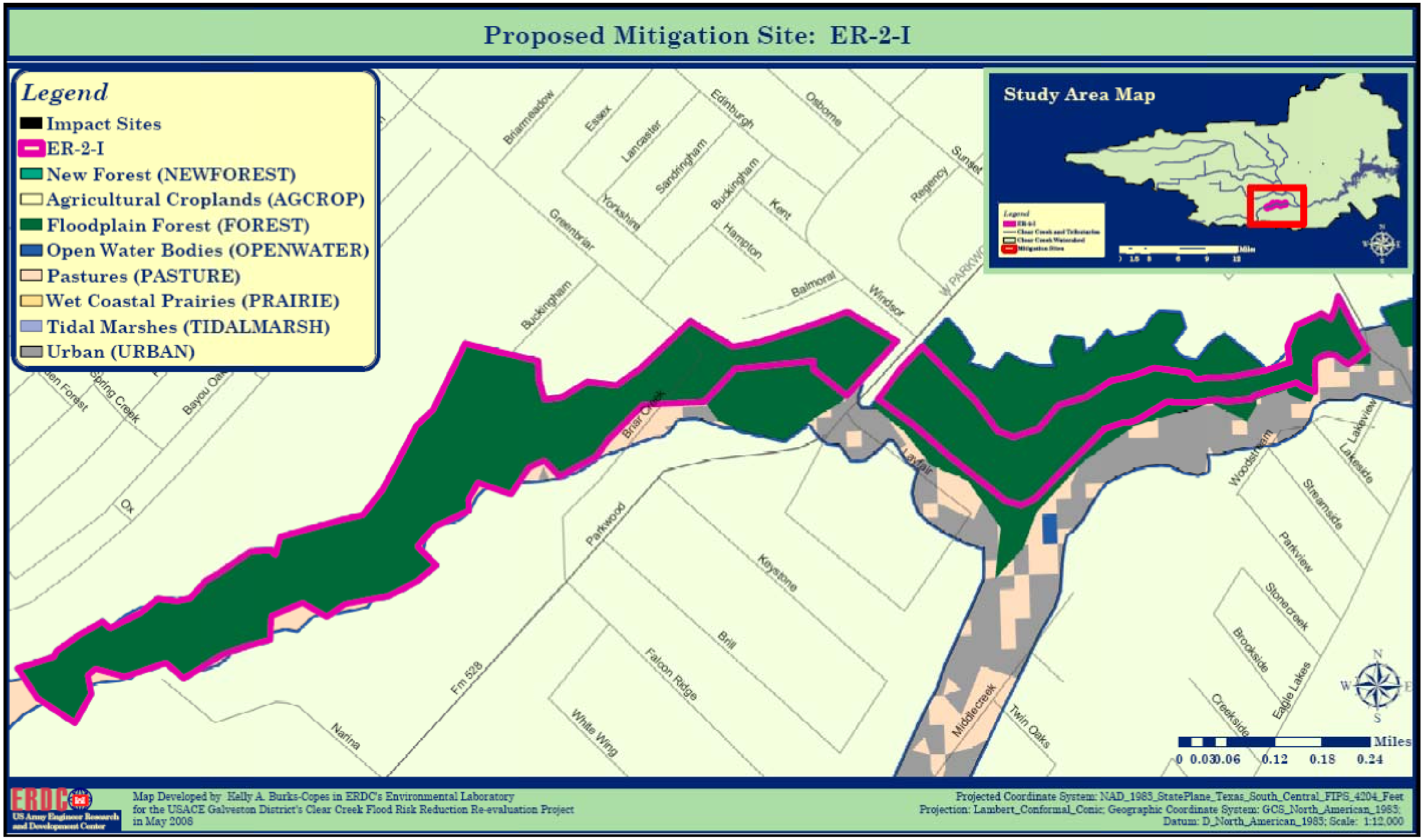

Figure 57. Cover type map of the ER-2-I mitigation measure.

Predicted WOP Trends (Quantity and Quality)

The same trends used to assess the WOP condition under the NED plan analysis were used to quantify the WOP conditions for the mitigation measures. Refer to the WOP sections above to review this information and the predicted WOP forecast for the Clear Creek watershed.[1]

Predicted WP Acreage Trends (Quantity)

In order to complete the HEP assessments, individual measures and increments were assessed independently (per Eco-Reach), and their cumulative effects were combined to generate an estimate of total benefits in terms of AAHUs. The first step was to develop acreage projections over the life of the project for each measure (Tables 34 - 45). In this manner, the E-Team was able to capture the localized affects of the various measures, yet maintain the landscape-level trends experienced across the affected eco-reaches (including the omnipresent urban encroachment).

Just as they did under the WOP conditions, these tables indicate urban encroachment will continue to change the face of the Clear Creek watershed over the next 50 years, regardless of the implementation of the NED plan and its various mitigation measures.

Table 34. WP acre projections for the ER-6-A1a mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	1,305	1,219	1,166	1,032	951	1,305	1,219	1,166	1,032	951
FOREST	489	448	426	368	334	489	448	427	372	339
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	180	163	154	132	119	180	163	154	132	119
PASTURES	8,378	7,814	7,527	6,811	6,381	8,378	7,814	7,527	6,811	6,381
PRAIRIE	1,077	982	928	792	711	1,077	982	933	811	738
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	2,871	3,674	4,099	5,165	5,804	2,871	3,674	4,093	5,142	5,772
TOTALS:	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300

[1] Electronic files available upon request - contact the District POC, Andrea Catanzaro (Table 1).

Table 35. WP acre projections for the ER-6-A1b mitigation measure.

Code	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	1,305	1,219	1,166	1,032	951	1,305	1,219	1,166	1,032	951
FOREST	489	448	426	368	334	489	448	427	372	339
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	180	163	154	132	119	180	163	154	132	119
PASTURES	8,378	7,814	7,527	6,811	6,381	8,378	7,814	7,527	6,811	6,381
PRAIRIE	1,077	982	928	792	711	1,077	982	933	811	738
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	2,871	3,674	4,099	5,165	5,804	2,871	3,674	4,093	5,142	5,772
TOTALS:	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300

Table 36. WP acre projections for the ER-6-A2a mitigation measure.

Code	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	1,305	1,219	1,166	1,032	951	1,305	1,219	1,166	1,032	951
FOREST	489	448	426	368	334	489	448	427	373	341
NEWFOREST	0	0	0	0	0	0	9	9	9	9
OPENWATER	180	163	154	132	119	180	163	154	132	119
PASTURES	8,378	7,814	7,527	6,811	6,381	8,378	7,807	7,520	6,804	6,374
PRAIRIE	1,077	982	928	792	711	1,077	982	928	792	711
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	2,871	3,674	4,099	5,165	5,804	2,871	3,672	4,096	5,158	5,795
TOTALS:	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300	14,300

Table 37. WP acre projections for the ER-4-C1 mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	2	2	2	2	2	2	2	2	2	2
FOREST	1,053	931	852	655	536	1,053	931	854	663	548
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	17	15	14	12	10	17	15	14	12	10
PASTURES	1,521	1,370	1,271	1,019	871	1,521	1,370	1,271	1,019	871
PRAIRIE	26	24	23	20	18	26	24	23	20	18
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	1,753	2,030	2,210	2,664	2,935	1,753	2,030	2,208	2,656	2,923
TOTALS:	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372

