ERDC/EL TR-13-18

US Army Corps
of Engineers®
Engineer Research and
Development Center

ERDC
INNOVATIVE SOLUTIONS
for a safer, better world

Ecosystem Management and Restoration Research Program

A Multi-Scale Approach to Assess and Restore Ecosystems in a Watershed Context

Ronald D. Smith and Charles V. Klimas

September 2013



Approved for public release; distribution is unlimited.

Environmental Laboratory

The US Army Engineer Research and Development Center (ERDC) solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at www.erdc.usace.army.mil.

To search for other technical reports published by ERDC, visit the ERDC online library at http://acwc.sdp.sirsi.net/client/default.

Ecosystem Management and Restoration
Research Program

ERDC/EL TR-13-18
September 2013

A Multi-Scale Approach to Assess and Restore Ecosystems in a Watershed Context

Ronald D. Smith and Charles V. Klimas

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

Final report

Approved for public release; distribution is unlimited.

Abstract

This report describes a multi-scale watershed assessment procedure that can be used to evaluate existing ecological conditions as well as proposed changes. The approach employs indicators of ecosystem integrity that are assessed at the stream reach scale using existing spatial data as well as field observations. Ecological integrity scores can be calculated using those indicators at multiple scales, ranging from the reach to the entire watershed. Reach-level integrity scores are dependant in part on upstream and downstream conditions; therefore, the method accounts for offsite effects of proposed impacts or restoration actions by recognizing degradation or improvement to areas not directly within the project footprint. Case studies are presented illustrating typical applications of the approach, including baseline and alternative impact assessments, as well as restoration scenarios.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Contents

Abstract ii

Figures and Tables iv

Preface vii

Unit Conversion Factors viii

1 Introduction 1

2 Baseline Assessment 4

Watershed assessment areas 4
Drainage basins and local drainage basins 7
Ranking criteria 8
Indicators 10
Reference condition 12
Indicator aggregation 13
Index models 14
Knowledge bases 18

3 Data Collection, Analysis, and Display 24

Field data collection 24
GIS spatial analysis 29
Calculating and displaying results 31

4 Applications 38

Baseline assessment 38
Impact alternatives analysis 38
Restoration alternatives analysis 39

References 41

Appendix A: Baseline Assessment Case Study 54

Appendix B: Alternatives Analysis Case Study 106

Appendix C: Restoration Scenario Assessment Case Study 114

Report Documentation Page

Figures and Tables

Figures

Figure 1. Ordination of assessment methods based on spatial scale and model accuracy/precision. 2
Figure 2. Name, location, and size of project watersheds in California. 3
Figure 3. Watershed Assessment Areas, local drainages, drainage basins, and stream, riparian, and upland components of the WAA. 5
Figure 4. Illustration of WAA upstream and downstream boundaries (dotted lines) drawn at changes in land use. 6
Figure 5. Knowledge base schematic for the Steelhead Habitat Condition ranking criterion. 19
Figure 6. Relationship between the Percent Canopy Cover indicator and truth-value. 20
Figure 7. Relationship between Tree Basal Area indicator and truth-value. 21
Figure 8. Relationship between indicator and truth-values for the Native Vegetation Community indicator. 22
Figure 9. Normalized cumulative distribution function with linear approximation of 10th and 90th percentiles. 23
Figure 10. Example riparian reach field data sheet 27
Figure 11. Summary of normalized indices of habitat integrity. 33
Figure 12. Indicator scores for Sycamore Canyon riparian reaches. 34
Figure 13. Otay River watershed showing WAA local drainage boundaries, main stem channels, and tributaries. 36
Figure 14. Habitat integrity indices for riparian reaches extrapolated WAAs for display purposes. 37
Figure A1. South Sacramento Habitat Conservation Plan project area. 55
Figure A2. Generalized cross section of a riparian ecotone. 57
Figure A3. Schematic of riparian reach features. 85
Figure A4a. Riparian reaches in the project take area. 89
Figure A5. Riparian reach main stem streams by category. 92
Figure A6. Geologic formations in the project take area. 94
Figure A7. Soil map units in the project take area (continued). 95
Figure A8. Riparian reach geomorphic zones. 97
Figure A9. Range of normalized Hydrologic Integrity Indices for riparian reaches. 99
Figure A10. Range of normalized Water Quality Integrity Indices for riparian reaches. 99
Figure A11. Range of normalized Habitat Integrity Indices for riparian reaches. 100
Figure A12. Hydrologic Integrity Indices for riparian reaches in the project take area. 101
Figure A13. Water Quality Integrity Indices for riparian reaches in the project take area. 104
Figure A14. Habitat Integrity Indices for riparian reaches in the project take area. 105
Figure B1. Study area showing major alternative corridor alignments. 107

Figure B2. Ranking Criterion 1: Directly impacted stream channels by Strahler order for alternative corridor alignments. 109
Figure B3. Ranking Criterion 2: Acres of riparian ecosystem directly impacted by alternative corridor alignments. 110
Figure B4. Ranking Criterion 3a: Total loss of hydrologic integrity units for all WAAs under each alternative corridor alignment. 111
Figure B5. Ranking Criterion 3a: Total loss of water quality integrity units for all WAAs under each alternative corridor alignment. 112
Figure B6. Ranking Criterion 3c: Total loss of habitat integrity units for all WAAs under each alternative corridor alignment. 113
Figure C1. Study area boundaries in the Otay River watershed. 118
Figure C2. Relationships of riparian reaches, local drainage areas, and drainage basins. 121
Figure C3. Riparian ecosystem geomorphic surfaces. 122
Figure C4. Generalized representation of landscape settings associated with geomorphic zones. 124
Figure C5. General form of Geomorphic Zone 1 and view of typical reach. 124
Figure C6. General form of Geomorphic Zone 2 and view of typical reach. 125
Figure C7. General form of Geomorphic Zone 3 and view of typical reach. 126
Figure C8. General form of Geomorphic Zone 4 and view of typical reach. 127
Figure C9. General form of Geomorphic Zone 5 and view of typical reach. 128
Figure 10. General form of Geomorphic Zone 6 and view of typical reach. 128
Figure C11. General form of Geomorphic Zone 7 and view of typical reach. 129
Figure C12. General form of Geomorphic Zone 8 and view of typical reach. 130
Figure C13. Typical pre- and post-restoration conditions of the Natural Template. 133
Figure C14. Typical pre- and post-restoration conditions of the Incised Template. 133
Figure C15. Typical pre- and post-restoration conditions of the Constrained Template. 134
Figure C16. Typical pre- and post-restoration conditions of the Aggraded Template. 135
Figure C17. Typical pre- and post-restoration conditions of riparian reaches assigned to the Engineered Template. 136
Figure C18. Geomorphic Zone assignments for riparian reaches. 142
Figure C19. Restoration Template assignments for riparian reaches. 142
Figure C20. Level-of-Effort assignments for riparian reaches. 142
Figure C21. Normalized baseline hydrology integrity indices for riparian reaches. 142
Figure C22. Normalized baseline water quality integrity indices for riparian reaches. 142
Figure C23. Normalized baseline habitat integrity indices for riparian reaches. 142
Figure C24. Increase in normalized hydrologic integrity index under Restoration Scenario 1. 142
Figure C25. Increase in normalized water quality integrity index under Restoration Scenario 1. 142
Figure C26. Increase in normalized habitat integrity index under Restoration Scenario 1. 142
Figure C27. Increase in normalized hydrology integrity index under Restoration Scenario 2. 142
Figure C28. Increase in normalized water quality integrity index under Restoration Scenario 2. 142
Figure C29. Increase in normalized habitat integrity index under Restoration Scenario 2. 142

Figure C30. Increase in normalized hydrologic integrity index under Restoration Scenario 3. 142
Figure C31. Increase in normalized water quality integrity index under Restoration Scenario 3 simulation. 142
Figure C32. Increase in normalized habitat integrity index under Restoration Scenario 3 simulation. 142

Tables

Table 1. Metric value ranges for scaling improved hydraulic conveyance to reference. 17
Table 2. Aggregation of indicator truth-values to determine ranking criterion truth-value. 21
Table 3. Data for characterizing riparian reaches and indicators. 25
Table 4. Range of indicator values for scaling the riparian corridor continuity indicators. 31
Table 5. Descriptive statistics for Otay River watershed metric values and indicator scores. 32
Table A1. Indicators used to assess riparian hydrologic, water quality, and habitat integrity. 60
Table A2. Land Use / Land Cover (LULC) types and their effect on loadings, impervious surfaces, and wildlife habitat suitability. 65
Table A3. Characteristics of riparian ecotones and associated main stem streams. 71
Table A4. Conditions for assigning the Sediment Regime indicator metric value. 75
Table A5. Meters of main stem stream, by category. 93
Table A6. Descriptive statistics for indicator metric values. 98
Table C1. Range and average dimensions of alluvial features by geomorphic zone. 138
Table C2. New scores assigned to riparian reach scale indicators based on Restoration Template 141

Preface

The watershed assessment approach presented here was largely developed by R. Daniel Smith of the Engineer Research and Development Center (ERDC), Corps of Engineers (CE) in the late 1990s to address natural resource management needs on Mirimar Air Station and Camp Pendleton Marine Corps Base in southern California. Dr. Charles Klimas (ERDC) joined Smith to help refine the process and conduct assessments in six additional California watersheds during the period from 2000- 2006. During that time they also developed a watershed restoration planning approach that is designed to interface with the assessment process. Subsequently Smith modified the assessment process by integrating knowledge bases and decision support systems for application in two additional watersheds in central and northern California.

The majority of the field effort was conducted by the two authors, but other persons assisted in some watersheds. In particular, Karen Adams (currently with the Washington State Department of Ecology) was largely responsible for data collection and data processing for the San Jacinto watershed study. Elizabeth Murray (ERDC) developed the block diagrams and most of the channel cross-section figures that appear in the document.

Various organizations provided support for the development of this assessment approach. However, the majority of the work and the case studies and examples presented herein were largely funded by the Los Angeles District (SPL), Corps of Engineers, as part of a Special Area Management Plan (SAMP) process encompassing much of coastal southern California. Fari Tabatabai (currently with San Francisco District, CE) and Jae Chung (currently with the Institute for Water Resources, CE) were the principal SPL project managers who initiated and monitored the individual watershed studies within the District. This synthesis report, which is designed to demonstrate how the process can be developed and applied in other watersheds and regions, was produced under the Ecosystem Management and Restoration Research Program (EMRRP) administered through ERDC. Glenn Rhett is the EMRRP Program Manager.

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

Unit Conversion Factors

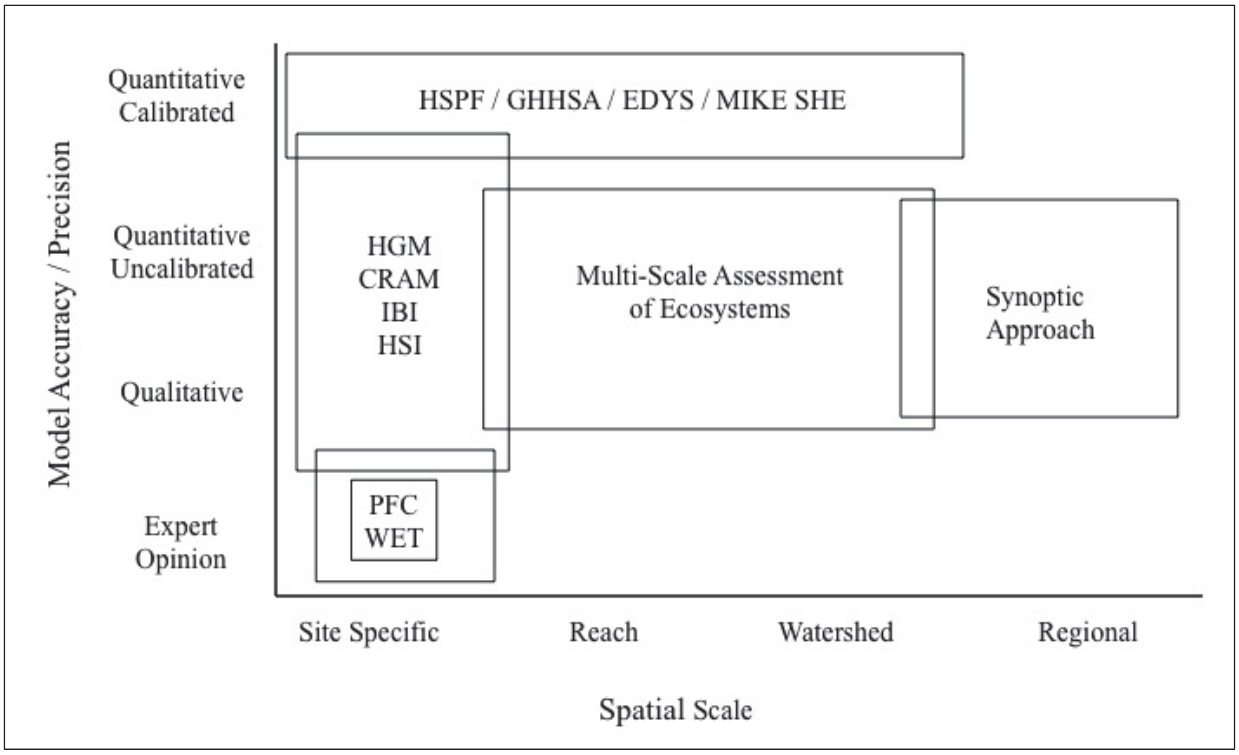
Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
square miles	2.589998 E+06	square meters

1 Introduction

Planners and regulators have long sought to develop practical and technically defensible methods for assessing project impacts and environmental benefits. Some success has been achieved at the site-specific scale with methods such as the Habitat Evaluation Procedures (HEP) (US Fish and Wildlife Service (USFWS) 1980), Proper Functioning Condition (PFC) (Prichard 1993), Indices of Biological Integrity (IBI) (US Environmental Protection Agency (USEPA) 2002), Rapid Assessment Method (RAM) (Anonymous 2004, California Wetlands Monitoring Workgroup 2009), and the Hydrogeomorphic (HGM) Approach (Smith et al. 1995). However, no practical methods have emerged that effectively incorporate the influence of the larger landscape or watershed context in the assessment of ecosystem condition, impacts, or restoration (Figure 1). The Synoptic Approach (Abbruzzese and Leibowitz 1997) incorporates a landscape context and has proven to be practical at regional scales, but does not provide the higher level of resolution required at smaller spatial scales. Hydrologic and watershed modeling systems such as the Hydrologic Simulation Program-Fortran (HSPF) (Bicknell et al. 1996, Skahill 2004); Gridded Surface Subsurface Hydrologic Analysis (GHHSA) (Downer et al. 2005, Fong et al. 2006), and Integrated Catchment Modeling (MIKE SHE) (Zhang and Johnson 2003) incorporate a watershed context, but in the authors' experience, these approaches are impractical in a planning or regulatory context where project areas are large, timeframes are short, and existing data and funding are sparse.

ERDC researchers have devised a multiple spatial scale approach that explicitly incorporates the watershed and/or landscape context into the assessment of baseline conditions, and allows consideration of various impact and restoration scenarios using the same assessment criteria (Figure 1). The "watershed context" of this approach naturally implies that the entire drainage basin is considered and assessed. However, it also reflects the fact that, by assessing ecosystem characteristics across multiple spatial scales, the interconnectedness of the entire system is accounted for. Degraded conditions or proposed impacts or restoration actions in one part of the watershed can be evaluated in terms of both their direct on-site effects, and at the same time, their effects on other parts of the system. This allows recognition of landscape-scale responses to site-specific actions, and accounts for the cascading effects of actions that interrupt key ecosystem processes.

Figure 1. Ordination of assessment methods based on spatial scale and model accuracy/precision.



This approach was developed and refined over the course of the past decade in a variety of California watersheds ranging in size from 200 to 3600 km^2 (Figure 2). The initial baseline assessment involves three steps. First, the watershed is divided into relatively homogenous assessment units. Second, geospatial information and field data are collected to characterize each of the assessment units in terms of selected biotic and abiotic indicators. Third, models are developed specifically for the project or are adapted from existing methods (e.g., HEP, IBI, HGM, etc.), to aggregate information and compare the condition of ecosystems in the assessment units of the watershed relative to a specified reference condition. Results from the baseline assessment are linked to a Geographic Information System (GIS) for display, interpretation, analysis of model sensitivity and the influence of missing data, comparison across assessment units, and, finally, deployment in a variety of subsequent uses. These uses include: 1) identification of priority areas based on project-specific criteria, 2) simulation of historical conditions, 3) determination of cumulative impacts, 4) analysis of the impacts or benefits of project alternatives, 5) development of watershed-scale restoration plans, 6) development of regional regulatory permit strategies, and 7) comparison of the costs and benefits of alternative restoration scenarios, and other applications.

Figure 2. Name, location, and size (square kilometers) of project watersheds in California.



This document describes and provides guidance on this multiple-scale approach, with a focus on: 1) the baseline assessment, 2) adopting existing or developing new aggregation models, 3) collecting and analyzing data and displaying results, 4) and finally, utilizing the results from a baseline assessment in a variety of subsequent applications. Case studies are used to illustrate development of a baseline assessment, analysis of alternative impacts, and development of an ecosystem restoration model that can be used in concert with the watershed assessment to identify the most effective and efficient options for watershed-scale restoration and mitigation plans.