Table 38. WP acre projections for the ER-5-C1 mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	28	25	24	21	20	28	25	24	21	20
FOREST	337	309	295	258	236	337	309	295	258	236
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	11	10	10	8	7	11	10	10	8	7
PASTURES	692	625	592	511	463	692	625	592	511	463
PRAIRIE	1,094	988	941	826	755	1,094	988	941	826	755
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	601	806	901	1,139	1,282	601	806	901	1,139	1,282
TOTALS:	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763

Table 39. WP acre projections for the ER-4-C2 mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	2	2	2	2	2	2	2	2	2	2
FOREST	1,053	931	852	655	536	1,053	931	860	683	576
NEWFOREST	0	0	0	0	0	0	5	5	5	5
OPENWATER	17	15	14	12	10	17	15	14	12	10
PASTURES	1,521	1,370	1,271	1,019	871	1,521	1,366	1,267	1,015	867
PRAIRIE	26	24	23	20	18	26	24	23	20	18
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	1,753	2,030	2,210	2,664	2,935	1,753	2,029	2,201	2,635	2,894
TOTALS:	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372

Table 40. WP acre projections for the ER-5-C2 mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	28	25	24	21	20	28	25	24	21	20
FOREST	337	309	295	258	236	337	309	295	258	236
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	11	10	10	8	7	11	10	10	8	7
PASTURES	692	625	592	511	463	692	625	592	511	463
PRAIRIE	1,094	988	941	826	755	1,094	988	941	826	755
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	601	806	901	1,139	1,282	601	806	901	1,139	1,282
TOTALS:	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763

Table 41. WP acre projections for the ER-4-D mitigation measure.

Code	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	2	2	2	2	2	2	2	2	2	2
FOREST	1,053	931	852	655	536	1,053	931	875	736	652
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	17	15	14	12	10	17	15	14	12	10
PASTURES	1,521	1,370	1,271	1,019	871	1,521	1,370	1,271	1,019	871
PRAIRIE	26	24	23	20	18	26	24	23	20	18
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	1,753	2,030	2,210	2,664	2,935	1,753	2,030	2,187	2,583	2,819
TOTALS:	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372	4,372

Table 42. WP acre projections for the ER-3-E mitigation measure.

Code	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	34	31	29	25	22	34	31	29	25	22
FOREST	253	206	196	171	156	253	206	206	206	206
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	20	17	16	14	12	20	17	16	14	12
PASTURES	2,522	2,196	2,069	1,747	1,555	2,522	2,196	2,069	1,747	1,555
PRAIRIE	0	0	0	0	0	0	0	0	0	0
TIDALMARSH	0	0	0	0	0	0	0	0	0	0
URBAN	1,869	2,248	2,388	2,741	2,953	1,869	2,248	2,378	2,706	2,903
TOTALS:	4,698	4,698	4,698	4,698	4,698	4,698	4,698	4,698	4,698	4,698

Table 43. WP acre projections for the ER-2-F mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	97	94	92	86	83	97	94	92	86	83
FOREST	1,095	941	869	689	581	1,095	941	899	793	730
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	66	62	60	56	53	66	62	60	56	53
PASTURES	1,997	1,814	1,716	1,470	1,323	1,997	1,814	1,716	1,470	1,323
PRAIRIE	33	28	26	20	17	33	28	26	20	17
TIDALMARSH	64	55	51	42	36	64	55	55	55	55
URBAN	763	1,121	1,301	1,752	2,022	763	1,121	1,267	1,635	1,854
TOTALS:	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115

Table 44. WP acre projections for the ER-2-G mitigation measure.

	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
Code	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	97	94	92	86	83	97	94	92	86	83
FOREST	1,095	941	869	689	581	1,095	941	880	728	636
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	66	62	60	56	53	66	62	60	56	53
PASTURES	1,997	1,814	1,716	1,470	1,323	1,997	1,814	1,716	1,470	1,323
PRAIRIE	33	28	26	20	17	33	28	26	20	17
TIDALMARSH	64	55	51	42	36	64	55	55	55	55
URBAN	763	1,121	1,301	1,752	2,022	763	1,121	1,286	1,700	1,948
TOTALS:	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115

Table 45. WP acre projections for the ER-2-I mitigation measure.

Code	Without-project Conditions					With-project Conditions				
	Calendar Year and Target Year					Calendar Year and Target Year				
	2000	2000	2000	2000	2000	2000	2020	2030	2055	2070
	TY0	TY0	TY0	TY0	TY0	TY0	TY1	TY11	TY36	TY51
AGCROP	97	94	92	86	83	97	94	92	86	83
FOREST	1,095	941	869	689	581	1,095	941	876	713	616
NEWFOREST	0	0	0	0	0	0	0	0	0	0
OPENWATER	66	62	60	56	53	66	62	60	56	53
PASTURES	1,997	1,814	1,716	1,470	1,323	1,997	1,814	1,716	1,470	1,323
PRAIRIE	33	28	26	20	17	33	28	26	20	17
TIDALMARSH	64	55	51	42	36	64	55	55	55	55
URBAN	763	1,121	1,301	1,752	2,022	763	1,121	1,290	1,715	1,968
TOTALS:	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115	4,115

Predicted WP Variable Trends (Quality)

Rather than presenting copious amounts of tables documenting variable projections here, the authors chose to provide a brief synopsis of general WP trends under the mitigation scenarios (and the E-Team assumptions supporting these trends).[1] Generally speaking, the E-Team surmised that the hydrologic parameters (hydroregime, roughness, etc.) would be improved with the proposed mitigation scenarios – the hydroregime would be returned to a somewhat natural state, sinuosity would be recovered, engineering designs would be tailored to introduce manageable levels of roughness (i.e., with tree plantings along the water's edge) and the overall depth of waters would be controlled to simulate more natural conditions. With respect to the vegetative components of the community model, the E-Team assumed mitigation efforts would contend with the invasive presence of exotics and noxious species in the system. They further assumed the planting scenarios adopted would improve the overhead, hanging vegetation and the instream cover returning the system to a shaded riverine complex. The E-team assumed in most instances that habitat fragmentation was still likely to occur in areas unprotected by the mitigation scenarios, and as such, they presumed that landscape level parameters such as adjacent landuse, patchsize, distance between patches, core and edge trends would likely emulate the WOP scenario (counteracting the fragmentation trends

[1] To review the variable WP projections for the mitigation measures contact the District.

seen under the unmitigated NED measure proposal). Detailed (native) planting schemes and intensive 30+ year maintenance measures were predicted to generate highly functioning systems in 40 years or less (Tables 46 - 60).

WP Results

The changes predicted above under the proposed mitigation measures resulted in quantifiable benefits for both the floodplain forest and wet coastal prairie communities across the watershed (Table 61).[1]

Table 46. FOREST cover type WP variable projections for the ER-6-A1a mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	30	30	30	40	45
	ROUGHNESS	0.11	0.08	0.08	0.08	0.08
	SINUOSITY	1.16	1.16	1.16	1.16	1.16
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	40	65	70	80	85
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	80	85
	INSTRMCOV	5	5	5	5	5
	NATIVE	70	75	75	80	80
	OVRHDCOV	30	20	20	20	20
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	5	4	4	4	4
	CORE	0	0	0	0	0
	EDGE	70	60	60	50	45
	NEIGHBOR	55	65	65	75	80
	PATCHSIZE	70	60	60	50	45

[1] To review electronic summaries of the without-project results generated by the E Team contact the District.