2 Baseline Assessment

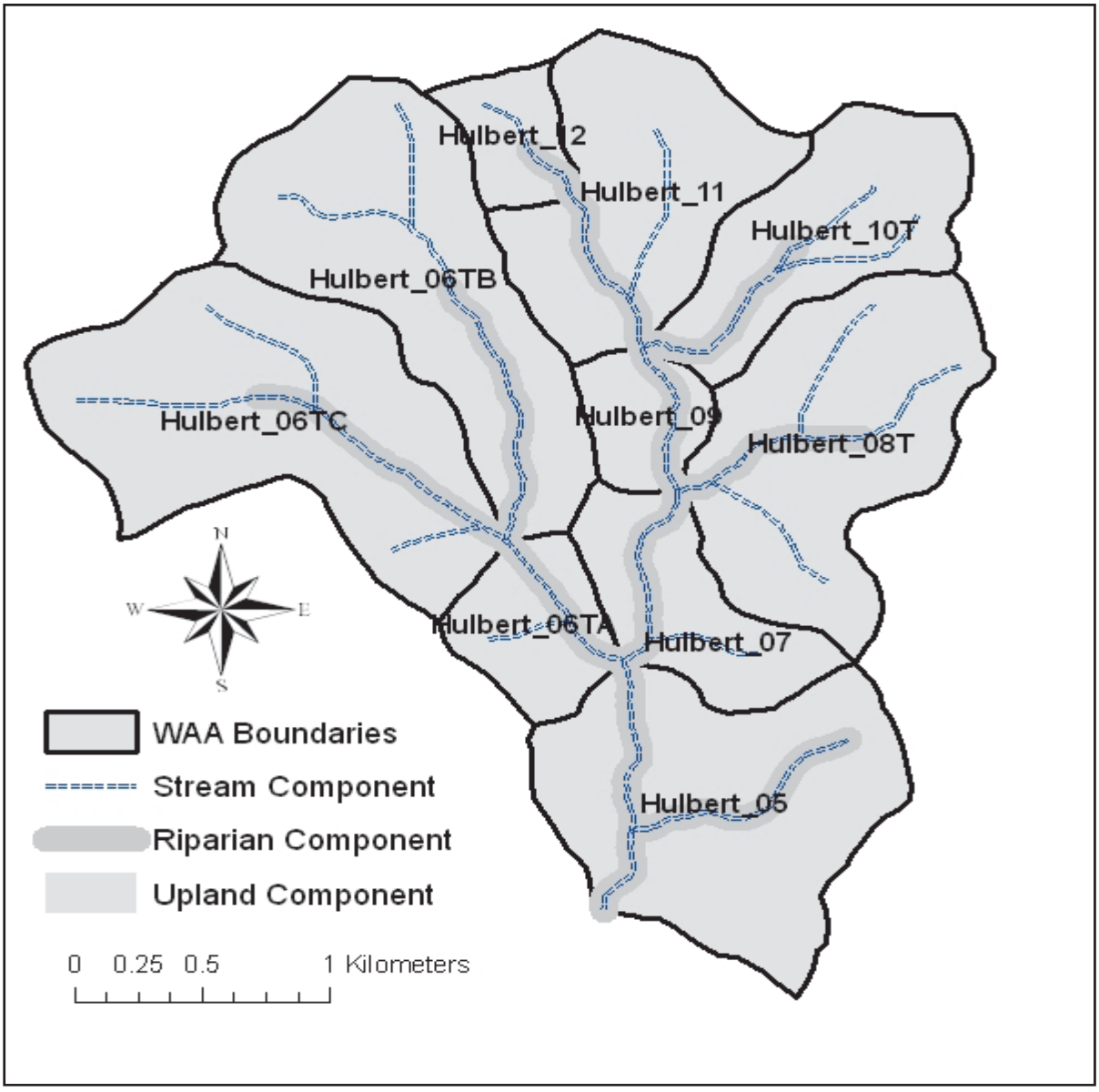
Watershed assessment areas

A fundamental consideration when working in watersheds or other large project areas is the spatial scale at which information is collected and synthesized. In order to assess and compare different areas within a watershed, a procedure is employed that divides the watershed into relatively homogenous assessment units at a spatial scale appropriate for summarizing information. These units are referred to as “watershed assessment areas” (WAAs). A variety of factors including geology, geomorphology, land use, vegetation, and stream characteristics are considered when establishing the WAAs. The objective is to identify areas that exhibit a low level of heterogeneity and to avoid the loss of important information. For example, consider a WAA that is a combination of mature forest and agricultural land. The results of the assessment will be an average of the two areas, and mask the fact that within the WAA there is a mature forest that may be a candidate for conservation, and an agricultural portion that may be a candidate for restoration. While it is not possible to completely eliminate heterogeneity and the "averaging effect” that results, heterogeneity can be minimized through the use of an appropriate spatial scale, and the judicious location of WAA boundaries (Jarvinen 1985) based on geology, geomorphology, land use, vegetation, and stream characteristics.

Watershed assessment areas are identified using several criteria in a procedure described by Smith and Tabatabai (2004). The first criterion is a second-order stream channel (Strahler 1957) "rule of thumb.” Using United States Geological Survey (USGS) 7.5-minute quadrangles as a stream base map, the rule-of-thumb is applied as follows. Move downstream from the origin of an intermittent or perennial headwater stream channel until it becomes a second-order stream. Continue downstream to the point where the second-order stream being followed is joined by a different second-order stream. This confluence serves as the downstream boundary of the WAA for the stream followed down from the headwater, and the upstream boundary for the next WAA. Continue moving downstream and establish additional WAA downstream boundaries at the confluence with other second-order or larger streams. Figure 3 illustrates this process for the drainage area associated with a stream named Hulbert Creek. Locate the

two second-order streams in the WAA polygons labeled Hulbert_06TC and Hulbert_06TB. The point where these two streams join defines the downstream boundary for the Hulbert_06TC and Hulbert_06TB WAAs. Further downstream, at the point where Hulbert_06TA joins Hulbert_07, a downstream boundary is established for the Hulbert _06TA and Hulbert_07 WAAs.

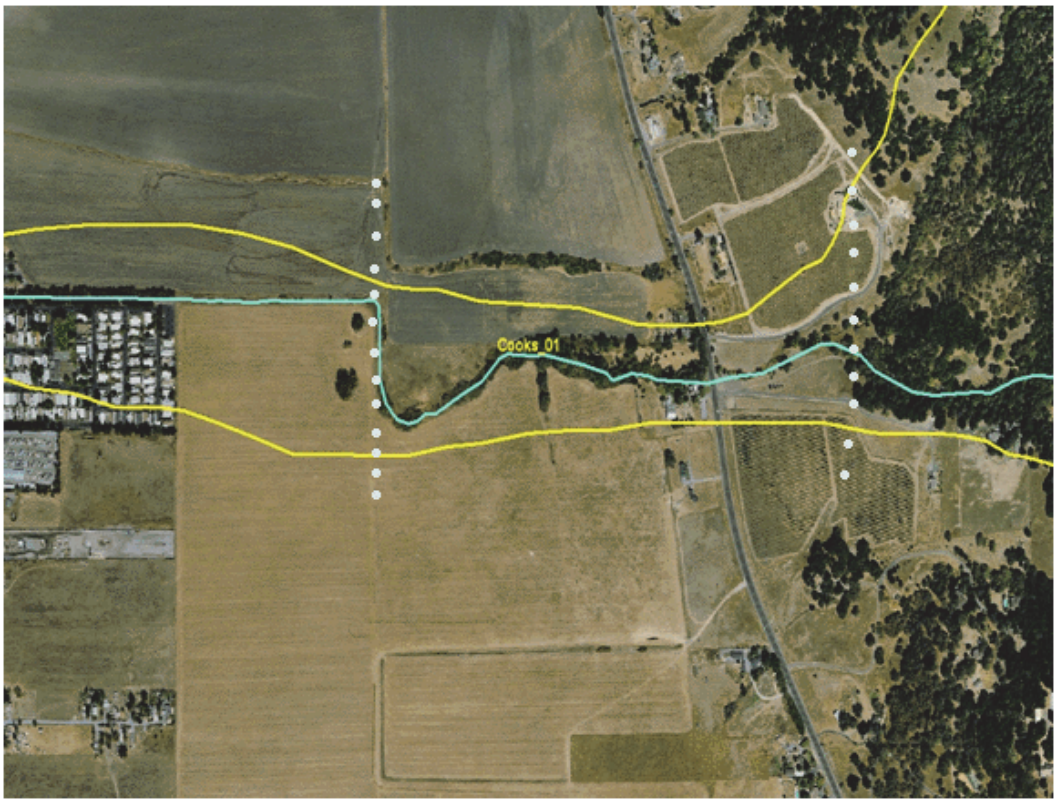
Figure 3. Watershed Assessment Areas, local drainages, drainage basins, and stream, riparian, and upland components of the WAA.



The second criterion that is used in establishing the downstream boundary of a WAA relates to the objective of identifying WAAs that are relatively homogenous. Initially, this criterion requires the use of high-resolution

aerial imagery followed by field reconnaissance as verification. The objective is to establish a downstream boundary for the WAA where a distinct geologic, geomorphic, vegetation, or land-use change occurs. For example, in Figure 4, dotted lines identify the boundaries between three WAAs. The first WAA occurs on the left, downstream side of the aerial image where a straightened stream channel runs through a residential development. The second WAA occurs in the middle of the image in an agricultural area where most of the riparian vegetation has been removed. The third occurs on the right side of the image where riparian vegetation is present on the natural stream channel running through wooded foothills.

Figure 4. WAA upstream and downstream boundaries (dotted lines) drawn at changes in land use.



Following application of the second-order rule-of-thumb and the geologic, geomorphic, vegetation, or land-use/land cover criteria, it may be feasible to establish smaller, more homogenous WAAs based on other readily available information. For example, in establishing WAA boundaries in the Russian River watershed in California (Smith 2008), some WAAs were further divided based on stream reaches designated by the California Department of Fish and Game (CDFG) to reflect the data-collection considerations of their stream survey program (CDFG 2002). The CDFG stream survey

reaches represented the highest resolution data (i.e., largest spatial scale) currently available for streams in the Russian River watershed, and since different factors used during assessment require different levels of data resolution, it was decided that WAAs should be delineated at a spatial scale corresponding to the highest resolution data available. This was done because it is relatively easy to aggregate data to a lower level of resolution, but relatively difficult to disaggregate data to a higher level of resolution at a later time if deemed necessary.

Finally, field reconnaissance was recommended to verify the WAA boundaries prior to the initiation of data collection. This is necessary because aerial imagery is not always up to date, and it can initially be difficult to distinguish features such as plant community types or geologic and geomorphic changes on aerial imagery. Field reconnaissance will help to calibrate users' eyes to the signature of different features on aerial imagery.

Drainage basins and local drainage basins

To facilitate assessment at multiple spatial scales, information is collected for each WAA in at least four different areas that represent distinct and increasing spatial scales. These include the "tributary riparian reach," "main stem riparian reach," "local drainage," and "drainage basin." The main stem riparian reach includes the main stem stream channel that enters the WAA from one or more upstream WAAs and exits the WAA to a downstream WAA. The main stem riparian reach is a polygon that includes the main stem stream channel and any riparian areas associated with the main stem stream channel. For example, in Figure 3, in the Hulbert_07 WAA, the main stem riparian reach begins downstream from the confluence of the main stem stream channels in the Hulbert_08T WAA and Hulbert_09 WAAs, and stops at the confluence with the main stem stream channel in the Hulbert_06T WAA.

A tributary riparian reach contains a lateral stream channel that drains directly to the main stem riparian reach. A tributary riparian reach polygon includes the tributary stream channel and any riparian areas associated with the tributary stream channel. For example, in Figure 3, in the Hulbert_05 WAA, a tributary riparian reach enters from the right-hand side just below the middle of the main stem riparian reach.

The local drainage basin includes the portion of the watershed that drains directly to the main stem riparian reach of a WAA, or indirectly to the main stem riparian reach of a WAA via a tributary riparian reach wholly within the boundaries of the WAA. For example, in Figure 3, the local drainage basin of Hulbert_05 includes the portion of the watershed below the downstream boundaries of the Hulbert_06TA and Hulbert_07 WAA polygons including the area drained by the single tributary entering from the east near the midpoint of the main stem stream in Hulbert_05. Similarly, in Figure 3, the local drainage basin for Hulbert_08T WAA includes the portion of the watershed above the downstream boundary of the Hulbert_08T WAA polygon including the area drained by the two tributaries entering the main stem stream in Hulbert_08T.

The drainage basin is consistent with the common use of the terms drainage basin or catchment and includes the portion of a watershed that drains to the downstream boundary of a WAA. For example, in Figure 3, the drainage basin for Hulbert_05 includes all portions of the watershed that drain to the downstream boundary of the Hulbert_05 WAA (i.e., in this case, the entire watershed shown in Figure 3). Similarly, in Figure 3, the drainage basin for Hulbert_09 includes the portion of the watershed encompassed by the Hulbert_09, Hulbert_10, Hulbert_11, and Hulbert_12 WAAs.

Once the upstream and downstream boundaries for each WAA are established, polygons representing the WAA drainage basin, local drainage, main stem riparian reach, and lines representing the main stem stream and tributaries are digitized using USGS 7.5-minute quadrangles as a base map (Figure 3).

Ranking criteria

Another factor that must be considered when incorporating the watershed context into an assessment is how to effectively summarize information representing multiple spatial scales. This is accomplished using one or more assessment or “ranking criteria” that summarize information collected at different spatial scales, and which serve as a basis for comparing ecosystems across different WAAs. The ranking criteria in this case fall into four general categories including ecosystem condition, vulnerability to future impacts, conservation potential, and restoration potential.

The condition category includes ranking criteria that consider whether the current structural characteristics and physical, chemical, and biological processes in a WAA, or the drainage basin of a WAA, are within the range of natural variability. In some cases, the criteria may reflect more subjective measures of condition identified by regulation or published guidelines.

There are numerous potential considerations concerning vulnerability. If the riparian ecosystems along the stream in one WAA are intact and support native vegetation, that WAA will receive a higher ranking for condition than another WAA where riparian ecosystems have been removed or invaded by exotic plant species. If a WAA has areas where future urban growth is projected to occur, the WAA is vulnerable to the myriad of potential impacts associated with development activities. A WAA that includes areas with a high potential for slope instability is more vulnerable to road building and other activities with the potential to increase erosion and sedimentation. Furthermore, a WAA that supports anadromous fish would be considered vulnerable to activities such as in-channel mining, changes in flow, or the removal of riparian vegetation.

The conservation potential category includes ranking criteria that consider whether existing conditions in the WAA make it a potential priority candidate for conservation. For example, an upland, riparian, or stream component of a WAA might be identified as suitable for conservation based on its condition, the size of its habitat patches, the number of endangered or threatened species present, or the fact that it is publicly owned.

Finally, the restoration potential category includes ranking criteria that consider whether current conditions in a WAA make it possible to enhance current conditions through restoration activities. Potential project objectives could be to identify areas where it would be possible to restore the greatest number of acres to a self-sustaining, natural condition for the least cost and effort. For example, lower cost and effort are associated with restoring an area of degraded native vegetation requiring small-scale or spot planting and exotic plant control, than the cost and effort required to restore agricultural areas requiring minor earth work and large-scale planting, or developed areas requiring infrastructure removal, major earth work, topsoil and seed bank replacement, and large-scale planting. All of these considerations can be incorporated into the assessment process.

Indicators

In order to assess and compare WAAs in terms of the selected ranking criteria, it is necessary to identify the characteristics and processes that influence the ranking criteria, collect information about those characteristics and processes, and then synthesize the information so that it can be used to make decisions concerning impacts, mitigation, restoration, and conservation. To assess riparian condition, a variety of characteristics and processes such as vegetation, hydrologic regimes, water quality, and connection to adjacent landscapes could be considered. The characteristics and processes that are used to assess ranking criteria are referred to as "indicators."

Indicators are measures that can be used to quickly and easily assess current status or condition. Indicators can also be used, over time, to track changes or trends in something of interest (National Academy of Sciences 2000). Indicators are typically employed in situations where it is unnecessary, inefficient, or impractical to deploy precise, quantitative metrics, mechanistic models, or statistical analysis for those purposes. Ecological indicators are measurable characteristics related to the structure, composition, or processes of an ecological system (USEPA 2002). A variety of biological and ecological assessment procedures use indicators. For example, the Habitat Evaluation Procedure uses habitat characteristic indicators to assess "habitat suitability" in lieu of the more difficult and time-consuming direct monitoring of animal populations (USFWS 1980). Indicators are also used in the Index of Biological Integrity and related methods (Karr and Chu 1997) to assess "biological integrity," in the Stream Visual Assessment Protocol (Natural Resources Conservation Service (NRCS) 1998) to assess "stream health," in the Synoptic Approach (Leibowitz et al. 1992; Abbruzzese and Leibowitz 1997) to assess "ecosystem function," in the Hydrogeomorphic Approach (Smith et al. 1995) to assess "wetland function," and in a wide variety of other procedures designed to screen alternatives, identify priorities, or otherwise make informed decisions where relative comparisons are appropriate, spatial scales are large, or the time and resources required for more detailed studies are unavailable.

Liebowitz and Hyman (1999) make an important distinction between "confirmed" and "judgment" indicators. Confirmed indicators are those in which the relationship between the indicator and what is being assessed (i.e., ranking criteria) can be described precisely (i.e., mathematically) with a specified level of statistical confidence. Judgment indicators, on the

other hand, are those in which a precise relationship between the indicator and the ranking criteria cannot be defined. The relationship is typically based on data, trends, or patterns presented in the literature and field observations, or on professional judgment. Given adequate resources, it is often possible to develop a precise relationship between a judgment indicator and ranking criteria. For example, it is possible, albeit difficult and expensive, to define a quantitative, mathematical relationship between land use and water quality in a watershed using hydrologic modeling methods (Hamlett et al. 1992).

The use of confirmed versus judgment indicators represents a tradeoff in terms of the degree of certainty of the relationship between the indicator and ranking criteria, and the ability to obtain the information necessary to assess ranking criteria. Some authors have questioned the use of judgment indicators (Conroy and Noon 1996, Schumaker 1996). However, in practice, the use of judgment indicators is often unavoidable given time and resource constraints, the lack of existing confirmed indictors, or the lack of quantitative data necessary to confirm the relationship between and indicator and ranking criteria (Abbruzzese and Leibowitz 1997).

In conducting a baseline assessment, indicators are defined as characteristics or processes that are used to assess the condition of a WAA with respect to one or more ranking criteria. For example, water temperature, dissolved oxygen, pool frequency, pool depth, embeddedness, and canopy cover are all indicators that could be used to assess the condition of anadromous fish stream habitat. Indicators may be either direct or indirect. The distinction between direct and indirect indicators is somewhat arbitrary, but generally, direct indicators are those based on a well-documented, empirical relationship between an indicator and a ranking criterion, and indirect indicators are those based on weaker empirical relationships and/or expert opinion. The direct/indirect designation for indicators provides a relative indication of the strength of the empirical relationship between indicators and ranking criteria.