Table 47. FOREST cover type WP variable projections for the ER-6-A1b mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	30	30	30	40	45
	ROUGHNESS	0.11	0.08	0.08	0.08	0.08
	SINUOSITY	1.16	1.16	1.16	1.16	1.16
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	40	65	70	80	85
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	80	85
	INSTRMCOV	5	5	5	5	5
	NATIVE	70	75	75	80	80
	OVRHDCOV	30	20	20	20	20
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	5	4	4	4	4
	CORE	0	0	0	0	0
	EDGE	70	60	60	50	45
	NEIGHBOR	55	65	65	75	80
	PATCHSIZE	70	60	60	50	45

Table 48. FOREST cover type WP variable projections for the ER-6-A2a mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	1	1	1	1
	EROSION	3	4	4	5	5
	IMPERVIOUS	30	30	30	40	45
	ROUGHNESS	0.11	0.08	0.08	0.08	0.08
	SINUOSITY	1.16	1.16	1.16	1.16	1.16
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	40	65	70	80	85

Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	80	85
	INSTRMCOV	5	5	5	5	5
	NATIVE	70	75	75	80	80
	OVRHDCOV	30	20	20	20	20
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	5	4	4	5	5
	CORE	0	0	0	0	0
	EDGE	70	65	65	55	50
	NEIGHBOR	55	15	15	15	15
	PATCHSIZE	70	65	65	55	50

Table 49. NEWFOREST cover type WP variable projections for the ER-6-A2a mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	0	1	1	1	1
	EROSION	0	4	4	5	5
	IMPERVIOUS	0	30	30	40	45
	ROUGHNESS	0	0.08	0.08	0.08	0.08
	SINUOSITY	0	1.16	1.16	1.16	1.16
	SUBSTRATE	0	1	1	1	1
	WATERDEPTH	0	65	70	80	85
Structure and Biotic Integrity (BIOINTEG)	CANTREE	0	5	30	70	75
	INSTRMCOV	0	5	5	5	5
	NATIVE	0	100	100	100	100
	OVRHDCOV	0	20	20	20	20
	VEGSTRATA	0	2	3	5	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	0	7	7	8	8
	AREAWETDRY	0	4	4	5	5
	CORE	0	0	0	0	0
	EDGE	0	65	65	55	50
	NEIGHBOR	0	15	15	15	15
	PATCHSIZE	0	65	65	55	50

Table 50. FOREST cover type WP variable projections for the ER-4-C1 mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	3	3	3	3
	EROSION	2	2	2	2	2
	IMPERVIOUS	40	45	50	60	70
	ROUGHNESS	0.11	0.12	0.12	0.12	0.12
	SINUOSITY	1.74	1.86	1.86	1.86	1.86
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	45	50	65	80
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	70	75
	INSTRMCOV	5	20	25	35	40
	NATIVE	60	65	67	70	70
	OVRHDCOV	60	60	60	70	75
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	5	4	4	3	3
	CORE	40	34	30	25	20
	EDGE	310	265	245	190	160
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	525	450	415	325	270

Table 51. NEWFOREST cover type WP variable projections for the ER-4-C1 mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	0	3	3	3	3
	EROSION	0	2	2	2	2
	IMPERVIOUS	0	45	50	60	70
	ROUGHNESS	0	0.12	0.12	0.12	0.12
	SINUOSITY	0	1.86	1.86	1.86	1.86
	SUBSTRATE	0	1	1	1	1
	WATERDEPTH	0	45	50	65	80

Structure and Biotic Integrity (BIOINTEG)	CANTREE	0	5	30	70	75
	INSTRMCOV	0	5	10	25	35
	NATIVE	0	100	100	100	100
	OVRHDCOV	0	60	60	65	70
	VEGSTRATA	0	2	3	5	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	0	8	8	8	8
	AREAWETDRY	0	4	4	3	3
	CORE	0	34	30	25	20
	EDGE	0	265	245	190	160
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	0	450	415	325	270

Table 52. FOREST cover type WP variable projections for the ER-5-C1 mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	3	3	3	3
	EROSION	3	3	3	3	3
	IMPERVIOUS	40	40	40	50	55
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.23	1.26	1.26	1.26	1.26
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	45	50	65	80
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	80	85
	INSTRMCOV	5	20	25	35	40
	NATIVE	60	65	65	70	70
	OVRHDCOV	20	20	20	30	35
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	20	18	17	15	13
	CORE	5	5	5	5	5
	EDGE	65	55	55	45	40
	NEIGHBOR	30	30	30	40	45
	PATCHSIZE	65	55	55	45	40

Table 53. FOREST cover type WP variable projections for the ER-4-C2 mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	3	3	3	3
	EROSION	2	2	2	2	2
	IMPERVIOUS	40	40	45	55	65
	ROUGHNESS	0.11	0.12	0.12	0.12	0.12
	SINUOSITY	1.74	1.86	1.86	1.86	1.86
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	45	50	65	80
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	70	75
	INSTRMCOV	5	20	25	35	40
	NATIVE	60	65	65	70	70
	OVRHDCOV	60	60	60	70	75
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	5	5	5	5	6
	CORE	40	41	40	30	25
	EDGE	310	280	260	200	165
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	525	480	440	345	285

Table 54. NEWFOREST cover type WP variable projections for the ER-4-C2 mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	0	3	3	3	3
	EROSION	0	2	2	2	2
	IMPERVIOUS	0	40	45	55	65
	ROUGHNESS	0	0.12	0.12	0.12	0.12
	SINUOSITY	0	1.86	1.86	1.86	1.86
	SUBSTRATE	0	1	1	1	1
	WATERDEPTH	0	45	50	65	80

Structure and Biotic Integrity (BIOINTEG)	CANTREE	0	5	30	70	75
	INSTRMCOV	0	5	10	25	35
	NATIVE	0	100	100	100	100
	OVRHDCOV	0	60	60	65	70
	VEGSTRATA	0	2	3	5	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	0	8	8	8	8
	AREAWETDRY	0	5	5	5	6
	CORE	0	41	40	30	25
	EDGE	0	280	260	200	165
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	0	480	440	345	285

Table 55. FOREST cover type WP variable projections for the ER-5-C2 mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	3	3	3	3
	EROSION	3	3	3	3	3
	IMPERVIOUS	40	40	40	50	55
	ROUGHNESS	0.11	0.11	0.11	0.11	0.11
	SINUOSITY	1.23	1.26	1.26	1.26	1.26
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	45	50	65	80
Structure and Biotic Integrity (BIOINTEG)	CANTREE	75	75	75	80	85
	INSTRMCOV	5	20	25	35	40
	NATIVE	60	65	65	70	70
	OVRHDCOV	20	20	20	30	35
	VEGSTRATA	6	6	6	6	6
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	7	7	8	8
	AREAWETDRY	20	18	17	15	13
	CORE	5	5	5	5	5
	EDGE	65	55	55	45	40
	NEIGHBOR	30	30	30	40	45
	PATCHSIZE	65	55	55	45	40

Table 56. FOREST cover type WP variable projections for the ER-4-D mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	1	3	3	3	3
	EROSION	2	2	2	2	2
	IMPERVIOUS	40	40	40	50	55
	ROUGHNESS	0.11	0.08	0.08	0.08	0.08
	SINUOSITY	1.74	3.1	3.1	3.1	3.1
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	45	45	50	65	80
Structure and Biotic Integrity (BIOINTEG)	CANTREE	65	65	65	70	75
	INSTRMCOV	5	20	25	35	40
	NATIVE	60	65	65	70	70
	OVRHDCOV	60	60	60	70	75
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	5	8	8	9	10
	CORE	40	38	35	30	25
	EDGE	310	280	265	225	200
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	525	475	445	380	340