Several factors influence the selection of indicators. The selected indicators must be applied over large areas, so low cost and rapid application are important factors. Therefore, indicators that can be evaluated remotely (i.e. through GIS processing of pre-existing spatial datasets) are preferred over indicators that require intense field data collection. It is also important that the relationship between the indicator and the ranking criteria is clearly

described, so that the model is transparent and understandable to all participating stakeholders, who would likely have a wide range of perspectives and interests. Finally, the selected indicators should be usable in a predictive mode, meaning that they should be capable of reflecting changes due to proposed impacts and restoration actions. Once these factors are considered, indicators can be selected based on a review of existing assessment methods, literature, field observations, available data, or the collective experience and expert judgment of individuals participating in the project.

Reference condition

In order to assess ecosystem condition, a standard of comparison or a "reference condition" must be defined (Smith et al. 1995; Brinson and Rheinhardt 1996; Rheinhardt and Brinson 1997; Rheinhardt et al. 1999; Bailey et al. 2004; Egan and Howell 2001, Smith and Carpenter 2008). Reference conditions are the desired range of conditions that biotic (e.g., vegetation and faunal species composition and abundance) or abiotic (e.g., vernal pool depth and slope) characteristics of an ecosystem exhibit. Given the variety of circumstances in which the concept of reference condition has been developed and applied, it is not surprising that there is some confusion surrounding the term. Stoddard et al. (2006) characterized the situation as follows:

> *All the authors of this paper, and by inference many of its readers, have had the experience of being well engaged in discussions among a mixed group, only to discover that participants use the phrase "reference condition" to refer to very different biological states, including the condition of ecosystems at some time in the past, the best of today's existing conditions, the conditions of systems in absence of human disturbance, or the condition that today's site might achieve if they were better managed.*

Stoddard et al. (2006) identified five categories of reference conditions in an attempt to promote clarity and specificity. These included: 1) Reference Condition Biological Integrity, defined by Karr and Dudley (1981) as, "…the ability to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat within a region;" 2) Minimally Disturbed Condition, defined as the absence of local human disturbance, while recognizing that minimal impacts related to human activities at the regional and global spatial scale are ubiquitous (e.g., deposition of atmospheric contaminants below the threshold required to have a

measurable impact on an ecosystem); 3) Historical Condition, defined as the condition that existed at some historical point in time (e.g., pre-settlement, pre-industrial, or pre-intensive agriculture); 4) Least Disturbed Condition, defined as the condition found in conjunction with landscapes with the least amount of human disturbance, or in other words, the best of what is left; and 5) Best Attainable Condition, defined as the Least Disturbed Condition in conjunction with the use of best management practices for a period of time long enough to be effective.

The majority of ecosystem assessment, restoration, or management situations in which reference conditions are applied adopt a definition of reference condition that corresponds to the minimally disturbed condition described above. The minimally disturbed condition is generally used in assessing riparian ecosystems, but published standards or guidelines may also be employed if they are available and pertinent, or the best attainable condition may be employed where fundamental and irreversible changes have occurred.

Generally, upland, riparian, and stream components of a WAA achieved a minimally disturbed condition when the structural characteristics and composition, and the physical, chemical, and biological processes exhibited were within the range of natural short- and long-term cycles, and when a diverse and sustainable suite of natural biological communities was supported. For example, when the upland component of a WAA includes extensive developed or agriculture areas, the upland component of the WAA would be considered to be in relatively poor ecological condition with respect to land use/land cover because the current condition land use/land cover deviates significantly from the native vegetation communities. Similarly, when the stream component of a WAA exhibits altered flow regimes due to dams or other upstream structural features, the stream component would be considered to be in relatively poor condition with respect to flow regime because of the deviation from natural flow patterns.

Indicator aggregation

Various methods are available to aggregate and synthesize indicator information so that it can be used to make decisions (Shilling et al. 2005, Chapter 6). Two basic approaches include: (1) mechanistic or process models that attempt to explain how systems work using mathematical equations that describe relevant system characteristics and processes (e.g., many hydrologic and water quality models), and (2) empirical models that

attempt to predict how a system works using relationships or trends based on empirical data (e.g., ecological indices such as Habitat Evaluation Procedures (HEP), Indices of Biological Integrity (IBI), and the Hydrogeomorphic (HGM) Approach). In practice, mechanistic models involve some element of empiricism, even if only the model assumptions, and empirical models contain mechanistic elements, even if only the list of inputs influencing the model output. Both of these approaches can be incorporated into the construction of watershed assessment models, either in the form of index models, or knowledge bases.

Index models

The initial watershed projects employed relatively simple index models similar to those used in the Habitat Evaluation Procedure (USFWS 1980), the Index of Biological Integrity and related methods (Karr and Chu 1997), the Stream Visual Assessment Protocol (NRCS 1998), and the Hydrogeomorphic (HGM) Approach (Smith et al. 1995). For example, in several southern California watersheds, Hydrologic Integrity of the riparian ecosystem was selected as a ranking criterion. Reference conditions for the ranking criterion were defined as riparian ecosystems that exhibit the range of frequency, magnitude, and temporal distribution of stream discharge, and surface and subsurface interaction between the stream channel, floodplain, and terraces, that historically characterized riparian ecosystems in the region (Bedford 1996, Poff et al. 1997, Richter et al. 1997). In the arid southwest, this translates into seasonal intermittent, ephemeral, or low flow periods, with annual bank-full discharges superimposed on a background of episodic, and often catastrophic, larger magnitude floods that inundate historical terraces (Graf 1979, 1998; Harris 1987; Fisher et al. 1982; Friedman et al. 1996a, 1996b).

Two categories of indicators were selected for the Hydrologic Integrity Index. The first focused on factors that influence frequency, magnitude, and temporal distribution of stream discharge, and the second category focused on the factors that influenced the hydrologic interactions among the stream channel, floodplain, and historical terraces. Direct measures of stream discharge are generally unavailable at the riparian reach scale in these watersheds. Consequently, several indicators were selected at the drainage basin scale with the assumption that an indirect estimate of deviation from the reference condition can be made based on changes in specific characteristics and processes of a drainage basin such as rainfall interception, infiltration, evapotranspiration, percolation, groundwater

flow, and surface water flow overland and in channels. Cultural alteration of the drainage basin alters these characteristics and processes, and consequently, stream discharge. It is difficult to quantify the exact nature of the relationship between specific drainage basin characteristics, as represented by the indicators, and stream discharge. However, it can generally be shown that as cultural alteration of a watershed increases, so does the deviation from short- and long-term historical patterns of frequency, magnitude, and distribution of stream discharge.

Indicators selected to reflect degree of cultural alteration in a drainage basin with the potential to influence stream discharge included:

- Improved Hydraulic Conveyance (drainage basin scale)
- Perennialized Stream Flow (drainage basin scale)
- Surface Water Retention (drainage basin scale)
- Import, Export, or Diversion of Surface Water (drainage basin scale)

Using values for frequency, magnitude, and distribution of stream discharge that are similar to the historical range of conditions does not alone ensure hydrologic integrity. Hydrologic integrity also depends on maintaining the interactions among the stream channel, floodplain, and terraces of the riparian ecosystems through overbank and subsurface flows. This interaction is critical to the maintenance of riparian plant communities, sediment storage, carbon dynamics, biogeochemical processes, and other characteristics and processes of riparian ecosystems.

Indicators selected to represent the interaction between the stream channel and the floodplain at the riparian reach and riparian reach tributary scale included:

- Improved Hydraulic Conveyance (main stem riparian reach scale)
- Improved Hydraulic Conveyance (tributary riparian reach scale)
- Perennialized Stream Flow (main stem riparian reach scale)
- Surface Water Retention (main stem riparian reach scale)
- Import, Export, or Diversion of Surface Water (main stem riparian reach scale)
- Riparian Vegetation Condition (main stem riparian reach scale)
- Floodplain Interaction (main stem riparian reach scale)

For each of the indicators used to assess the hydrologic integrity ranking criterion, a definition or description of the indicator was developed. For example, the Improved Hydraulic Conveyance indicator was defined as the degree to which engineering techniques have been used to increase the capacity of channels to convey surface water downstream. In general these techniques involve reducing the frictional resistance (i.e., roughness) caused by channel substrate, vegetation, woody debris, and other objects in the channel (Barnes 1967), minimizing the wetted perimeter, and/or shortening the length of a channel. Increasing the volume of water and velocity at which water is conveyed downstream can result in a significant change in the hydrologic regime, and hence hydrologic integrity, in the riparian reach where the alteration occurs as well as in upstream and downstream reaches. For example, removal of vegetation decreases channel stability and increases erosion by reducing the resistance afforded by the network of plant roots, and by increasing the velocity and, consequently, the erosive force of water in the channel. A straightened stream reach will typically respond by incising to reestablish a more energy-efficient and stable channel slope (Shankman and Samson 1991). This in turn initiates head cutting and increased erosion upstream. Downstream of an altered stream channel the hydrologic regime can also be affected in terms of increased peak discharges, a decrease in channel stability, and an increase in erosion due to increased water velocity. Note that this indicator is referred to as "Altered Hydraulic Conveyance" in later iterations of the assessment approach described in this report. This was done to better reflect the likely adverse ecological effects of channel modifications.

A measurement protocol was developed for each indicator. The metric used to measure the Improved Hydraulic Conveyance indicator is the percent of the main stem and tributary riparian reaches in the WAA with improved hydraulic conveyance. High-resolution aerial photography was used initially to estimate the value of the metric followed by field verification. At the drainage basin scale, the metric was calculated as the weighted average of the percent of Improved Hydraulic Conveyance for all upstream WAAs in the drainage basin of the WAA using Equation 1.

$$\sum_{i=1}^{i_n}\left[IHC_{WAA} * \left(ML_{WAA} \Big/ ML_{DB}\right)\right] \quad (1)$$

where

IHC_{WAA} = Percent of main stem and tributary riparian reaches in WAA with improved hydraulic conveyance
ML_{WAA} = Length of main stem and tributary riparian reaches in WAA
ML_{DB} = Length of main stem and tributary riparian reaches in drainage basin

Finally, each indicator was scaled to a reference condition. In this example, the Improved Hydraulic Conveyance indicator is assigned an indicator score between 1 and 5 based on the percentage of the channel with improved hydraulic conveyance. Metric value ranges were designated based on natural groupings of the data collected for the project, and the subjective integration of numerous field observations relating metric values to a reference condition. A metric value ≤5 (i.e., less than 5% of the reach exhibited improved hydraulic conveyance) represented concurrence with the reference condition, and is assigned an indicator score of 5. As the metric value increased, the indicator score assigned decreased. For example, if the metric value was >15% and ≤30%, an indicator score of 3 was assigned, and if the metric value was >50%, an indicator score of 1 was assigned. The Hydrologic Integrity Index was calculated by entering the scores for Improved Hydraulic Conveyance and other indicators into Equation 2.

Table 1. Metric value ranges for scaling improved hydraulic conveyance to reference.

Metric Value Range	Indicator Score
≤5% of the main stem and tributary riparian reach with IHC	5
>5 and ≤15% of the main stem and tributary riparian reach with IHC	4
>15 and ≤30% of the main stem and tributary riparian reach with IHC	3
>30 and ≤50% of the main stem and tributary riparian reach with IHC	2
>50% of the main stem and tributary riparian reach with IHC	1

The Hydrologic Integrity Index is calculated using the following equation:

$$\left(\left(IHC_{RR} + IHC_{RRT}\right)/2\right) + PSF_{RR} + SWR_{RR} + IED_{RR} + \left(\left(IHC_{DB} + PSF_{DB} + SWR_{DB} + IED_{DB}\right)/4\right) + FI_{RR} + IMP_{RR}\frac{1}{2} \quad (2)$$

where:

IHC_{RR} = Improved Hydraulic Conveyance of main stem riparian reach

IHC_{RRT} = Improved Hydraulic Conveyance of tributary riparian reaches
IHC_{DB} = Improved Hydraulic Conveyance in drainage basin
PSF_{RR} = Perennialized Stream Flow of main stem riparian reach
PSF_{DB} = Perennialized Stream Flow in drainage basin
SWD_{RR} = Surface Water Detention of main stem riparian reach
SWD_{DB} = Surface Water Detention in drainage basin
IED_{RR} = Import, Export, Diversion of surface water in main stem riparian reach
IED_{DB} = Import, Export, Diversion of surface water in drainage basin
FI_{RR} = Floodplain Interaction of main stem riparian reach
IMP_{LD} = Imperviousness of local drainage

Other indicators of ecosystem integrity were similarly defined, scored, and aggregated to develop the indices used in the assessment. Appendix A illustrates the process for the South Sacramento Habitat Conservation Project area in California.

Knowledge bases

An alternative method for generating assessment indices was used in the later watershed projects, where a knowledge-based approach was employed. In order to understand the components of a knowledge base, and how indicators are used to assess ranking criteria, consider the schematic of a hypothetical Steelhead Habitat Condition knowledge base developed for the Russian River watershed in northern California (Figure 5). In the knowledge base schematic, Steelhead Habitat Condition, the ranking criterion, is represented by the dark gray box, and the indicators are represented by the light gray boxes. The indicators, including Percent Pools, Percent Embeddedness, Percent Stream Canopy, and Upper Water Temperature, were identified as important factors that influence steelhead habitat condition in the Russian River Basin Fisheries Restoration Plan (CDFG 2002).

In a knowledge base, the assessment is based on a proposition that defines the optimal, ideal, or, in this case, reference condition for each indicator. The propositions for the indicators in the Steelhead Habitat Condition knowledge base are shown in Figure 5. For example, for the Percent of Stream Canopy indicator, >80% stream canopy cover is considered the optimal habitat condition for steelhead. Each indicator is evaluated in terms of trueness or "truth-value" of the indicator metric in relation to the proposition. That is, a truth-value is assigned to an indicator based on a

formal relationship between the indicator and the proposition. The formal relationship is defined based on field data, literature values, expert opinion, intuitive reasoning, or it is derived empirically from the range of indicator values collected during the project. In the case of the hypothetical Steelhead Habitat Condition knowledge base, the relationships between indicators and truth-values are based on optimal steelhead habitat conditions identified in the Russian River Basin Fisheries Restoration Plan (CDFG 2002).

Figure 5. Knowledge base schematic for the Steelhead Habitat Condition ranking criterion.

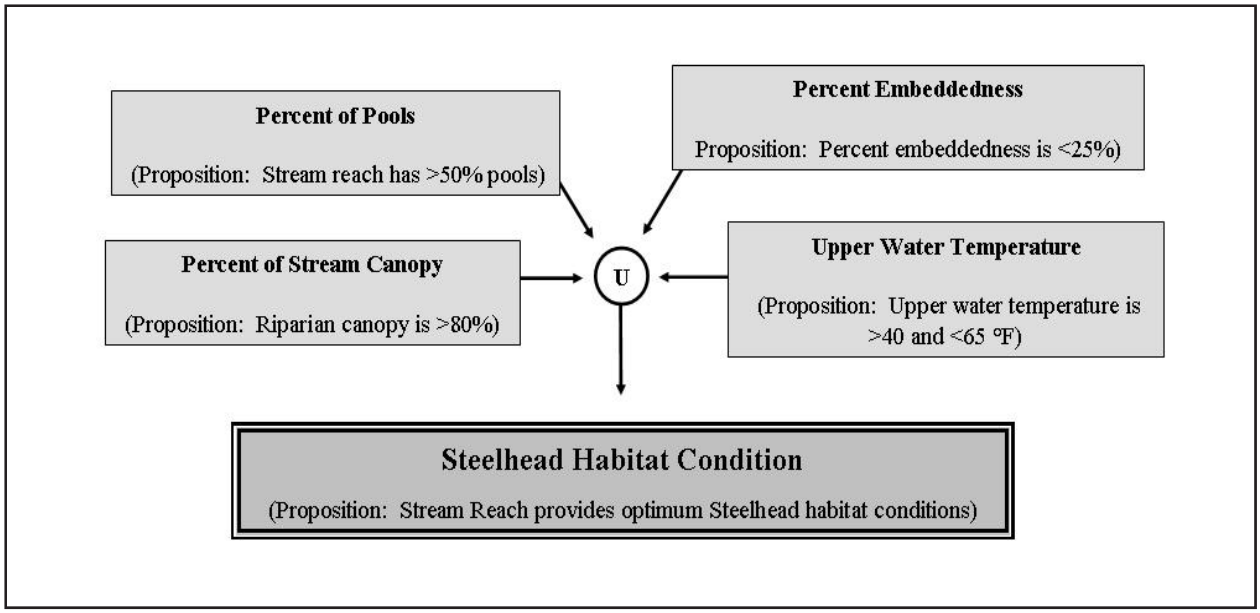
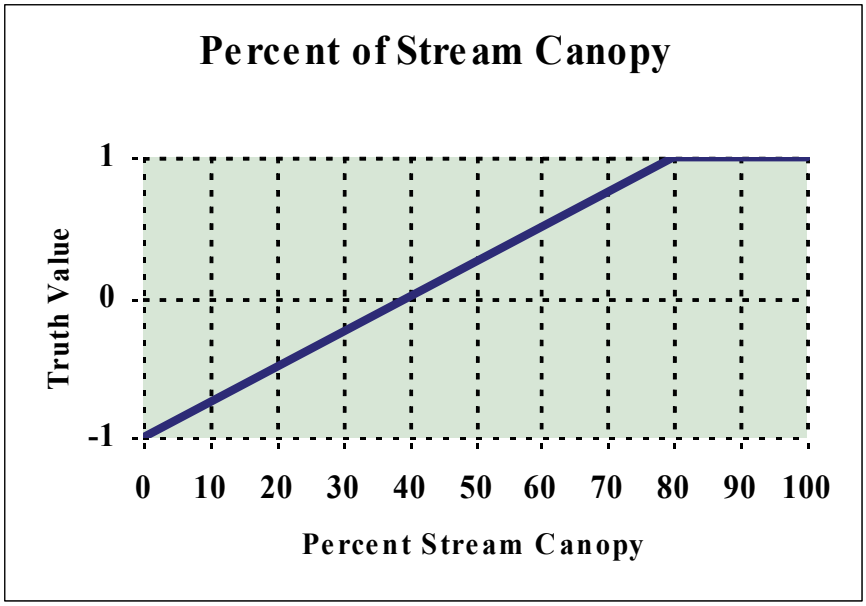


Figure 6 shows the relationship between the Percent of Stream Canopy indicator and the truth-value. If the Percent of Stream Canopy is ≥80%, a truth-value of "1" (i.e., totally true) is assigned. If the Percent of Stream Canopy is 0%, a truth-value of "-1" (i.e., totally false) is assigned. If the Percent of Stream Canopy is between 0% and 80%, a truth-value between "1" and "-1" is assigned based on fuzzy logic. Fuzzy logic makes it possible to incorporate “partial truth,” as opposed to classical Boolean logic, where things are either totally true or totally false.