Table 57. FOREST cover type WP variable projections for the ER-3-E mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	3	2	2	1	1
	EROSION	4	4	4	4	4
	IMPERVIOUS	55	65	65	75	85
	ROUGHNESS	0.11	0.08	0.08	0.08	0.08
	SINUOSITY	1.64	1.64	1.64	1.64	1.64
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	40	65	70	80	85

Structure and Biotic Integrity (BIOINTEG)	CANTREE	45	45	45	45	45
	INSTRMCOV	0	5	5	15	20
	NATIVE	40	45	45	50	55
	OVRHDCOV	40	40	40	40	40
	VEGSTRATA	5	5	5	5	5
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	3	8	8	8	8
	AREAWETDRY	0	20	20	20	20
	CORE	0	0	0	0	0
	EDGE	240	205	205	205	205
	NEIGHBOR	0	0	0	0	0
	PATCHSIZE	255	205	205	205	205

Table 58. FOREST cover type WP variable projections for the ER-2-F mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	5	2	2	1	1
	EROSION	3	3	3	3	3
	IMPERVIOUS	40	40	40	50	55
	ROUGHNESS	0.1	0.08	0.08	0.08	0.08
	SINUOSITY	1.57	1.57	1.57	1.57	1.57
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	30	55	60	70	75
Structure and Biotic Integrity (BIOINTEG)	CANTREE	70	70	70	70	70
	INSTRMCOV	25	65	65	65	65
	NATIVE	75	85	85	90	90
	OVRHDCOV	60	60	60	60	60
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	2	7	7	8	8
	AREAWETDRY	10	14	14	13	13
	CORE	10	10	10	8	7
	EDGE	135	125	120	110	100
	NEIGHBOR	35	35	35	45	50
	PATCHSIZE	155	140	135	115	100

Table 59. FOREST cover type WP variable projections for the ER-2-G mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	5	2	2	1	1
	EROSION	3	3	3	3	3
	IMPERVIOUS	40	40	40	50	55
	ROUGHNESS	0.1	0.08	0.08	0.08	0.08
	SINUOSITY	1.57	1.57	1.57	1.57	1.57
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	30	55	60	70	75
Structure and Biotic Integrity (BIOINTEG)	CANTREE	70	70	70	70	70
	INSTRMCOV	25	65	65	65	65
	NATIVE	75	85	85	90	90
	OVRHDCOV	60	60	60	60	60
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	2	7	7	8	8
	AREAWETDRY	10	12	11	10	10
	CORE	10	10	10	10	10
	EDGE	135	125	115	100	90
	NEIGHBOR	35	35	35	45	50
	PATCHSIZE	155	140	130	115	105

Table 60. FOREST cover type WP variable projections for the ER-2-I mitigation measure.

Model Components	Variables	Calendar Years and Target Years				
		2000	2020	2030	2055	2070
		TY0	TY1	TY11	TY36	TY51
Soils and Hydrology (HYDRO)	ALTERHYDRO	5	2	2	1	1
	EROSION	3	3	3	3	3
	IMPERVIOUS	40	40	40	50	55
	ROUGHNESS	0.1	0.08	0.08	0.08	0.08
	SINUOSITY	1.57	1.57	1.57	1.57	1.57
	SUBSTRATE	1	1	1	1	1
	WATERDEPTH	30	55	60	70	75

Structure and Biotic Integrity (BIOINTEG)	CANTREE	70	70	70	70	70
	INSTRMCOV	25	65	65	65	65
	NATIVE	75	85	85	90	90
	OVRHDCOV	60	60	60	60	60
	VEGSTRATA	7	7	7	7	7
Spatial Integrity and Disturbance (SPATIAL)	ADJLANDUSE	2	7	7	8	8
	AREAWETDRY	10	6	6	5	4
	CORE	10	10	10	10	10
	EDGE	135	125	115	95	80
	NEIGHBOR	35	45	45	55	65
	PATCHSIZE	155	140	130	105	85

Table 61. Final results for the mitigation analysis.

Mitigation Measure	Eco-Reach 2	Eco-Reach 3	Eco-Reach 4	Eco-Reach 5	Eco-Reach 6	SUM of Net AAHUs
ER-6-A1a					8	8
ER-6-A1b					8	8
ER-6-A2a					20	20
ER-4-C1			97			97
ER-5-C1				34		34
ER-4-C2			117			117
ER-5-C2				34		34
ER-4-D			179			179
ER-3-E		48				48
ER-2-F	99					99
ER-2-G	65					65
ER-2-I	46					46
SUM of Net AAHUs	210	48	393	68	36	755

The single most productive measure was the *D* measure that produces 179 AAHUs in Eco-Reach 4. The *C2* scenario was the next most productive measure, generating 117 AAHUs in Eco-Reach 4 and an additional 34 AAHUs in Eco-Reach 5 (Total = 151 AAHUs). Following closely behind was the *C1* measure that produces 97 AAHUs in Eco-Reach 4 and an additional 34 AAHUs in Eco-Reach 5 (Total = 131 AAHUs). It was important to note that 106 AAHUs were needed to fully compensate for the proposed NED measure – three of these measures could stand alone as replacement measures for the predicted losses (i.e., *C1*, *C2*, and *D*) (Figure 58).

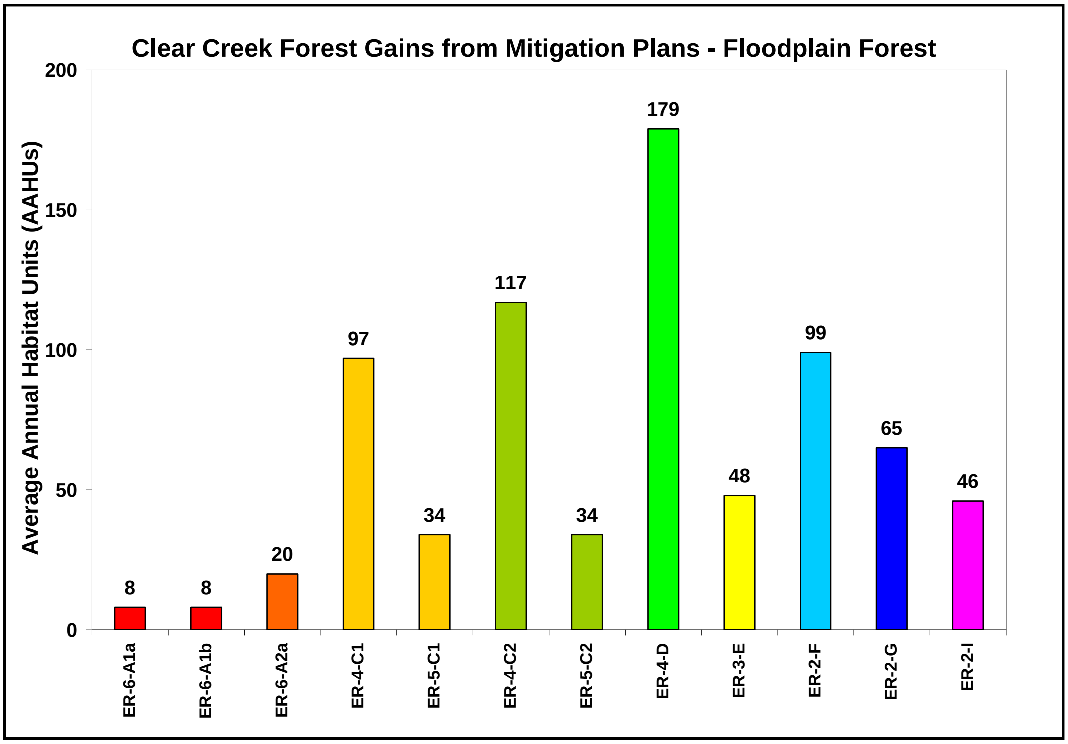

Figure 58. Final results of the HEP analysis providing the results of the mitigation measures for the forested floodplain community.