For example, using Boolean logic, a tree might be defined as “large” if it has a basal area ≥ 5.0 m^2. Therefore, a tree with a basal area of 6.0 m^2 would be considered “large,” and a tree with a basal area of 3.0 m^2 would be considered “not large.” Using fuzzy logic, a numerical truth-value that indicates the degree of “largeness” is determined for trees with a basal area < 5.0 m^2 based on a set of breakpoints. Breakpoints define the value at

Figure 6. Relationship between the Percent Canopy Cover indicator and truth-value.



which an indicator is assigned either a totally true or totally false truth-value. For example, in Figure 7 the totally true breakpoint for “large” trees is defined at a basal area of 5.0 m². Any tree with a basal area ≥ 5.0 m² is assigned a truth-value of “1.” The totally false breakpoint for “large” trees is defined at a basal area of 0.1 m². Any tree with a basal area ≤ 0.1 m² is assigned a truth-value of “-1.” For trees with a basal area between 0.1 m² and 5.0 m², an intermediate truth-value is assigned to reflect its degree of largeness. For example, a tree with a basal area of 4.0 m² is assigned a truth-value of "0.8,” and a tree with a basal area of 1.0 m² is assigned a truth-value of "-0.75,” and so forth.

In the knowledge base ranking, criteria are assigned a truth-value by aggregating the truth-values of the antecedent indicators. For example, in the hypothetical Steelhead Habitat Condition knowledge base schematic (Figure 5), the arrows from the four antecedent indicators point to a circled "U.” This symbol indicates that the truth-values of the antecedent indicators are aggregated by averaging to determine the truth-value for the ranking criterion. Table 2 shows this aggregation for the Steelhead Habitat Condition primary assessment criterion for five hypothetical WAAs. There are a variety of options for aggregating truth-values in a knowledge base to impose a specific constraint or bias.

Figure 7. Relationship between Tree Basal Area indicator and truth-value.

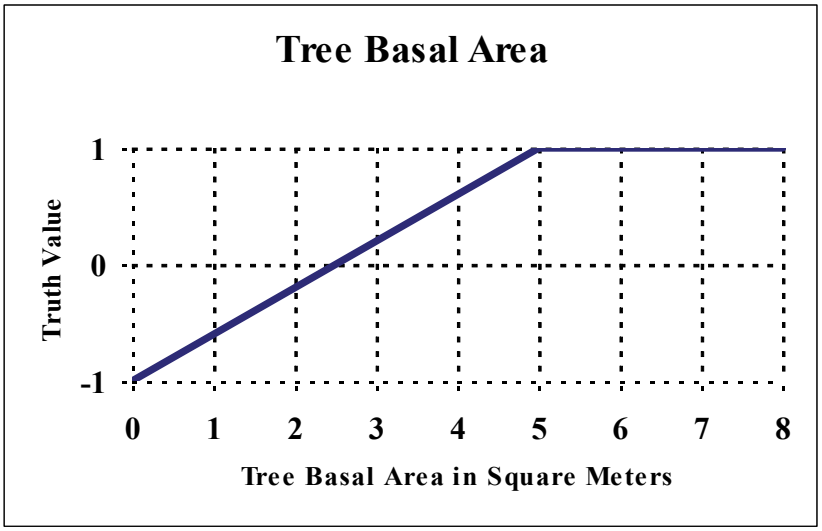
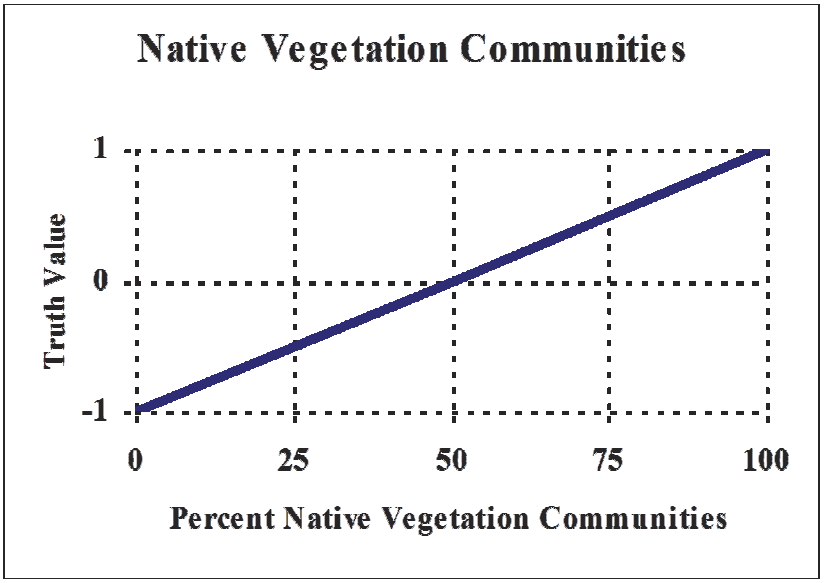


Table 2. Aggregation of indicator truth-values to determine ranking criterion truth-value.

WAAs	Indicators				Steelhead Habitat Condition Truth-Value (Average of Indicator Truth-Values)
	Upper Water Temperature Indicator Truth-Value	Embedded (%) Indicator Truth-Value	Riparian Canopy (%) Indicator Truth-Value	Primary Pools (%) Indicator Truth-Value	
1	1	1	1	1	1
2	1	0.5	0.5	0.5	0.5
3	-1	-1	1	1	0
4	-1	1	-1	-1	-0.5
5	-1	-1	-1	-1	-1

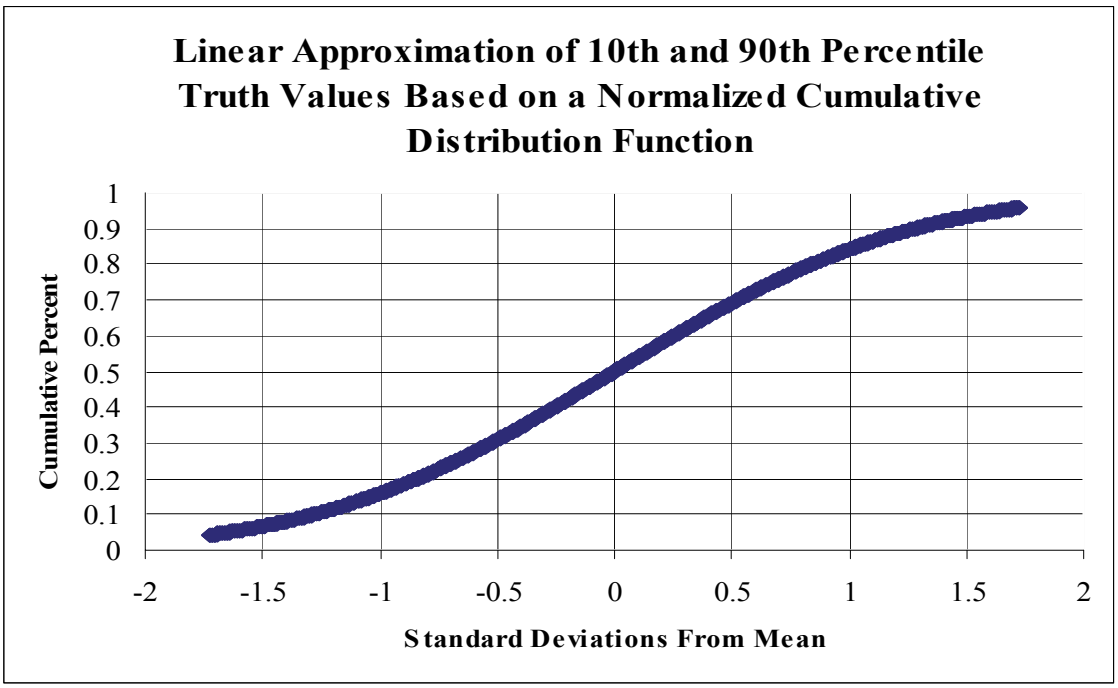
Ideally, the formal relationship defined between an indicator and truth-value is based on regionally collected field data or literature values. This is illustrated in the hypothetical Steelhead Habitat Condition knowledge base described above, where the relationships are based on information published in the Russian River Basin Fisheries Restoration Plan (CDFG 2002). However, this type of information is not always available, and sometimes it is necessary to rely on expert opinion, intuition, or more empirical approaches to determine the relationships between indicators and truth-values. An example of an intuitively derived relationship between an indicator and truth-value is shown in Figure 8 for the Native Vegetation Communities indicator. Under natural conditions, it can be presumed that native vegetation communities occupied 100% of the landscape. It is therefore intuitive that if a WAA is 100% occupied by native vegetation communities, a truth-value of "1" is assigned and if native vegetation communities cover none of a WAA, then a truth-value of “-1” is assigned.

Figure 8. Relationships between indicators and truth-values for the Native Vegetation Community indicator.



For some indicators there are no field data, literature values, expert opinion, or intuitive bases for defining the relationship between an indicator and truth-values. In these situations, an empirical approach is used to establish the relationship. Conceptually, this involves using the range of indicator values from WAAs across the watershed and setting the totally true break-point slightly below the maximum indicator value, and the totally false breakpoint slightly below the minimum indicator value. Specifically, this was accomplished by calculating the mean and standard deviation of all indicator values and using the 10th and 90th percentiles of the linear approximation of the normalized cumulative distribution function as the totally false ("-1") and totally true ("1") truth-value breakpoints, respectively (Figure 9). While not valid outside the context of the project watershed, this approach provides reproducible, relative relationships between indicator values and truth-values for indicators that lack the information to establish a relationship between an indicator and truth-value. As with the previously described index model method, a variety of ecosystem assessment indices can be generated using this knowledge base approach.

Figure 9. Normalized cumulative distribution function with linear approximation of 10th and 90th percentiles.



3 Data Collection, Analysis, and Display

Data collection during the baseline assessment normally consists of a field component that includes the collection of information related to ecosystem characteristics and indicators, and a GIS component that includes visual examination of high-resolution aerial photography and spatial analysis of other themes. Depending on the ranking criteria that have been selected, the specifics of data collection will vary to some degree. This chapter describes a typical data collection process that is used to assess the condition of riparian ecosystems in a watershed.

Table 3 lists the information that is collected for the riparian reach in each WAA. Indicator measurements used to assess the riparian ecosystem condition are usually supplemented with information on a variety of other characteristics of each riparian reach that is anticipated to be needed for future work related to mitigation or restoration. The second column in Table 3 identifies the procedure that is used to collect information for each characteristic and indicator. Information on some characteristics and indicators is gathered in the field during the site visits, while information on other characteristics is gathered through the visual examination of high-resolution aerial photographs and other thematic layers (e.g., vegetation, land use, soils, and streams) and various spatial analysis techniques in a GIS environment. Generally, fieldwork is completed prior to conducting any GIS analysis because the configuration of WAAs can change as a result of field observations.

Field data collection

Main stem and tributary riparian reaches in each WAA are characterized during a field visit to each WAA. At each site, the general strategy is to begin at the downstream end of the riparian reach and conduct a walking reconnaissance of the main stem channel and major tributaries in the WAA. On longer reaches, a walking reconnaissance is normally conducted by driving to multiple representative locations along the riparian reach. On headwater reaches, the walking reconnaissance generally includes at least the lower one-third of the riparian reach. Following the reconnaissance at each WAA, a decision is made to either retain the initial upstream/downstream boundaries of the WAA, or to modify those boundaries. On average, a two-person crew can complete fieldwork at a rate of 15 WAAs per day.

Table 3. Data for characterizing riparian reaches and indicators.

Characteristic or Indicator Description	Procedure
Riparian Reach ID	GIS
Drainage Basin	GIS
USGS 7.5-Minute Topographic Quad	GIS
Main stem Downstream End Coordinates (UTM)	GIS
Main stem Upstream End Coordinates (UTM)	GIS
Size of Mapped Riparian Ecosystem in Riparian Reach Local Drainage (ha)	GIS
Size of Mapped Riparian Ecosystem in Riparian Reach Drainage Basin (ha)	GIS
Size of Riparian Reach Local Drainage (LD) (ha)	GIS
Length of Local Drainage Perimeter (m)	GIS
Size of Riparian Reach Drainage Basin (DB) Area (ha)	GIS
Valley Type (Rosgen)	Field
Valley Length (m)	Field / GIS
Valley Width (m)	Field / GIS
Main stem Downstream End Elevation (m)	GIS
Main stem Upstream End Elevation (m)	GIS
Valley Slope (%) (Estimated From 7.5-Minute Topo)	Calculated
Engineered Channel Type or Rosgen Stream Type	Field
Main Stem Channel Length (m)	GIS
Main Stem Channel Length in DB (m)	GIS
Main Stem and Tributary Channel Length in Local Drainage (m)	GIS
Main Stem and Tributary Channel Length in Drainage Basin (m)	GIS
Main Stem Channel Length / Main stem Channel and Tributary Channels Length	Calculated
Drainage Density	Calculated
Channel Slope	Calculated
Sinuosity	Calculated
Bank-full Width (ft)	Field
Bank-full Width (m)	Calculated
Floodprone Width (ft)	Field
Floodprone Width (m)	Calculated
Bank-full Maximum Depth (in)	Field
Bank-full Maximum Depth (cm)	Calculated
Bank-full Mean Depth (in)	Field
Bank-full Mean Depth (cm)	Calculated
Bank-full Cross-Sectional Area (m^2)	Calculated
Width / Depth Ratio	Calculated

Characteristic or Indicator Description	Procedure
Entrenchment Ratio	Calculated
Natural Channel Substrate Bedrock / Boulder (%)	Field
Natural Channel Substrate Cobble (%)	Field
Natural Channel Substrate Gravel (%)	Field
Natural Channel Substrate Sand (%)	Field
Natural Channel Substrate Silt / Clay (%)	Field
Indicator 1 % of Main Stem with Improved Hydraulic Conveyance	Field
Indicator 2 % of Blueline Tributaries with Improved Hydraulic Conveyance	Field
Indicator 3 % of Main Stems in DB with Improved Hydraulic Conveyance	Field/GIS
Indicator 4 % of Main Stem with Perennialized Stream Flow	Field
Indicator 5 % of Main Stems in DB with Perennialized Stream Flow	Field/GIS
Indicator 6 % of Main Stem Lacking Floodplain Interaction	Field
Indicator 7 % of Main Stem Channel with Surface Water Retention	Field/GIS
Indicator 8 % of Drainage Basin with Surface Water Retention	Field/GIS
Indicator 9 % of Main Stem with Surface Water Imported, Exported, or Diverted	Field/GIS
Indicator 10 % of DB with Surface Water Imported, Exported, or Diverted	Field/GIS
Indicator 11 Imperviousness Index	GIS
Indicator 12 Sediment Regime Condition Index	Field
Indicator 13 Exotic Plant Species Index	Field
Indicator 14 Riparian Vegetation Condition Index - Floodplain	Field
Indicator 15 Riparian Vegetation Condition Index - Terrace	Field
Indicator 16 % Main Stem Corridor Breaks in Riparian Reach	Field/GIS
Indicator 17 % Main Stem Corridor Breaks in Drainage Basin	Field/GIS
Indicator 18 % Cultural Alteration in a 300' Buffer	Field/GIS
Indicator 19 % of LULC Contributing to Nutrient Increase	GIS
Indicator 20 % of LULC Contributing to Pesticide Increase	GIS
Indicator 21 % of LULC Contributing to Hydrocarbon Increase	GIS
Indicator 22% of LULC Contributing to Sediment Increase	GIS
Indicator 23 % of LULC Contributing to Nutrient Increase	GIS
Indicator 24 % of LULC Contributing to Pesticide Increase	GIS
Indicator 25 % of LULC Contributing to Hydrocarbon Increase	GIS
Indicator 26% of LULC Contributing to Sediment Increase	GIS
Indicator 27 % of Suitable Wildlife Habitat in Local Drainage	GIS

Based on the observations made during the walking reconnaissance, a representative portion of the riparian reach is selected and a riparian reach data sheet is completed (Figure 10). The data sheet includes a

location to record information on characteristics and indicators, notes on the species and geomorphic setting of the dominant plant communities (i.e., bank-full channel, floodplain, terrace), measurement of channel characteristics with cross- sectional drawings, and general field notes about the nature of the riparian reach.

Figure 10. Example riparian reach field data sheet (continued).

Reach Identifier _____ **Date** ____ / ____ / 2001 **Field Crew:** _____
UTM Coordinate at Sample Point 11S - _____ mE _____ mN
7.5 Minute Quad _____ **Elevation Downstream End** _____ (ft) **Upstream End** _____ (ft)
Valley Type II III VII VIII Other: _____ **Valley Length** _____ (ft) **Width** _____ (ft)
Stream Type (based on field observations): Aa+ A B C D Da E F G
BKF Width _____ (ft) **BKFmax Depth** _____ ft / in **BKFmean Depth** _____ ft / in **Floodprone Width** _____ (ft)
Channel Substrate (%) Bedrock/Boulder _____ Cobble _____ Gravel _____ Sand _____ Silt/Clay _____
Bank Substrate (%) Bedrock/Boulder _____ Cobble _____ Gravel _____ Sand _____ Silt/Clay _____

Riparian Reach Indicators (mainstem riparian reach)

AHC: % of reach with altered hydraulic conveyance (straightened, channelized, dredged, piped, _____) .____
PSF: % of reach with perennialized streamflow (return flow, urban runoff, irrigation, interbasin tranfer, _____) .____
FI: % of floodplain isolated from overbank flow (each side of streams accounts for 50%).....____
SR: condition of sediment regime in reach (enter sediment regime index 5-1where 5 = reference condition).....____
ARV: % of BKFC, FPA, and T1 throughout reach occupied by woody native and non-native, non-invasive riparian vegetation ...____
EXO: exotic plant species in BKFC, FPA, and T1 of reach (enter exotic species index 5-1: <5 5-20 20-50 50-75 75-100) .....____
RCCR: % of BKFC, FPA, and T1 throughout reach with corridor breaks /gaps resulting from cultural alteration.....____
RRBr: % of 300 ft. buffer throughout reach with restorable culturally altered features (grazed lands, dirt roads, _____) .____
RRBnr: % of 300 ft buffer throughout reach with unrestorable culturally altered features (paved roads, urban, _____) .____

Riparian Reach Tributary Indicators (all unsampled, named tributaries draining to mainstem riparian reach)

AHC-tribs: % of tribs with altered hydraulic conveyance (filled, straightened, piped, _____).____
ARV-tribs: % of BKFC, FPA, and T1 on tribs occupied by woody native and non-native, non-invasive riparian vegetation.....____
RRBr-tribs: % of 300 ft. buffer on tribs with restorable culturally altered features (grazed lands, dirt roads, _____) .____
RRBnr-tribs: % of 300 ft buffer on tribs with unrestorable culturally altered features (paved roads, urban, _____).____

BANKFULL CHANNEL (C)	**TREES**	**TALL SHRUBS / SAPS**	**LOW SHRUBS / HERBS**
	% Cover Total _____	% Cover Total _____	% Cover Total _____
Veg. Condition at Sample (circle one)	% Cover Exotics _____	% Cover Exotics _____	% Cover Exotics _____
5 4 3 2 1	Dominant Species	Dominant Species	Dominant Species
Veg. Condition at Sample is:			
Typical of reach _____			
Better than average _____			
Worse than average _____			

ACTIVE FLOODPLAIN (FP)	**TREES**	**TALL SHRUBS / SAPS**	**LOW SHRUBS / HERBS**
	% Cover Total _____	% Cover Total _____	% Cover Total _____
Veg. Condition at Sample (circle one)	% Cover Exotics _____	% Cover Exotics _____	% Cover Exotics _____
5 4 3 2 1	Dominant Species	Dominant Species	Dominant Species
Veg. Condition at Sample is:			
Typical of reach _____			
Better than average _____			
Worse than average _____			

TERRACE 1 (T1)	**TREES**	**TALL SHRUBS / SAPS**	**LOW SHRUBS / HERBS**
	% Cover Total _____	% Cover Total _____	% Cover Total _____
Height Above Bankfull _____ (ft)	% Cover Exotics _____	% Cover Exotics _____	% Cover Exotics _____
Average Width _____ (ft)	Dominant Species	Dominant Species	Dominant Species
Veg. Condition at Sample (circle one)			
5 4 3 2 1			
Veg. Condition at Sample is:			
Typical of reach _____			
Better than average _____			
Worse than average _____			

Figure 10. (continued).

Reach Identifier _____ **Date** ____ / ____ / 2001 **Field Crew:** _____
UTM Coordinate at Sample Point 11S - _____ mE _____ mN
7.5 Minute Quad _____ **Elevation Downstream End** _____ (ft) **Upstream End** _____ (ft)
Valley Type II III VII VIII Other: _____ **Valley Length** _____ (ft) **Width** _____ (ft)
Stream Type (based on field observations): Aa+ A B C D Da E F G
BKF Width ____ (ft) **BKFmax Depth** ____ ft / in **BKFmean Depth** ____ ft / in **Floodprone Width** ____ (ft)
Channel Substrate (%) Bedrock/Boulder ____ Cobble ____ Gravel ____ Sand ____ Silt/Clay ____
Bank Substrate (%) Bedrock/Boulder ____ Cobble ____ Gravel ____ Sand ____ Silt/Clay ____

Riparian Reach Indicators (mainstem riparian reach)
AHC: % of reach with altered hydraulic conveyance (straightened, channelized, dredged, piped, _____) .____
PSF: % of reach with perennialized streamflow (return flow, urban runoff, irrigation, interbasin tranfer, _____) .____
FI: % of floodplain isolated from overbank flow (each side of streams accounts for 50%).....____
SR: condition of sediment regime in reach (enter sediment regime index 5-1where 5 = reference condition).....____
ARV: % of BKFC, FPA, and T1 throughout reach occupied by woody native and non-native, non-invasive riparian vegetation ...____
EXO: exotic plant species in BKFC, FPA, and T1 of reach (enter exotic species index 5-1: <5 5-20 20-50 50-75 75-100) .....____
RCCR: % of BKFC, FPA, and T1 throughout reach with corridor breaks /gaps resulting from cultural alteration.....____
RRBr: % of 300 ft. buffer throughout reach with restorable culturally altered features (grazed lands, dirt roads, _____) .____
RRBnr: % of 300 ft buffer throughout reach with unrestorable culturally altered features (paved roads, urban, _____) .____

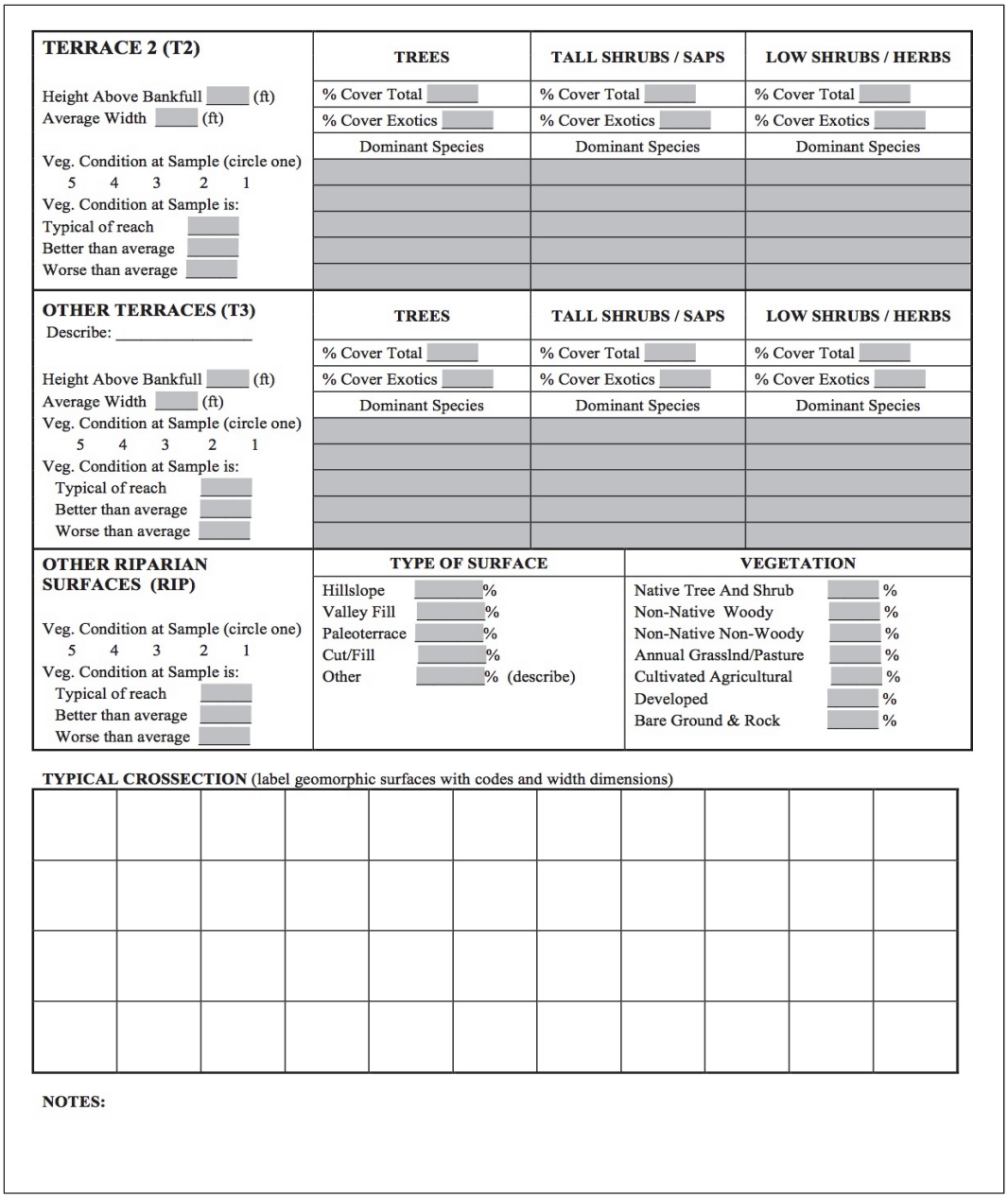
Riparian Reach Tributary Indicators (all unsampled, named tributaries draining to mainstem riparian reach)
AHC-tribs: % of tribs with altered hydraulic conveyance (filled, straightened, piped, _____) .____
ARV-tribs: % of BKFC, FPA, and T1 on tribs occupied by woody native and non-native, non-invasive riparian vegetation.....____
RRBr-tribs: % of 300 ft. buffer on tribs with restorable culturally altered features (grazed lands, dirt roads, _____) .____
RRBnr-tribs: % of 300 ft buffer on tribs with unrestorable culturally altered features (paved roads, urban, _____) .____

BANKFULL CHANNEL (C)	**TREES**	**TALL SHRUBS / SAPS**	**LOW SHRUBS / HERBS**
	% Cover Total ____	% Cover Total ____	% Cover Total ____
Veg. Condition at Sample (circle one)	% Cover Exotics ____	% Cover Exotics ____	% Cover Exotics ____
5 4 3 2 1	Dominant Species	Dominant Species	Dominant Species
Veg. Condition at Sample is:			
Typical of reach ____			
Better than average ____			
Worse than average ____			

ACTIVE FLOODPLAIN (FP)	**TREES**	**TALL SHRUBS / SAPS**	**LOW SHRUBS / HERBS**
	% Cover Total ____	% Cover Total ____	% Cover Total ____
Veg. Condition at Sample (circle one)	% Cover Exotics ____	% Cover Exotics ____	% Cover Exotics ____
5 4 3 2 1	Dominant Species	Dominant Species	Dominant Species
Veg. Condition at Sample is:			
Typical of reach ____			
Better than average ____			
Worse than average ____			

TERRACE 1 (T1)	**TREES**	**TALL SHRUBS / SAPS**	**LOW SHRUBS / HERBS**
	% Cover Total ____	% Cover Total ____	% Cover Total ____
Height Above Bankfull ____ (ft)	% Cover Exotics ____	% Cover Exotics ____	% Cover Exotics ____
Average Width ____ (ft)	Dominant Species	Dominant Species	Dominant Species
Veg. Condition at Sample (circle one)			
5 4 3 2 1			
Veg. Condition at Sample is:			
Typical of reach ____			
Better than average ____			
Worse than average ____			

Figure 10. (concluded).



TERRACE 2 (T2)

Height Above Bankfull _____ (ft)
Average Width _____ (ft)

Veg. Condition at Sample (circle one)
5 4 3 2 1
Veg. Condition at Sample is:
Typical of reach _____
Better than average _____
Worse than average _____

TREES	TALL SHRUBS / SAPS	LOW SHRUBS / HERBS
% Cover Total _____	% Cover Total _____	% Cover Total _____
% Cover Exotics _____	% Cover Exotics _____	% Cover Exotics _____
Dominant Species	Dominant Species	Dominant Species

OTHER TERRACES (T3)
Describe: _____

Height Above Bankfull _____ (ft)
Average Width _____ (ft)
Veg. Condition at Sample (circle one)
5 4 3 2 1
Veg. Condition at Sample is:
Typical of reach _____
Better than average _____
Worse than average _____

TREES	TALL SHRUBS / SAPS	LOW SHRUBS / HERBS
% Cover Total _____	% Cover Total _____	% Cover Total _____
% Cover Exotics _____	% Cover Exotics _____	% Cover Exotics _____
Dominant Species	Dominant Species	Dominant Species

OTHER RIPARIAN SURFACES (RIP)

Veg. Condition at Sample (circle one)
5 4 3 2 1
Veg. Condition at Sample is:
Typical of reach _____
Better than average _____
Worse than average _____

TYPE OF SURFACE		VEGETATION	
Hillslope	_____%	Native Tree And Shrub	_____ %
Valley Fill	_____%	Non-Native Woody	_____ %
Paleoterrace	_____%	Non-Native Non-Woody	_____ %
Cut/Fill	_____%	Annual Grasslnd/Pasture	_____ %
Other	_____% (describe)	Cultivated Agricultural	_____ %
		Developed	_____ %
		Bare Ground & Rock	_____ %

TYPICAL CROSSECTION (label geomorphic surfaces with codes and width dimensions)

NOTES:

GIS spatial analysis

Following the completion of fieldwork, values are calculated for those indicators requiring spatial analysis in a GIS environment (Table 3). For some indicators, the values are based solely on spatial analysis. For other indicators, information collected in the field is used in combination with spatial analysis to calculate values. The Riparian Corridor Continuity indicator is used here as an example of the latter case.

Riparian Corridor Continuity indicates the degree to which the main stem channel of a riparian reach exhibits an uninterrupted vegetated riparian corridor. Riparian ecosystems typically form a relatively continuous corridor along the stream channel and floodplain. Intact vegetated corridors allow animals to move to locations throughout a watershed on a daily, seasonal, or annual basis (La Polla and Barrett 1993; Machtans et al. 1996; Naiman et al. 1993). Gaps in the continuous riparian corridor can occur as a result of natural fluvial processes during large magnitude events (Hawkins et al. 1997). However, gaps are more frequently created as a result of cultural alterations such as roads, power and pipeline corridors, agricultural activities, and urban/industrial development.

This indicator was measured at the riparian reach scale as the percent of flood-prone area along the main stem channel of the riparian reach occupied by native and non-native vegetation communities with adequate height and structure to allow faunal movement. For example, annual grassland with no shrub or tree component was considered to represent a corridor gap. The difference between this indicator and Area of Native Riparian Vegetation was that for the RCC indicator, the vegetation corridor could be composed of native or non-native riparian species, whereas for the NRV indicator, only native riparian vegetation communities were considered. The percent of flood-prone area occupied by native riparian vegetation was estimated based on field observations, aerial photographs, and riparian vegetation community mapping (e.g. Lichvar 2003). At the drainage basin scale, Riparian Corridor Continuity was calculated as the weighted average of the percent of Riparian Corridor Continuity for all riparian reaches in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[\frac{RCC_{RR} * \left(ML_{RR} \big/ ML_{DB}\right)}{100}\right] \tag{3}$$

where:

RRC_{RR} = % of main stem in a riparian reach with vegetation corridor gaps
ML_{RR} = length of main stem channel in a riparian reach
ML_{DB} = length of main stem channel of all riparian reaches in drainage basin

The reference condition was defined as <5% of the floodplain of the main stem channel of the riparian reach occupied with riparian vegetation communities. Indicator scores were assigned based on the range of indicator values in Table 4.

Table 4. Range of indicator values for scaling the riparian corridor continuity indicators.

Indicator Value Range	Score
<5% of riparian reach with gaps/breaks due to cultural alteration	5
>5 and <15% of riparian reach with gaps/breaks due to cultural alteration	4
>15 and <30% of riparian reach with gaps/breaks due to cultural alteration	3
>30 and <50% of riparian reach with gaps/breaks due to cultural alteration	2
>50% of riparian reach with gaps/breaks due to cultural alteration	1

Calculating and displaying results

Once fieldwork and spatial analysis are completed, all data related to ecosystem characteristics and indicators are entered into a spreadsheet, where the indices for each ranking criterion are calculated, and tables and graphs for displaying the results are created. When this is accomplished, the information can be linked or joined to tables in a GIS environment in order to display information in a watershed context. For those projects in which knowledge bases were used, the Ecosystem Management Decision Support 3.2 (EMDS) accomplished the task of integrating the data into a GIS. The EMDS is an ArcGIS extension with a powerful toolset for integrating output from a Netweaver knowledge base (Reynolds et. al. 1996, 2000; Reynolds 2002; Reynolds and Hessburg 2005). The EMDS allows the output from a knowledge base to be displayed and interpreted and evaluated with respect to the influence of missing data. EMDS also simulates alternative scenarios and analyzes priorities and other decision support functions. Information about EMDS is available at: http://www.institute.redlands.edu/emds/.