Ultimately, the identification of suitable mitigation measures hinged upon the cost analyses comparisons of the proposed measures. Below the authors detail the HEP and CEA/ICA analyses that evaluated the productivity of the proposed mitigation measures for the study.

Cost Analysis

Cost effectiveness (CEA) and incremental cost analyses (ICA) were performed using the IWR Planning Suite software.[1] The sections below summarize the outputs, costs and CEA/ICA results generated as the E-Team evaluated the suite of Clear Creek mitigation alternatives.

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

Plan Costs

The District developed annualized "first costs" for the proposed mitigation measures using a 4.875% interest rate and a 0.053722282 amoritization rate for construction (amortized over the 50-year project life) (Table 62).[1] These costs were then added to the annualized O&M costs for each measure and summed to generate the total annualized costs per measure (Table 63).

All possible combinations of these measures were generated in the CE-ICA analysis to form potential mitigation plans with 2 exceptions:

1. the increments of measure *A1* (i.e., *a* and *b*) could not be combined together; and
2. the increments of measure C (i.e., *C1* and *C2*) could not be combined together.

Table 62. First cost annualization data for the proposed mitigation measures.

Measures	Description	Contract Cost	Monitoring	Total	Annualized First Cost
ER-6-A1 (Forest)	20 acre restoration Floodplain Forest	$4,738,450	$23,692	$4,762,142	**$255,833**
ER-6-A2a	29 acre restoration/9 acres creation Floodplain Forest	$2,015,770	$10,079	$2,025,849	**$108,833**
ER-4-C1 + ER-5-C1	31 acres restoration Floodplain Forest	$2,739,208	$13,696	$2,752,904	**$147,892**
ER-4-C2 + ER-5-C2	103 acres restoration Floodplain Forest	$5,634,123	$28,171	$5,662,294	**$304,191**
ER-4-D	272 acres restoration Floodplain Forest	$9,446,370	$47,232	$9,493,602	**$510,018**
ER-3-E	241 acres restoration Floodplain Forest	$8,373,210	$41,866	$8,415,076	**$452,077**
ER-2-F	388 acres restoration Floodplain Forest	$13,454,180.00	$67,271	$13,521,451	**$726,403**
ER-2-G	144 acres restoration Floodplain Forest	$5,016,465.00	$25,082	$5,041,547	**$270,843**
ER-2-I	91 acres restoration Floodplain Forest	$3,185,710.00	$15,929	$3,201,639	**$171,999**

Interest rate = 4.875%.

Amoritization factor = 0.053722282.

Project Life =50 years.

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

Table 63. Annualized costs input into the cost analyses for the Clear Creek mitigation plans.

Measures	Description	Annualized First Cost	Annualized O&M	Total Annualized Costs
ER-6-A1 (Forest)	20 acre restoration Floodplain Forest	$255,833	$192,341	**$448,174**
ER-6-A2a	29 acre restoration/9 acres creation Floodplain Forest	$108,833	$116,381	**$225,214**
ER-4-C1 + ER-5-C1	31 acres restoration Floodplain Forest	$147,892	$94,942	**$242,834**
ER-4-C2 + ER-5-C2	103 acres restoration Floodplain Forest	$304,191	$315,454	**$619,645**
ER-4-D	272 acres restoration Floodplain Forest	$510,018	$833,042	**$1,343,060**
ER-3-E	241 acres restoration Floodplain Forest	$452,077	$738,100	**$1,190,177**
ER-2-F	388 acres restoration Floodplain Forest	$726,403	$1,188,310	**$1,914,713**
ER-2-G	144 acres restoration Floodplain Forest	$270,843	$441,022	**$711,866**
ER-2-I	91 acres restoration Floodplain Forest	$171,999	$278,702	**$450,701**

These 384 possible plans, in turn, were compared against the total annualized outputs generated in the HEP analyses (AAHUs) using CE/ICA (Table 64).

Table 64. Costs and outputs submitted to CE/ICA analysis.

Measures	Average Annual Habitat Units (AAHUs)	Total Annualized Costs	Annualized Cost per Output ($/AAHU)
ER-6-A1	8	430405	$53,801
ER-6-A2a	20	225214	$11,261
ER-4-C1 + ER-5-C1	131	242835	$1,854
ER-4-C2 + ER-5-C2	151	619645	$4,104
ER-4-D	179	1343060	$7,503
ER-3-E	48	1190177	$24,795
ER-2-F	99	1914714	$19,341
ER-2-G	65	711866	$10,952
ER-2-I	46	450701	$9,798

Cost Analysis Results

Cost Effective Analysis

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. Table 65 and Figure 59 below detail the results of the cost effective analyses for the floodplain forest mitigation plans. Twenty-nine plans (combinations of measures) were considered cost- effective. These ranged from $225,214 and $6,885,782 and produced between 20 and 616 AAHUS of floodplain forest.

Table 65. Cost-effective analysis results for the floodplain forest mitigation plans.

Count	Potential Mitigation Plans for the Floodplain Forest Community	Reaches Affected	Average Annual Habitat Units (AAHUs)	Costs ($1000)	Average Cost ($1000)
1	No Action Plan	--	0	0	0
2	A2a	6	20	225,214	11,261
3	C1	4 and 5	131	242,835	1,854
4	C1 + A2a	4, 5 and 6	151	468,049	3,100
5	C1 + I	2, 4 and 5	177	693,536	3,918
6	C1 + I + A2a	2, 4, 5 and 6	197	918,750	4,664
7	C1 + G + A2a	2, 4, 5 and 6	216	1,179,915	5,463
8	C2 + I + A2a	2, 4, 5 and 6	217	1,295,560	5,970
9	C1 + G + I	2, 4 and 5	242	1,405,402	5,807
10	C1 + D	4 and 5	310	1,585,895	5,116
11	C1 + D + A2a	4, 5 and 6	330	1,811,109	5,488
12	C1 + D + I	2, 4 and 5	356	2,036,596	5,721
13	C1 + D + I + A2a	2, 4, 5 and 6	376	2,261,810	6,015
14	C1 + D + G + A2a	2, 4, 5 and 6	395	2,522,975	6,387
15	C2 + D + I + A2a	2, 4, 5 and 6	396	2,638,620	6,663
16	C1 + D + G + I	2, 4 and 5	421	2,748,462	6,528
17	C1 + D + G + I + A2a	2, 4, 5 and 6	441	2,973,676	6,743
18	C2 + D + G + I + A2a	2, 4, 5 and 6	461	3,350,486	7,268
19	C2 + D + G + I + A1a + A2a	2, 4, 5 and 6	469	3,780,891	8,062
20	C1 + D + E + G + I + A2a	2, 3, 4, 5, and 6	489	4,163,853	8,515
21	C1 + D + F + G + A2a	2, 4, 5 and 6	494	4,437,689	8,983

Count	Potential Mitigation Plans for the Floodplain Forest Community	Reaches Affected	Average Annual Habitat Units (AAHUs)	Costs ($1000)	Average Cost ($1000)
22	C2 + D + E + G + I + A2a	2, 3, 4, 5, and 6	509	4,540,663	8,921
23	C1 + D + F + G + I	2, 4, 5 and 6	520	4,663,176	8,968
24	C1 + D + F + G + I + A2a	2, 4, 5 and 6	540	4,888,390	9,053
25	C2 + D + F + G + I + A2a	2, 4, 5 and 6	560	5,265,200	9,402
26	C2 + D + F + G + I + A1a + A2a	2, 4, 5 and 6	568	5,695,605	10,027
27	C1 + D + E + F + G + I + A2a	2, 3, 4, 5, and 6	588	6,078,567	10,338
28	C2 + D + E + F + G + I + A2a	2, 3, 4, 5, and 6	608	6,455,377	10,617
29	C2 + D + E + F + G + I + A1a + A2a	2, 3, 4, 5, and 6	616	6,885,782	11,178

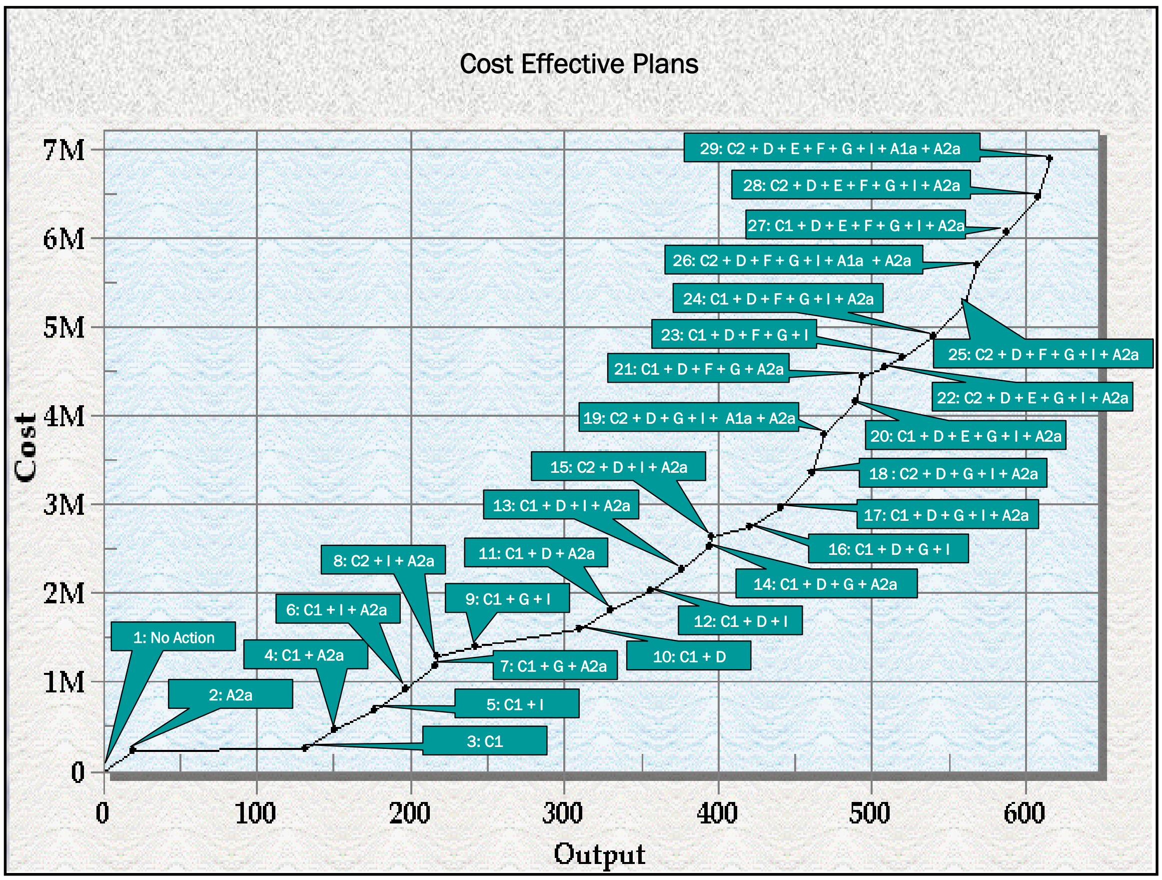

Figure 59. Cost-effective analysis results (graphical depiction) for the floodplain forest mitigation plans.

Incremental Cost Analysis

ICA compared the incremental costs for each additional unit of output. 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. Table 66 and Figure 60 below detail the results of the incremental cost analyses for the floodplain forest mitigation plans.

Nine combinations of designs were considered incrementally effective. These ranged from $242,835 and $6,885,782 and produced between 131 and 616 AAHUS of floodplain forest. The first plan, *ER-4-C1/ER-5-C1* generated enough outputs (131 AAHUs) to satisfy the mitigation requirements (-106 AAHUs), and was the most cost-effective, incrementally effective solution proposed.

Table 66. Incremental cost analysis results for the floodplain forest mitigation plans.

Count	Potential Mitigation Plans for the Floodplain Forest Community	Reaches Affected	Average Annual Habitat Units (AAHUs)	Costs ($1000)	Average Cost ($1000)	Incremental Cost ($1000)	Incremental Outputs (AAHUs)	Incremental Cost Per Output ($1000)
1	No Action	--	0	$0	$0	$0	0	$0
2	C1	4 and 5	131	$242,835	$1,854	$242,835	131	$1,854
3	C1 + D	4 and 5	310	$1,585,895	$5,116	$1,343,060	179	$7,503
4	C1 + D + I	2, 4 and 5	356	$2,036,596	$5,721	$450,701	46	$9,798
5	C1 + D + G + I	2, 4 and 5	421	$2,748,462	$6,528	$711,866	65	$10,952
6	C1 + D + G + I + A2a	2, 4, 5, and 6	441	$2,973,676	$6,743	$225,214	20	$11,261
7	C2 + D + G + I + A2a	2, 4, 5, and 6	461	$3,350,486	$7,268	$376,810	20	$18,841
8	C2 + D + F + G + I + A2a	2, 4, 5, and 6	560	$5,265,200	$9,402	$1,914,714	99	$19,341
9	C2 + D + E + F + G + I + A2a	2, 3, 4, 5, and 6	608	$6,455,377	$10,617	$1,190,177	48	$24,795
10	C2 + D + E + F + G + I + A1a + A2a	2, 3, 4, 5, and 6	616	$6,885,782	$11,178	$430,405	8	$53,801