Assessment results can be displayed in a variety of ways, including tables, graphs, and GIS maps. Tables are typically created to display descriptive statistics of indicator values and scores and knowledge base truth-values. For example, Table 5 summarizes the minimum, maximum, and mean value of each indicator, and the frequency of indicator scores for all WAAs. The distribution of index values for the ranking criteria are also typically included. For example, Figure 11 summarizes the Habitat Integrity Index for the 210 WAAs in a watershed. In this example, the index exhibits a

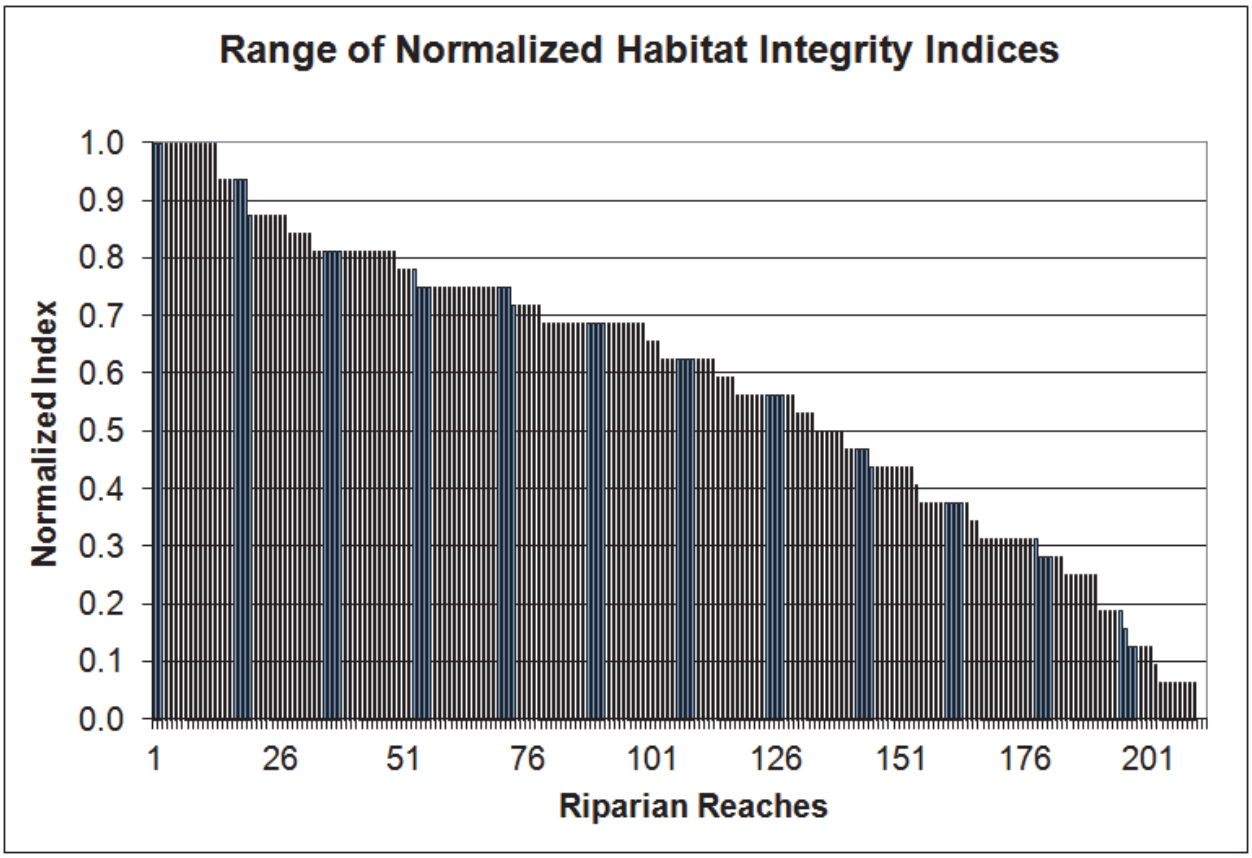
relatively wide and even spread (i.e., 1.0 to 0.07) across the possible range of the index. These results are interpreted as evidence that the indicators were scaled to the reference condition appropriately, and that they are sensitive enough to distinguish between different riparian habitat conditions that occurred in the watershed.

Table 5. Descriptive statistics for Otay River watershed metric values and indicator scores.

#	Indicator	Minimum Metric Value	Maximum Metric Value	Mean Metric Value	Frequency of Scores				
					Score 1	Score 2	Score 3	Score 4	Score 5
1	IHC_{RR}	0	100	11.4	19	5	14	8	166
2	IHC_{RRT}	0	100	9.3	16	5	9	7	175
3	IHC_{DB}	0	100	7.9	13	1	8	29	161
4	PSF_{RR}	0	100	12.3	25	2	0	0	185
5	PSF_{DB}	0	100	7.5	14	5	5	20	168
6	FI_{RR}	0	100	4.9	9	1	2	6	194
7	SWD_{RR}	0	100	13.6	25	6	7	4	170
8	SWD_{DB}	0	100	6.9	4	5	17	52	134
9	IED_{RR}	0	100	6.1	13	0	0	0	199
10	IED_{DB}	0	100	50.1	118	5	2	0	87
11	IMP_{RR}	NA*	NA*	NA*	4	31	101	59	17
12	SR_{RR}	NA*	NA*	NA*	14	55	69	45	29
13	EXO_{RR}	NA*	NA*	NA*	18	37	53	60	44
14	RVC_{F}	NA*	NA*	NA*	12	53	92	37	18
15	RVC_{T}	NA*	NA*	NA*	14	49	80	49	19
16	RCC_{RR}	0	100	38.9	64	25	44	25	54
17	RCC_{DB}	0	100	35.5	55	33	67	29	28
18	BUF_{RR}	0	100	52.3	55	33	67	29	28
19	$LULCN_{LD}$	0	100	64.6	144	31	19	7	11
20	$LULCP_{LD}$	0	100	21.5	40	27	14	10	121
21	$LULCH_{LD}$	0	100	15.9	31	8	9	22	142
22	$LULCS_{LD}$	0	100	60.7	128	33	23	15	13
23	$LULCN_{DB}$	0	100	62.3	134	26	24	12	17
24	$LULCP_{DB}$	0	100	18.6	35	32	14	16	115
25	$LULCH_{DB}$	0	100	22.9	31	10	7	19	145
26	$LULCS_{DB}$	0	100	55.3	132	30	21	17	11
27	WH_{LD}	0	100	27.5	52	18	17	15	110

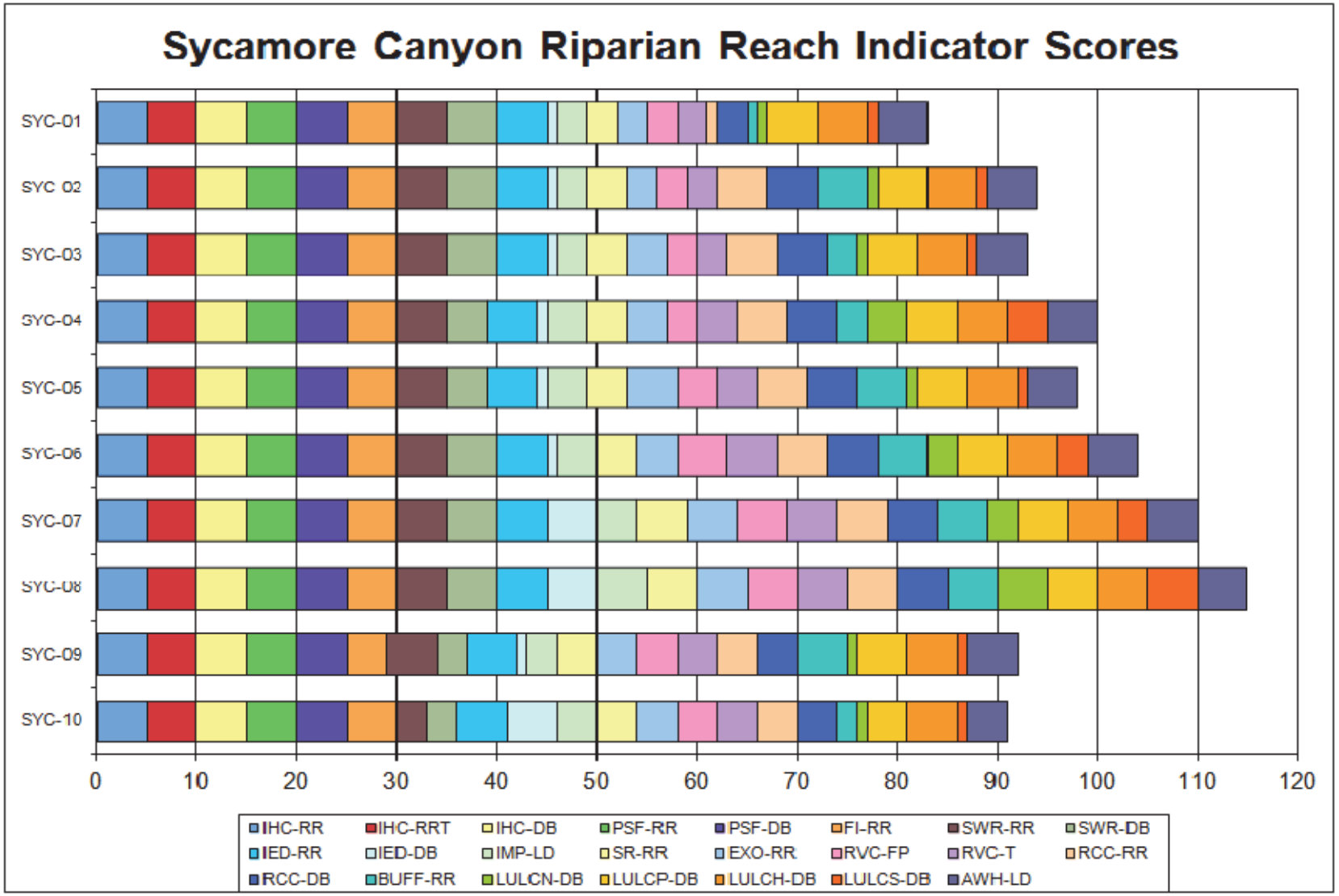
* NA = Not Applicable because metric value is recorded directly as a score.

Figure 11. Summary of normalized indices of habitat integrity.



Another way to present the results is shown in Figure 12. This figure shows indicator scores for a series of WAAs moving from the bottom to the top of a large canyon. This type of display is often useful in interpreting results. For example, it can be seen in general that the condition of riparian ecosystems degrades from the top to the bottom of the canyon, with the exception of the SYC-09 and SYC-10 WAAs. The SYC-09 and SYC-10 WAAs have a lower index because the land use in the drainage basin is agricultural, which results in a low score for the LULCCN-DB (#19 increased nutrients) and LULCS-DB (#23 increased sediments) indicators, as well as the SWR-DB (#8 surface water retention in impoundments) indicator. Also, a series of narrow bars near the middle of the figure represent the IED-DB (#10 import, export, or diversion of surface water) indicator. This signifies that the hydrologic regimes in the SYC-01 through SYC-06 WAAs are significantly affected by an alteration to the flow regime. This alteration is a result of an import or export of surface water that occurs in SYC-09 WAA, which is immediately upstream of SYC-06, because the main stem channels of the SYC-09 and SYC-07 WAAs join at the upstream boundary of the SYC-06 WAA.

Figure 12. Indicator scores for Sycamore Canyon riparian reaches.



Another useful way to display results of the baseline assessment is through watershed maps developed in a GIS environment. For example, Figure 13 illustrates the main stem channels, tributaries, and local drainage boundary for each WAA in the Otay River watershed. Figure 14 summarizes the Habitat Integrity Index ranking criteria for each WAA in the watershed. The darker green WAA polygons are those with a high Habitat Integrity Index, while the lighter green WAA polygons are those with a low Habitat Integrity Index. The pattern displayed is a common and easily interpreted one: the value of the index is low in areas of urban development, rural development, and agriculture, and higher in the more remote, undeveloped mountainous areas of the watershed.

Figure 13. Otay River watershed showing WAA local drainage boundaries, main stem channels, and tributaries.

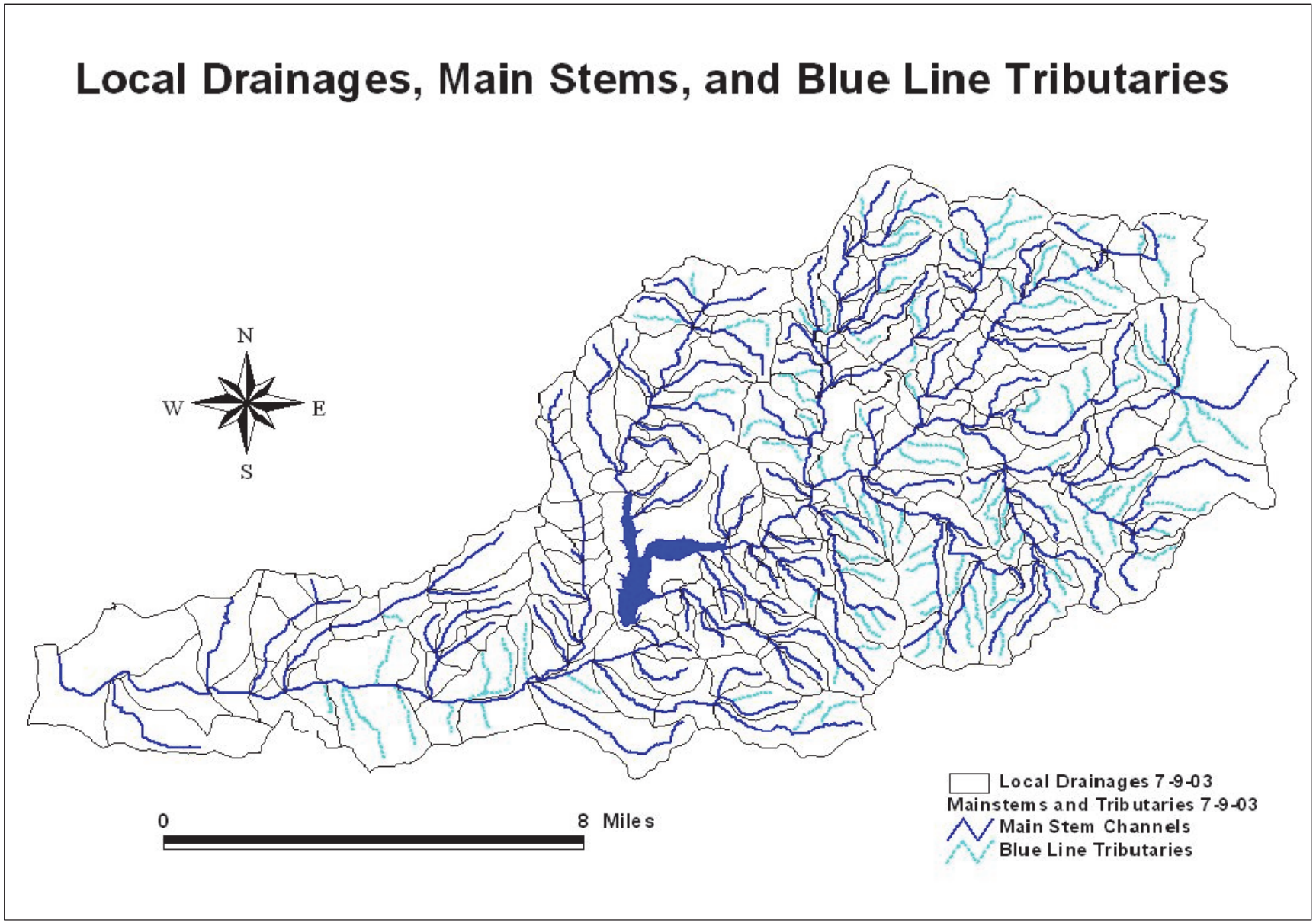
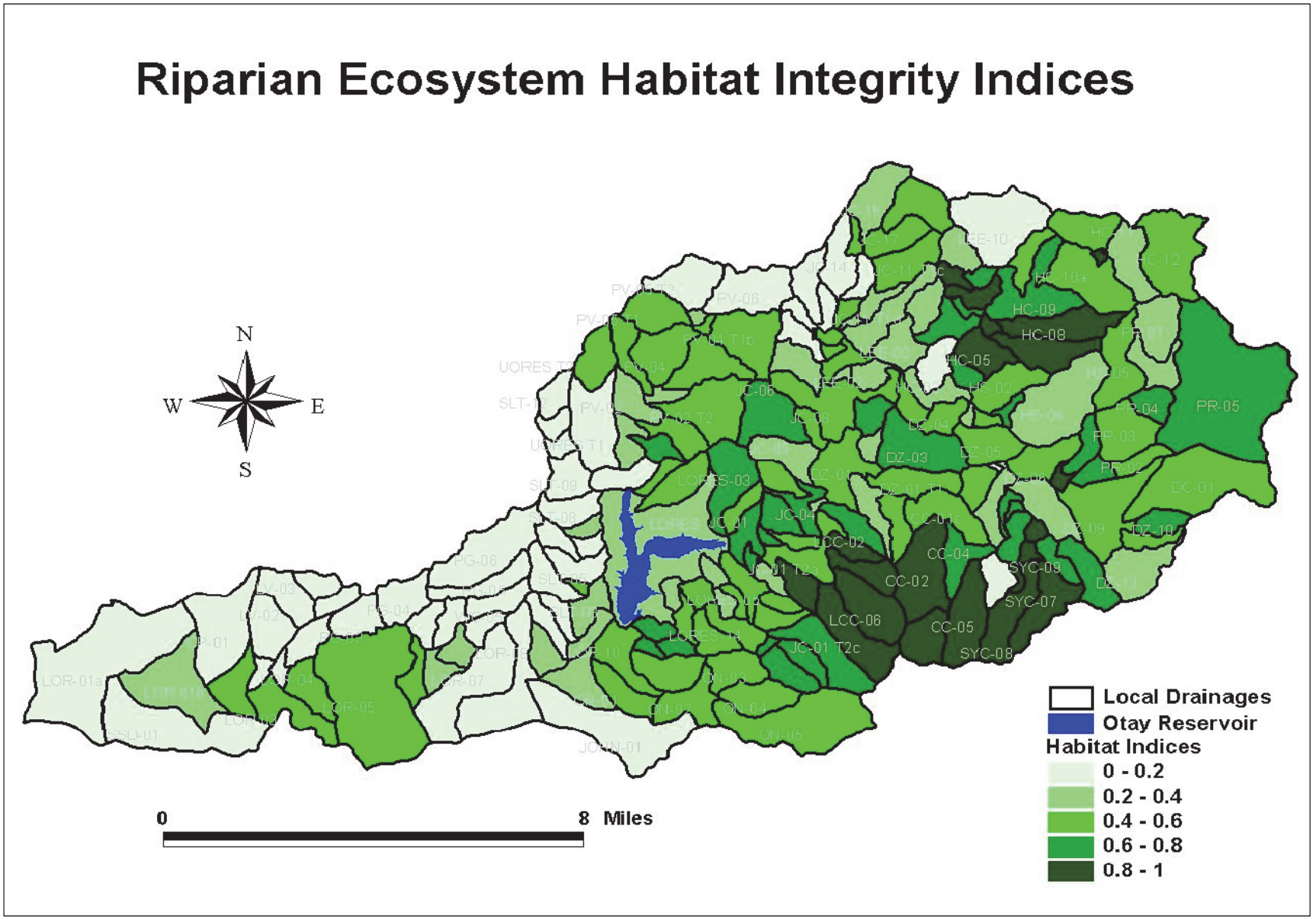


Figure 14. Habitat integrity indices for riparian reaches extrapolated WAAs for display purposes.



4 Applications

Baseline assessment

The baseline assessment process has clear utility for a variety of purposes, such as identifying particularly functional or degraded portions of the watershed from various perspectives. The graphic displays of assessment results often are sufficient to accomplish these types of tasks. Appendix A presents a simple example of how a baseline assessment is typically conducted and presented, using the South Sacramento Habitat Conservation Project in California as the case study.