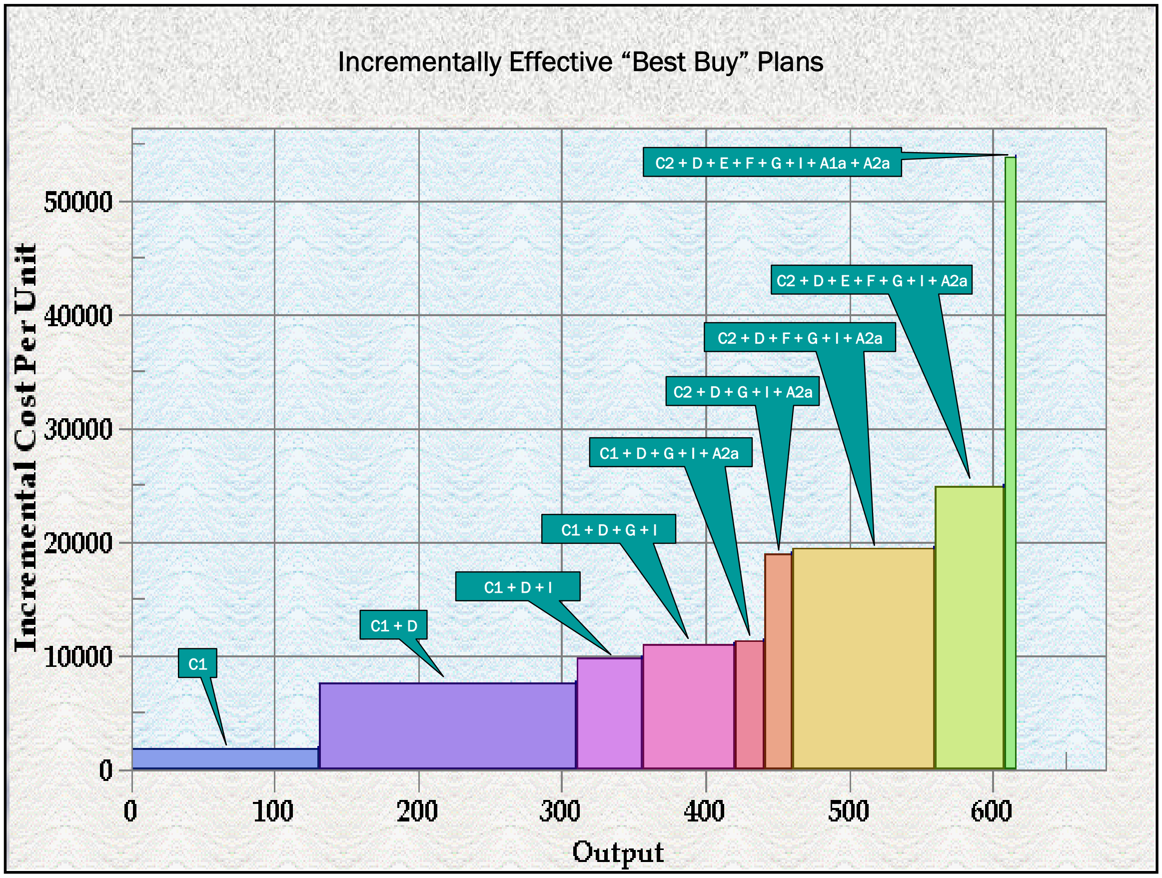

Figure 60. Incremental cost analysis results (graphical depiction) for the floodplain forest mitigation plans.

7 Summary and Conclusions

Although the District went to great lengths to avoid and minimize impacts under the proposed NED plan, impacts were still anticipated (106 AAHUs for the floodplain forest community). These impacts must be fully compensated for (in-kind), and as such, a suite of mitigation plans afforded full compensation in a cost effective and incrementally effective manner. By focusing on each cost analysis result in turn, the results indicate *ER-4/5-C1* compensates for the impacts in a cost effective, incrementally effective manner (Table 67). The total cost for the NED plan, with mitigation, would be $339,126,000 (i.e., the fully-funded cost), and would result in net overall benefits in excess of the impacts (+25 AAHUs of floodplain forest). The overall footprint of the project would encompass 729 acres. Although 278 acres of floodplain forest would be impacted, 155 acres would be preserved, restored and/or reestablished with the implementation of on-site avoidance, and minimization activities as well as the construction of the indicated offsite mitigation plan.

Given these results, the District can reasonably assume that the goals and objectives of the Clear Creek study have been met – the impacts of the proposed plan can be offset and the community structure and functions will remain intact for the Clear Creek ecosystems. This community-based approach allowed the E-Team to assess impacts and benefits in terms of key components (i.e., hydrology and soils, biotic integrity, and spatial complexity) with the intent of mimicking the dynamic processes seen in the natural ecosystems of the region, yielding more comprehensive and holistic results. The approach served to inject valuable on-the-ground knowledge of experts and stakeholders into the strategic planning of the study's alternative designs and served as a forum for the transparent assessment of impacts to the system's critical ecosystem functions and structure throughout the process.

Table 67. Summary of the measures incorporated into the final NED plan and the conversion of the forested community other landscape features to construct the plan (units = acres for all columns except the last column on the right).

Measures	Footprints (Acres)	FOREST (Floodplain Forest)			PRAIRIE	AGCROP	OPENWATER	PASTURES	URBAN	Net Annualized Outputs (AAHUs)
		Impacted	Preserved, Restored and Rehabilitated	reestablished Floodplain Forest (NEWFOREST)	Coastal Prairies	Farms and Croplands	Open Bodies of Water Deeper than 1-3m	Old Fields, Haylands and Pastures	Existing Residential, Industrial and Transportation	Floodplain Forest
Mainstem-Upstream Conveyance (*Super C*)	432	-186	88	33	-3	0	-1	-71	-15	-64
Mainstem-Downstream Conveyance [*C5(d)*]	109	-72	34	0	0	0	0	-2	-1	5
Turkey Creek Conveyance (*TKC1d*)	68	-20	0	0	0	0	-1	-43	-4	-47
Mary's Creek Conveyance (Ma*C2a*)	63	0	0	0	-5	0	0	-45	-13	0
Mud Gully Conveyance (*MudG1b*)	26	0	0	0	0	0	0	-5	-21	0
NED Plan Totals	1,010	-278	122	33	-8	0	-2	-166	-54	-106
ER-4-C1 and ER-5-C1	31	0	31	0	0	0	0	0	0	131
Mitigation Plan	31	0	31	0	0	0	0	0	0	131

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Appendix A: Notation

AAHU	Average Annual Habitat Unit
BCDD	Brazoria County Drainage District No. 4
BCR	Benefit-Cost Ratio
CEA	Cost Effectiveness Analysis
CT	Cover Type
EC	Engineering Circular
EIS	Environmental Impact Statement
ER	Eco-Reach
ERDC-EL	Engineer Research and Development Center, Environmental Laboratory
E-Team	Ecosystem Assessment Team
ETR	Expert Technical Review
ETRT	Expert Technical Review Team
EXHEP	EXpert Habitat Evaluation Procedures Module
EXHGM	EXpert Hydrogeomorphic Approach to Wetland Assessments Module
GBNEP	Galveston Bay National Estuary Program
GIS	Geographic Information System
GRP	General Reevaluation Plan
HCFCD	Harris County Flood Control District
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HSI	Habitat Suitability Index
HU	Habitat Unit
ICA	Incremental Cost Analysis
ITRT	Independent Technical Review Team
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
NED	National Economic Development Plan
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NRC	National Research Council
NRCS	Natural Resources Conservation Service
O&M	Operations and Maintenance
PDT	Project Delivery Team
PMIP	USACE Planning Models Improvement Program
RA	Relative Area
ROW	Right-of-Way
SI	Suitability Index
TCEQ	Texas Commission on Environmental Quality
TGLO	Texas General Land Office
TPWD	Texas Parks and Wildlife Department
TY	Target Year
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WOP	Without-project Condition
WP	With-project Condition

Appendix B: Glossary of Terms

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 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, 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 (i.e., 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 2003).

Cover Type (CT)

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

Ecosystem

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

Ecosystem Assessment Team (E-Team)

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

Ecosystem Integrity

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

Equivalent Optimal Area (EOA)

The concept of equivalent optimal area (EOA) is used in HEP applications where the composition of the landscape, in relation to providing life requisite habitat, is an important consideration. An EOA is used to weight the value of the LRSI score to compensate for this inter-relationship. For example, for optimal wood duck habitat conditions, at least 20 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.