Impact alternatives analysis

The process used to develop a baseline assessment is readily adapted to more complex analyses. In particular, it can be used to efficiently examine a variety of project alternatives to assess their potential impacts, including those that may occur far outside the project footprint due to disruption of ecosystem processes. Alternatives analyses are primarily exercises in creating separate "future condition" analyses for each alternative by substituting the baseline assessment values for each indicator with postulated post-project values within the project footprint. For example, within the project footprint of a proposed housing development, the baseline land use designation (e.g., agriculture, native forestland) would be changed to "developed," and the affected index values in the affected WAAs would be appropriately reassigned. Once all affected indices and WAAs have been assigned post-project scores, the watershed scale analysis is run to generate a post-project assessment that can be compared to the baseline condition and to post-project assessments for all other proposed project alternatives. This allows a much more meaningful comparison among alternatives than a site-specific tally of affected acreage, and in some cases, can highlight the potential for adverse effects to radiate throughout the ecosystem from apparently small impacts. With this information in hand, planners can apply more traditional economic analyses to the least-impact alternatives to identify a recommended project design.

Appendix B presents an example of an alternatives analysis for a set of possible alternative highway alignments in the San Juan and San Mateo watersheds in southern California. Note also that this same procedure

(modifying input scores based on observed or postulated changes in ecosystem condition) can be employed to continually update the baselines analysis and keep the database current.

Restoration alternatives analysis

A third major potential use for this system is to identify ecosystem restoration or mitigation opportunities, and to compare potential projects or combinations of projects to help select the most effective and efficient options. In practice, the final analysis for this application is conducted the same way as the alternatives analysis, except that the changes made to the input database reflect repairs rather than impacts to the ecosystem. Once postulated restoration actions are defined and described in terms of a restoration "footprint," they can be used to modify the input scores for the affected WAAs and a new post-restoration assessment can be run for the entire watershed. As with the impact alternatives analysis, this process can identify restoration projects that are particularly effective in improving ecosystem integrity throughout the system. For example, among multiple potential projects that would close gaps in riparian animal migration corridors, this process will quickly distinguish between projects that improve animal access to relatively small or densely developed parts of the watershed from those that re-establish access to extensive existing corridors that extend into remote refuge areas.

In one way, this watershed assessment method is not as readily applied to scenario testing for mitigation or restoration design as it is for more traditional assessments of alternative construction impacts. Where impacts derive from land development, highway projects, and other types of construction, the costs associated with alternative project designs can be fairly readily estimated and used to conduct the economic parts of the overall planning process. However, in the case of ecosystem restoration, initial site conditions and other constraints make it difficult to attach an estimate of relative cost to various competing projects without site-specific field evaluations and preliminary designs. This additional time-consuming and costly step is a major impediment to using the watershed assessment procedure in a scenario-testing mode to quickly screen and rank competing potential restoration or mitigation plans.

Recognizing this limitation, a system was developed to rate the restoration potential and estimate the associated relative restoration costs for each WAA at the time the baseline field assessments were conducted. This

process was limited to riparian systems, since they are the principal focus of restoration activities in the region being worked in, and riparian systems are also the most likely to be subject to mitigation requirements under federal and state regulations. However, the same concept could be extended to upland areas.

The general approach is to classify each riparian area in terms of its geomorphic characteristics, characterize the current condition, assign a general restoration design template, and then estimate the level of effort necessary to meet the design target. The effort involved to develop this information is not trivial; it requires a good familiarity with the ecology of the system and an understanding of common restoration practices. Even so, the resulting evaluations are not intended to be anything more than conceptual designs that allow estimation of relative costs, not in terms of dollars, but in terms of effort expended. However, by developing this information and associating it with the watershed baseline condition database, users can rapidly test a wide variety of restoration mitigation scenarios for both their ecological effectiveness, as well as the relative magnitude of the costs likely to be associated with each scenario.

The approach used to develop this information and apply it to alternative restoration scenarios is illustrated in Appendix C. The example used is the Otay River watershed in southern California. Note that this information, and particularly the classification of riparian sites and vegetation types, will vary and must be developed independently for every watershed, although the basic components of the approach are transferrable.

References

Abbruzzese, B., and S. G. Leibowitz. 1997. A synoptic approach for assessing cumulative impacts to wetlands. *Environmental Management* 21:457-475.

Allan, J. D., and A.S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience* 43: 32-43.

Allan, J. D., D. L. Erickson, and J. Fay. 1997. The influence of catchment land use on stream integrity across multiple scales. *Freshwater Biology* 37:149-161.

Anonymous. 2004. *Minnesota Routine Assessment Method (MnRAM) Evaluating Wetland Function, Version 3.0: Comprehensive General Guidance.*

Armour, C. L., D. A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16: 7-11.

Arnold, C. L., and C. J. Gibbons. 1996. Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association* 62:243–258.

Aspen Environmental Group. 2004. *Draft Otay River Watershed Assessment Technical Report*. San Diego, CA: County of San Diego Department of Planning and Land Use.

Bailey, S. A., M. C. Horner-Devine, G. Luck, L. A. Moore, K. M. Carney, S. Anderson, C. Betrus, and E. Fleishman. 2004. Primary productivity and species richness: Relationships among functional guilds, residency groups and vagility classes at multiple spatial scales. *Ecography* 27: 207-217.

Bain, M. B., J. T. Finn, and H. E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69:382-92.

Barbour, M. G., and J. Major (eds.) 1977. *Terrestrial vegetation of California*. New York: John Wiley and Sons.

Barling, R. D., and I. D. Moore. 1994. Role of buffer strips in management of waterway pollution: A review. *Environmental Management* 18:543-558.

Barnes, H. H. 1967. *Roughness characteristics of natural channels.* U.S. Geological Survey Water Supply Paper 1849. Washington, D.C.

Basnyat, P., L. D. Teeter, K. M. Flynn, and B. G. Lockaby. 1999. Relationship between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. *Environmental Management* 23: 539-549.

Bedford, B. L. 1996. The need to define hydrologic equivalence at the landscape scale for freshwater wetland mitigation. *Ecological Applications* 61: 57-68.

Benke, A., E. Willeke, F. Parrish, and D. Stites. 1981. *Effects of urbanization on stream ecosystems.* Completion report Project No. A-055-GA. Office of Water Research and Technology, US Dept. of Interior. Washington D.C.

Bicknell, B. R., J. C. Imhoff., J. L. Kittle, Jr., A. S. Donigian, Jr., and R. C.Johanson. 1996. *Hydrological Simulation Program – FORTRAN User's Manual For Release 11*. Athens, GA: Environmental Research Laboratory, Office Of Research And Development, U.S. Environmental Protection Agency.

Blair, R. B. 1996. Land use and avian species diversity along an urban gradient. *Ecological Applications* 6:506-519.

Bolstad, P. V., and W. T. Swank. 1997. Cumulative impacts of land use on water quality in a southern Appalachian watershed. *Journal of the American Water Resources Association* 33:519-533.

Bonham, C. D. 1989. *Measurements for terrestrial vegetation*. New York: John Wiley and Sons.

Booth, D. 1991. Urbanization and the natural drainage system-impacts, solutions and prognoses. *Northwest Environmental Journal* 7(1):93-118.

Booth, D. B., and C. R. Jackson. 1997. Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation. *Journal of the American Water Resources Association* 35:1077–1090.

Bowman, R. H. 1973. *Soil Survey of the San Diego Area, California, Part I.* USDA Soil Conservation Service and Forest Service and cooperating agencies. San Diego, CA.

Brinson, M. M., and R. D. Rheinhardt. 1996. The role of reference wetlands in functional assessment and mitigation. *Ecological Applications* 61:69-76.

Brode, J. M., and R. B. Bury. 1984. The importance of riparian systems to amphibian and reptiles. In *California Riparian Systems: Ecology, Conservation, and Productive Management,* ed. R. E. Warner and K. M. Hendrix, 30-36. Berkeley, CA: University of California Press.

Brugam, R. B. 1978. Human disturbance and the historical development of Linsley Pond. *Ecology* 59:19-36.

Busch, D. E., and S. D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecotones of the southwestern U.S. *Ecological Monographs* 65:347-370.

California Coastal Conservancy. 2001. Southern California Coastal Watershed and Wetland Inventories. http://eureka.regis.berkeley.edu/wrpinfo/index.html (Accessed 15 July 2003).

California Department of Fish and Game (CDFG). 2002. *Stream Survey Reports and GIS Coverage for Tributaries of the Russian River watershed*, unpublished draft.

California Wetlands Monitoring Workgroup. 2009. *Using CRAM (California Rapid Assessment Method) to Assess Wetland Projects as an Element of Regulatory and Management Programs*: 46.

Caruso, B. S., and R. C. Ward. 1998. Assessment of nonpoint source pollution from inactive mines using a watershed based approach. *Environmental Management* 22:225-243.

Charbonneau, R., and G. M. Kondolf. 1993. Land use change in California, USA: Nonpoint source water quality impacts. *Environmental Management* 17:453-460.

Clifford, H., T. Bergen, and S. Spear. 1996. *The geology of California*. San Diego, CA: Sunbelt Publication.

Conroy, M. J., and R. R. Noon. 1996. Mapping of species richness for conservation of biological diversity: Conceptual and methodological issues. *Ecological Applications* 6:763-773.

Cooper, D. J., D. M. Merritt, D. C. Anderson, and R. A. Chimner. 1999. Factors controlling the establishment of Fremont cottonwood seedlings on the Upper Green River, USA. *Regulated Rivers: Research and Management* 15:419-440.

Cooper, S. R. 1995. Chesapeake Bay watershed historical land use: Impact on water quality and diatom communities. *Ecological Applications* 5:703-723.

Costanza, R., B. G. Norton, and B. D. Haskell. 1991. *Ecosystem health: New goals for environmental management*. Washington, DC: Island Press.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. *North American Journal of Fisheries Management* 5:330-339.

Davies, B. R., M. Thoms, and M. Meador. 1992. An assessment of the ecological impacts of inter-basin water transfers and their threats to river basin integrity and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 23:833-843.

Debano, L. F. and L. J. Schmidt. 1990. Potential for enhancing riparian habitats in the southwestern United States. *Forest Ecology and Management* 33:385-403.

Dinius, S. H. 1987. Design of an index of water quality. *Water Resources Bulleti*n 23:833-843.

Downer, C. W., F. L. Ogden, J. Neidzialek, and S. Liu. 2005. GSSHA: A model for simulating diverse streamflow generating processes. Chapter 6 in *Watershed Models,* ed. V. P. Singh and D. Frevert. Boca Raton, FL: CRC Press.

Dunne, T., and L. B. Leopold. 1978. *Water in environmental planning*. San Francisco, CA: W. H. Freeman and Company.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266:753-762.

Egan, D., and E. A. Howell, ed. 2001. *The Historical Ecology Handbook: a Restorationist's Guide to Reference Ecosystems*. Washington, DC: Island Press.

Ehrenfeld, J. G. 1983. The effects of changes in land-use on swamps of the New Jersey pine barrens. *Biological Conservation* 25:353-75.

Evett, E. A. 1994. *Effects of urbanization and land use changes on low stream flow*. North Carolina Water Resources Research Institute, Report No. 284.

Faber, P. M., E. Keller, A. Sands, and B. M. Massey. 1989. *The Ecology of Riparian Habitats of the Southern California Coastal Region: A Community Profile*. U.S. Fish and Wildlife Service Biological Report 85(7.27). Washington, DC.

Finch, D. M., and S. H. Stoleson, ed. 2000. *Status, ecology, and conservation of the southwestern willow flycatcher*. Gen. Tech. Rep. RMRS-GTR-60. Ogden, UT: U.U. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Fisher, S. G., L. J. Gray, N. B. Grimm, and D. E. Busch. 1982. Temporal succession in a desert stream ecosystem following flash flooding. *Ecological Monographs* 52:93-110.

Fischer, R. A., and J. C. Fischenich. 2000. *Design recommendations for riparian corridors and vegetated buffer strips*. EMRRP Technical Notes Collection. ERDC-TN-EMRRP-24. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Fong, M. T., C. W. Downer, and A. R. Byrd. 2006. A *GSSHA model of the Perris Basin of the San Jacinto River Watershed, Riverside County, California,"* Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN III-76. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Articles;370

Franzreb, K. E. 1989. *Ecology and conservation of the endangered least Bell's vireo*. U.S. Fish and Wildlife Service Biological Report 89.

Friedman, J. M., W. R. Osterkamp, and W. M. Lewis. 1996a. The role of vegetation and bed level fluctuations in the process of channel narrowing. *Geomorphology* 14:341-351.

Friedman, J. M., W. R. Osterkamp, and W. M. Lewis. 1996b. Channel narrowing and vegetation development following a Great Plains flood. *Ecology* 77:2167-2181.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management* 10:199-214.

Goodwin, C. N., C. P. Hawkins, and J. L. Kershner. 1997. Riparian restoration in the western United States: Overview and perspective. *Restoration Ecology* 5:4-14.

Graf, J. B., R. H. Webb, and R. Hereford. 1991. Relation of sediment load and floodplain formation to climatic variability, Paria River drainage basin. *Bulletin of the Geological Society of America* 103:1405-1415.

Graf, W. L. 1979. The development of montane arroyos and gullies. *Earth Surface Processes* 4:1-14.

Graf, W. L. 1998. *Fluvial processes in dryland rivers*. New York: Springer-Verlag.

Gregory, S.V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience* 41:540-551.

Guralnik, D. B., and J. H. Friend. 1968. *Webster's New World Dictionary of the American Language*. New York: The World Publishing Company.

Hadley, R. F., and W.W. Emmett. 1998. Channel changes downstream from a dam. *Journal of the American Water Resources Association* 34:629-637.

Hamlett, J. M., D. A. Miller, R. L. Day, G. W. Peterson, G. M. Baumer, and J. Russo. 1992. Statewide GIS based ranking of watersheds for agricultural pollution prevention. *Journal of Soil and Water Conservation* 47:399-404.

Harris, R. E. 1987. Occurrence of vegetation on geomorphic surfaces in the active floodplain of a California alluvial stream. *American Midland Naturalist* 118: 393-405.

Hastings, A., and S. Harrison. 1994. Metapopulation dynamics and genetics. *Annual Review of Ecology and Systematics* 25:167-188.

Hawkins, C. P., K. L. Bartz, and C. M. U. Neale. 1997. Vulnerability of riparian vegetation to catastrophic flooding: Implications for riparian restoration. *Restoration Ecology* 5:75-84.

Hendricks, B. J., and J. P. Rieger. 1989. Description of nesting habitat for least Bell's vireo in San Diego County. In *Riparian Systems Conference: Protection, Management, and Restoration for the 1990's*, D. L. Abel, coordinator, 285-292. U.S. Forest Service General Technical Report PSW-110. Berkley, CA.

Howarth, R. W., J. R. Fruci, and D. Sherman. 1991. Inputs of sediment and carbon to an estuarine ecosystem: Influence of land use. *Ecological Applications* 1:27-39.

Hubbard, J. P. 1977. Importance of riparian ecotones: Biotic considerations. In *Importance, preservation, and management of riparian habitat: A symposium*, technical coordinators R. R. Johnson and D. A. Jones, 14-18. U.S. Forest Service General Technical Report RM-43. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: A method for assessing stream potentials. *Environmental Management* 10:629-635.

Hunsaker, C. T., and D. A. Levine. 1995. Hierarchical approaches to the study of water quality in rivers. *BioScience* 45:193-203.

Hynes, H. B. N. 1975. The stream and its valley. *Verh. Internat. Verin. Limnol.* 19:1-15.

Illhardt, B. L., E. S. Veery, and B. J. Palik. 2000. Defining riparian areas. In *Riparian management*, ed. E. S. Veery, J. W. Hornbeck, and C. A. Dolloff, 23-42.

Jarvinen, O. 1985. Conservation indices in land use planning: Dim prospects for a panacea. *Orins Fennica* 62:101-106.

Johnson, L. B., C. Richards, G. E. Host, and J. W. Arthur. 1997. Landscape influences on water chemistry in midwestern stream ecosystems. *Freshwater Biology* 37:193-208.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. In *International Large River Symposium*, ed. D. P. Dodge, 110-127. Canadian Special Publications in Fisheries and Aquatic Sciences 106.

Karr, J. R. 1996. Ecological integrity and ecological health are not the same. In *Engineering Within Ecological Constraints*, ed. P. C. Schultze, 97-109. Washinton, DC: National Academy Press.

Karr, J. R. 1999. Defining and measuring river health. *Freshwater Biology* 41:221-234.

Karr, J. R., and D. Dudley. 1981. Ecological perspectives on water quality goals. *Environmental Management* 5:55-68.

Karr, J. R., and E. W. Chu. 1997. *Biological monitoring and assessment: Using multimetric indices effectively*. EPA 235-R97-001. Seattle, WA: University of Washington.

Keeley, J. E. 2002. Native American impacts on fire regimes of the California coastal ranges. *Journal of Biogeography* 29:303-320.

Keller, E. A. 1972. Development of alluvial stream channels: A five-stage model. *Geological Society of America Bulletin* 83:1531-1536.

Kershner, J. L. 1997. Setting riparian/aquatic restoration objectives within a watershed context. *Restoration Ecology* 5:15-24.

Klein, R. 1979. Urbanization and stream quality impairment. American Water Resources Association. *Water Resources Bulletin* 15(4).

Knopf, F. L., R. R. Johnson, T. Rich, F. B. Samson, and R. C. Szaro. 1988. Conservation of riparian ecotones in the United States. *Wilson Bulletin* 100:272-284.

Knox, J. C., P. J. Bartlein, K. K. Hirschboek, and R. J. Muckenhirn. 1975. *The response of floods and sediment yields to climatic variation and land use in the Upper Mississippi Valley*. Madison, WI: Institute of Environmental Studies, University of Wisconsin.

Kondolf, G. M. 1997. Hungry water: Effects of dams and gravel mining on river channels. *Environmental Management* 21:533-51.

Kondolf, G. M., J. W. Webb, M. J. Sale, and T. Felando. 1987. Basic hydrologic studies for assessing impacts of flow diversions on riparian vegetation - examples from streams of the Eastern Sierra Nevada, California, USA. *Environmental Management* 11:757-769.