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) (i.e., Life Requisite Model)

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

Multi-Criteria Decision Analysis (MCDA)

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

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

National Economic Development (NED) Plan

For all project purposes except ecosystem restoration, the alternative plan that reasonably maximizes net 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 (i.e., 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 (i.e., 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 analyses 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:

Relative Area = Acres of Cover Type
Total Applicable Area

where:

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

Risk

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

Sampling Method

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

Between March and April, run five random 50-m transects through the relevant cover types. Every 10-m along the transect, place a 10-m^2 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).

Sensitivity Analysis

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

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

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

Spreadsheet

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

Suitability Index (SI)

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

Target Year (TY)

A unit of time measurement used in HEP that allows the project manager to anticipate and direct significant changes (in area or quality) within the project (or site). As a rule, the baseline TY is always TY = 0, where the baseline year is defined as a point in time before proposed changes would be implemented. As a second rule, there must always be a TY = 1, and a TY = X_2. TY_1 is the first year 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 (or behaves) as it was intended.

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

Without-project Condition(WOP) (i.e., No Action Plan or No Action Alternative)

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

With-project Condition (WP)

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

Appendix C: Index Model Components and Variables

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

Table C1. Variables used in the Clear Creek community index models.

Variable Code	Variable Description
ADJLANDUSE	Identification of the Predominant Adjacent Lands Use Class
ALTERHYDRO	Alterations of Hydrology That Effect Hydroperiod
AREAWETDRY	Ratio of Wet to Total Prairie or Forest Acreage
CANTREE	Percent Tree Canopy Cover
CORE	Size of the Core Area (acres)
EDGE	Size of the Edge Area (acres)
EROSION	Erosion Potential
IMPERVIOUS	Percent of the Area That Is Developed
INSTRMCOV	The Amount of the Stream Characterized By In-Stream Cover (%)
NATIVE	Percent Tree Canopy That Is Native Species
NEIGHBOR	Distance to the Nearest Neighbor of Like Patches (m)
OVRHDCOV	Percent of the Water Surface Shaded By Overhanging Vegetation
PATCHSIZE	Patch Size (acres)
ROUGHNESS	Manning's Roughness
SINUOSITY	Ratio of the Stream Distance Between Two Points On Channel and Straight-Line Distance Between Points
SUBSTRATE	Substrate Composition
VEGSTRATA	Vegetation Strata
WATERDEPTH	Average Water Depth (cm)

Appendix D: Model Review Comments and Actions Taken to Address Issues

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 assure fair and impartial review of the products, members of the Laboratory-based Technical Review Team (LTRT) were chosen on the basis of expertise, seniority in the laboratory chain of command, and USACE planning experience.

The following were members of the LTRT:

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

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

1. Whether the concepts, assumptions, features, methods, analyses, and details were appropriate and fully coordinated;

[1] Resumes for Dr. Casper and Ms. Brandreth (i.e., the technical peer reviewers) 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; and
5. Whether the products met the customer's needs and expectations.

LTRT Review Comments and Responses

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

LTRT Technical Reviewer Curriculum Vitae

US Army Corps of Engineers

ERDC

U.S.ARMY

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

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

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

Beth Brandreth

Photo

Ecosystem Biologist, Regional Technical Specialist—Philadelphia District
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Professional Experience

Ecosystem Biologist, Regional Technical Specialist, Environmental Resource Branch, Planning Division, US Army Corps of Engineers, Philadelphia, PA., 1991 to present.

- Perform a variety of environmental evaluations including Environmental Assessments (EA), Environmental Impact Statements (EIS), and technical reports on District activities
- Conduct surveys and investigations to determine potential impacts (of proposed activities) on water quality, wetlands, and fish and wildlife resources
- Make recommendations to minimize and/or mitigate adverse impacts, as well as to enhance subject resources
- Coordinate environmental aspects of District activities with State, interstate, and Federal agencies
- Conduct Habitat Evaluation Procedure (HEP) analyses and incremental cost analyses for Federal environmental restoration projects
- Identify the need for and acquire permits and Water Quality Certificates for Federal projects
- Act as primary Point of Contact for endangered species coordination in the District
- Prepare Biological Assessments for endangered species as necessary
- Act as mentor to other District employees with regard to cost effectiveness and incremental cost analyses (CE/ICA)
- Aid in teaching modules for the CORE Environmental Considerations in Planning course

Education

- B.S. Marine Biology, 1990, Fairleigh Dickinson University
- A.S. Biology, 1988, Luzerne County Community College

Presentations/Teaching

- Planning Associates Coastal Course, 2003, 2005, 2006, 2008 and 2009.
- Environmental Chiefs' Meeting, 2000, 2003, 2006 and 2009.
- Economic and Environmental Analysis Conference, 2002, 2004, 2006 and 2008.
- Baltimore District CE/ICA Workshop, 2001.
- Environmental Considerations in Planning Training Course, 2001 – Present

Recent Publications

IWR Report 02-R-5 "Lessons Learned from Cost Effectiveness and Incremental Cost Analyses (CE/ICA)", 2002.

USACE Feasibility Report/EIS, 2002. "Manasquan Inlet to Barnegat Inlet Feasibility Study".

USACE Section 7 Biological Assessment for Potential Impacts to the Piping Plover and Seabeach Amaranth Resulting from Beach Nourishment Projects Along the New Jersey Coast, 2001.

Other Professional Activities

- Dredging and dredged material disposal
- Beach restoration
- Environmental restoration
- Planning and construction of water resources projects such as flood control, and shoreline and stream erosion control
- Regulatory functions

March 2010

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
July 2013	Final report	

4. TITLE AND SUBTITLE Clear Creek Watershed Flood Risk Management Habitat Assessments Using Habitat Evaluation Procedures (HEP)	**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
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center Environmental Laboratory 3909 Halls Ferry Road, Vicksburg, MS 39180-6199	**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/EL TR-13-15
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Headquarters, U.S. Army Corps of Engineers Washington, DC 20314-1000	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The cumulative effects of urban development along the Clear Creek (southern Texas) over the last 100 years has led to substantial increases in flooding. The flooding can be directly attributed to both the narrowing of the floodplain and the construction of buildings and infrastructure in the region's flood-prone areas. In 1999, the USACE Galveston District initiated a feasibility study to revise past efforts and formulate new solutions to address the Clear Creek problems and contacted the U.S. Army Engineer Research and Development Center's Environmental Laboratory (ERDC-EL) in 2003 for assistance. The District is preparing an Environmental Impact Statement (EIS), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the impacts of proposed flood risk management measures in the watershed. 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 studies; (4) evaluate potential impacts; and (5) recommend and evaluate potential mitigation measures. Between 2003 and 2008, this team designed, calibrated, and applied a landscape-level community-based index model for the system's floodplain forests using standard Habitat Evaluation Procedures (HEP). One hundred and one floodplain forest Average Annual Habitat Units (AAHUs) were lost due to the proposed flood risk management measures. Twelve individual mitigation plans were evaluated to offset the impacts detailed in the NED plan. The outputs for the various mitigation scenarios ranged from 9-180 AAHUs for the forests' communities. The results of both the impact and mitigation assessments are provided herein. The intent of this document is to provide details of the HEP application (for both the impact and the mitigation assessments) for the Clear Creek project. Readers interested in the scientific basis upon which the models were developed should refer to the authors' second report entitled, *Floodplain Forest Community Index Model for the Clear Creek Watershed, Texas* (Burks-Copes and Webb in preparation).

15. SUBJECT TERMS
Clear Creek Watershed
Flood Risk Management
Habitat Evaluation Procedures

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		176	