Kovalchik, B. L., and L. A. Chitwood. 1990. Use of geomorphology in the classification of riparian plant associations in mountainous landscapes of central Oregon, USA. *Forest Ecology and Management* 33-4:405-18.

Kuenzler, E. J. 1977. *Water quality in North Carolina Coastal Plain streams and effects of channelization*. Water Resources Research Institute Report No. 127. Raleigh, NC: University of North Carolina.

Kuenzler, E. J. 1986. Land use and nutrient yields of the Chowan River watershed. In *Watershed research perspectives*, ed. D. L. Correll, 77-107. Washington, DC: Smithsonian Institution Press.

La Polla, V. N., and G. W. Barrett. 1993. Effects of corridor width and presence on the population dynamics of the meadow vole *Microtus pennsylvanicus*. *Landscape Ecology* 8:25-37.

Ladson, A. R., J. W. Lindsay, J. A. Doolan, B. L. Finlaysons, B. T. Hart, P. S. Lake, and J. W. Tilleard. 1999. Development and testing of an index of stream condition for waterway management in Australia. *Freshwater Biology* 41:453-468.

Lee, L. C., M. C. Rains, J. A. Mason, and W. J. Kleindle. 1997. *Peer review draft guidebook to hydrogeomorphic functional assessment of riverine waters/wetlands in the Santa Margarita Watershed.*

Leibowitz, S. G., and J. B. Hyman. 1999. Use of scale invariance in evaluating judgment indicators. *Environmental monitoring and assessment* 58: 283-303.

Leibowitz, S. G., B. Abbruzzese, P. R. Adamus, L. E. Hughes, and J. T. Irish. 1992. *A synoptic approach to cumulative impact assessment: A proposed methodology*. EPA/600/R-92/167. Corvallis, OR: US Environmental Protection Agency, Environmental Research Laboratory.

Lichvar, R. 2003. *Landscape scale delineation of wetlands and waters of the United States in the Otay Watershed, San Diego County, California*. Final Report to the U.S. Army Corps of Engineers, Los Angeles District. Hanover, NH: US Army Engineer Research and Development Center.

Lichvar, R., and J. S. Wakeley. 2004. *Review of ordinary high water mark indicators for delineating arid streams in the Southwestern United States*. Technical Report ERDC/EL TR-04-1. Vicksburg, MS: US Army Engineer Research and Development Center.

Lichvar, R., D. C. Finnegan, M. P. Ericsson, and W. Ochs. 2006. *Distribution of ordinary high water mark (OHWM) indicators and their reliability in identifying the limits of waters of the United States in arid southwestern channels*. Technical Report ERDC/CRREL TR-06-5. Hanover, NH: US Army Engineer Research and Development Center.

Ligon, F. K., W. E. Dietrich, W. J. Trush. 1995. Downstream ecological effects of dams. *BioScience* 45:183-92.

Lotspeich, F. B., and W. S. Platts. 1982. An integrated land-aquatic classification system. *North American Journal of Fisheries Management* 2:138-149.

Machtans, C. S., M. A. Villard, and S. J. Hannon. 1996. Use of riparian buffer strips as movement corridors by forest birds. *Conservation Biology* 10:1366-79.

Malanson, G. P. 1993. *Riparian landscapes*. New York: Cambridge University Press.

Miles, S. R., and C. B. Goudey (compilers). 2003. *Ecological units of California: Section 261B southern California Coast*. San Francisco, CA: USDA Forest Service. http://www.fs.fed.us/r5/projects/ecoregions/261b.htm (Accessed 15 July 2003).

Miltner, R. J., and E. T. Rankin. 1998. Primary nutrients and the biotic integrity of rivers and streams. *Freshwater Biology* 40:145-158.

Naiman, R. J., and H. Decamps. 1990. The ecology and management of aquatic terrestrial ecotones. Volume 4, *Man and the Biosphere*. Paris, France: Parthenon Press.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3: 209-12.

National Academy of Sciences. 2000. *Ecological indicators for the Nation*. Washington, DC: National Academy Press.

Natural Resources Conservation Service (NRCS). 1998. *California unified watershed assessment*. http://www.ca.nrcs.usda.gov/features/projects/cwap/UWAreportf.html

Olson, C., and R. Harris. 1997. Applying a two-stage system to prioritize riparian restoration at the San Luis Rey River, San Diego County, California. *Restoration Ecology* 5: 43-55.

Oregon Water Enhancement Board. 1999. *Oregon Watershed Assessment Manual*. http://www.oregon.gov/OWEB/docs/pubs/ws_assess_manual.shtml

Osborne, L. L., and D. A. Kovacic. 1993. Riparian vegetated buffer strips in water quality restoration and stream management. *Freshwater Biology* 29:243-258.

Perry, J., and E. Vanderklein. 1996. Water quality management of a natural resource. Cambridge, MA: Blackwell Science.

Peterjohn, W. T. and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed - observations on the role of a riparian forest. *Ecology* 65:1466-1475.

Peterjohn, W. T. and D. L. Correll. 1986. The effect of riparian forest on the volume and chemical composition of baseflow in an agricultural watershed. In *Watershed Research Perspectives*, ed. D. L. Correll. Washington, DC: Smithsonian Institution Press.

Petersen, R. C., L. M. Petersen, and J. O. Lacoursiere. 1992. A building block model for stream restoration. In *The Conservation and Management of Rivers,* ed. P. Boon, G. E. Petts, and P. Callow. Chichester, UK: John Wiley and Sons.

Petts, G.E. 1996. Water allocation to protect river ecosystems. *Regulated Rivers Research and Management* 12:353-65.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromburg. 1997. The natural flow regimes: A paradigm for river conservation and restoration. *BioScience* 47:769-784.

Power, M. E., R. J. Stout, C. E. Cushing, P. P. Harper, F. R. Hauer, W. J. Matthews, P. B. Moyle, B. Statzner, and I. R. Wais. 1988. Biotic and abiotic controls in river and stream communities. *Journal of the North American Benthological Society* 7:456-79.

Power, M. E., W. E. Dietrich, and J. C. Finlay. 1996. Dams and downstream aquatic biodiversity: Potential food web consequences of hydrologic and geomorphic change. *Environmental Management* 20:887-95.

Prichard, D. 1993. *Riparian area management: Process for assessing proper functioning condition for lentic riparian wetland areas*. Boulder, CO: U.S. Department of the Interior Bureau of Land Management Service Center.

Radmacher, R., and J. Ryden. 2005. *South Sacramento habitat conservation plan* (Draft). http://www.planning.saccounty.net/habitat-conservation/overview.html

Rapport, D. J. 1989. What constitutes ecosystem health? *Perspectives in Biology and Medicine* 33:120-133.

Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, and R. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7:433-55.

Reynolds, K. M. 2002. *Ecosystem Management Decision Support 3.0*. General Technical Report PNW-GTR-470. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station. http://www.fsl.orst.edu/emds/

Reynolds, K. M., and P. F. Hessburg. 2005. Decision support for integrated landscape evaluation and restoration planning. *Forest Ecology and Management* 207:263-278.

Reynolds, K. M., M. Jensen, J. Andreason, and I. Goodman. 2000. Knowledge-based assessment of watershed condition. *Computers and Electronics in Agriculture* 27:315-333.

Reynolds, K. M., P. Cunningham, L. Bednar, M. Saunders, M. Foster, R. Olson, D. Schmoldt, D. Latham, B. Miller, and J. Steffenson. 1996. A design framework for a knowledge-based information management system for watershed analysis in the Pacific Northwest U.S. *AI Applications* 10:9-22.

Rheinhardt, R. D., and M. M. Brinson. 1997. Applying wetland reference data to functional assessment, mitigation, and restoration. *Wetlands* 17:195-215.

Rheinhardt, R. D., M. C. Rheinhardt, M. M. Brinson, and K. E. Faser, Jr. 1999. Application of reference data for assessing and restoring headwater ecosystems. *Restoration Ecology* 7: 241–51.

Richards, C. L., and G. E. Host. 1994. Examining land use influences on stream habitats and macroinvertebrates: A GIS approach. *Water Resources Bulletin* 30:729-37.

Richards, C. L., L. B. Johnson, and G. E. Host. 1996. Landscape scale influences on stream habitats and biota. *Canadian Journal of Fisheries and Aquatic Sciences* 53:295-311.

Richards, K. 1982. *Rivers: Form and process in alluvial channels*. London, UK: Methuen and Company.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10:1163-1174.

Richter, B. D., J. V. Baumgartner, R. Wigington, and D. P. Braun. 1997. How much water does a river need? *Freshwater Biology* 37:231-249.

Rood, S. B., and J. M. Mahoney. 1990. Collapse of riparian popular forests downstream from dams in western prairies: Probable causes and prospects for mitigation. *Environmental Management* 14:451-464.

Rosgen, D. 1996. *Applied river morphology*. Pagosa Springs, CO: Wildland Hydrology.

Rothrock, J. A., P. K. Barten, and G. L. Ingman. 1998. Land use and aquatic biointegrity in the Blackfoot River watershed, Montana. *Journal of the American Water Resources Association* 34:565-81.

Rumsby, B. T., and M. G. Macklin. 1994. Channel and floodplain response to recent abrupt climate change: The Tyne Basin, Northern England. *Earth Surface Processes and Landforms* 19:499-515.

Ryan, P. A. 1991. Environmental effects of sediment on New Zealand streams: A review. *New Zealand Journal of Marine and Freshwater Research* 25:207-21.

Schubauer-Berigan, M. K., M. Smith, J. Hopkins, and S. M. Cormier. 2000. Using historical biological data to evaluate status and trends in the Big Darby Creek watershed (Ohio, USA). *Environmental Toxicology and Chemistry* 19:1097-1105.

Schueler, T. R. 1994. The importance of imperviousness. *Watershed Protection Techniques 1*: 100–111.

Schueler, T. R., and H. K. Holland (ed.) 2000. *The practice of watershed protection*. Ellicott City, MD: Center for Watershed Protection.

Schumaker, N. H. 1996. Using landscape indices to predict habitat connectivity. *Ecology* 77: 1210-1225.

Scrimgeour, G. J., and D. Wicklum. 1996. Aquatic ecosystem health and integrity: Problems and potential solutions. *Journal of the North American Benthological Society* 15:254-261.

Sedell, J. R., and K. J. Luchessa. 1981. Using the historical record as an aid to salmonid habitat enhancement. Paper presented at *American Fisheries Society Symposium Proceedings: Acquisition and Utilization of Aquatic Habitat Inventory Information*.

Sedgwick, J. A., and F. L. Knopf. 1991. Prescribed grazing as a secondary impact in a western riparian floodplain. *Journal of Range Management* 44:369-374.

Shankman, D., and S. A. Samson. 1991. Channelization effects on Obion River flooding, Western Tennessee. *Water Resources Bulletin* 27:247-54.

Shilling, F. S., S. Sommarstrom, R. Kattelmann, B. Washburn, J. Florsheim, and R. Henly. 2005. *California Watershed Assessment Manual, Volume 1*. Prepared for the California Resources Agency and the California Bay-Delta Authority. http://cwam.ucdavis.edu/

Skahill, B. E. 2004. *Use of the Hydrological Simulation Program – FORTRAN (HSPF) model for watershed studies*. SMART Technical Notes Collection. ERDC/TN SMART-04-1. Vicksburg, MS: US Army Engineer Research and Development Center.

Smith, D. W., and W. L. Verrill. 1998. Vernal pool-soil-landform relationships in the Central Valley, California. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems– Proceedings from a 1996 Conference*, ed. C.W. Witham, E. T. Bauder, D. Belk, W. R. Ferren, Jr., and R. Ornduff, 15-23. Sacramento, CA: California Native Plant Society.

Smith, R. D. 2004. *Assessment of riparian ecosystem integrity: Otay River Watershed, San Diego County, California*. Final Report to the U.S. Army Engineer District, Los Angeles. Vicksburg, MS: US Army Engineer Research and Development Center.

Smith, R. D. 2005. *Alternatives analysis for San Juan and Western San Mateo Creek Watersheds, Orange County, California: Potential impacts to waters of the United States and riparian ecosystems*. Vicksburg, MS: US Army Engineer Research and Development Center.

Smith, R. D. 2006. *Synthesis Report of Supplementary Habitat and Hydrology Studies in the San Jacinto, Santa Margarita, and Otay Watersheds in Support of Special Area Management Plans*. Vicksburg, MS: US Army Engineer Research and Development Center.

Smith, R. D. 2008. *Russian River Watershed Management Plan: Baseline Watershed Assessment Synthesis Report*. Vicksburg, MS: US Army Engineer Research and Development Center.

Smith, R. D., and C. V. Klimas. 2006. *Riparian Restoration Plan Otay River Watershed: General design criteria and site selection*. Report to the US Army Engineer District, Los Angeles, Regulatory Branch. Vicksburg, MS: US Army Engineer Research and Development Center.

Smith, R. D., and F. Tabatabai. 2004. Assessing riparian ecosystem integrity, analyzing alternative development scenarios, and planning for restoration in a watershed context. *Aquatic Resources News - A Regulatory Newsletter* 3:2-9.

Smith, R. D., and L. T. Carpenter. 2008. Reference-based approaches for ecosystem assessment, restoration, management and monitoring. *Environmental Management* 23: 118-130.

Smith, R. D., A. Amman, C. Bartoldus, and M. M. Brinson. 1995. *An approach for assessing wetland functions based on hydrogeomorphic classification, reference wetlands, and functional indices*. Technical Report WRP-DE-9. Vicksburg, MS: US Army Engineer Waterways Experiment Station.

South Sacramento Habitat Conservation Plan (SSHCP). 2005 (Draft). *South Sacramento Habitat Conservation Plan. Appendix B: Grassland habitat account and conservation goals for the South Sacramento Habitat Conservation Plan*. Sacramento, CA: May and Associates.

Statzner, B., H. Capra, L. W. G. Higler, and A. L. Roux. 1997. Focusing environmental management budgets on non-linear systems responses: Potential for significant improvements to freshwater ecosystems. *Freshwater Biology* 37:463-472.

Stephenson, J. R., and G. M. Calcarone. 1999. *Southern California mountains and foothills assessment: Habitat and species conservation issues*. General Technical Report GTR-PSW-175. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.

Stoddard, J., P. Larsen, C. P. Hawkins, R. Johnson, and R. Norris. 2006. Setting expectations for the ecological condition of running waters: The concept of reference conditions. *Ecological Applications* 16:1267-1276.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union* 38:913-920.

Strand, R. G. 1962. *Geologic Map of California, San Diego-El Centro Sheet*. Sacramento, CA: California Division of Mines and Geology.

Stromberg, J. C., and D. C. Patten. 1990. Riparian vegetation instream flow requirements: A case study from a diverted stream in eastern Sierra Nevada. *Environmental Management* 14:185-194.

Stromberg, J. C., and D. C. Patten. 1991. Instream flow requirements for cottonwoods at Bishop Creek, Inyo County, California. *Rivers* 2:1-11.

Suter, G. W. 1993. A critique of ecosystem health concepts and indexes. *Environmental Toxicology and Chemistry* 12:1533-1539.

Taylor, D. W. 1982. *Eastern Sierra riparian vegetation: Ecological effects of stream diversions*. Mono Basin Research Group Contribution Number 6.

Trimble, S. W. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. *Science* 278:1442-1444.

U.S. Environmental Protection Agency (USEPA). 2002. *Methods for evaluating wetland conditions: #6 Developing metrics and indexes of biological integrity*. EPA-822-R-02-016. Washington, DC: Office of Water, U.S. Environmental Protection Agency.

U. S. Fish and Wildlife Service (USFWS). 1980. Ecological Services Manual (101-104 ESM). Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Division of Ecological Services.

Veery, E. S., C. A. Dolloff, and M. E. Manning. 2004. Riparian ecotones: A functional definition and delineation for resource assessment. *Water, Air, and Soil Pollution: Focus* 4:67-94.

Vought, L. M. B., J. Dahl, C. L. Pederson, and J. O. Lacoursiere. 1994. Nutrient retention in riparian ecotones. *Ambio* 23:342-348.

Wang, L. Z., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. *Fisheries* 22:6-12.

Warner, R. E., and K. M. Hendrix (ed.). 1984. *California riparian systems*. Berkeley, CA: University of California Press.

Warren, C. E. 1979. *Toward classification and rationale for watershed management and stream protection*. EPA-600/3-79-059. U.S. Environmental Protection Agency.

Wilber, D. H., R. E. Tighe, and L. J. Oneil. 1996. Associations between changes in agriculture and hydrology in the Cache River Basin, Arkansas, USA. *Wetlands* 16:366-78.

Williams, G. P. 1978. Bankfull discharge of rivers. *Water Resources Research* 14:1141-1154.

Williamson, R. B., R. K. Smith, and J. M. Quinn. 1992. Effects of riparian grazing and channelization on streams in Southland, New Zealand. 1. Channel form and stability. *New Zealand Journal of Marine and Freshwater Research* 26:241-58.

Zhang, Z., and B. E. Johnson. 2003. *MIKE SHE Flow Modeling System Evaluation for the Santa Margarita River Watershed*. Vicksburg, MS: US Army Engineer Research and Development Center.

Appendix A: Baseline Assessment Case Study

Introduction

This case study is a baseline assessment of riparian integrity in the proposed South Sacramento Habitat Conservation Plan (SSHCP) project area (Figure A1). It is presented here to illustrate the use of integrity indices in conducting a watershed assessment. The SSHCP is a regional approach to addressing issues related to urban development, habitat conservation, open space protection, and agricultural protection. The SSHCP will consolidate environmental efforts to protect and enhance wetland (primarily vernal pools), riparian, aquatic, and upland habitats to provide ecologically viable conservation areas. It will also minimize regulatory hurdles and streamline the permitting process for projects that engage in development activities (Radmacher and Ryden 2005).

The project had two objectives. The first was to assess riparian integrity under current conditions and then use that information to compare and visually display riparian integrity across the project area. The second objective was to provide a procedure to estimate direct and indirect impacts of future projects on riparian integrity through the simulation of proposed project impacts. The latter is particularly useful in a planning context to determine which of two or more project alternatives will have the least impact to riparian integrity, or to compare baseline conditions to actual, or simulated, post-project conditions in order to determine the extent of mitigation requirements (Smith 2005). Additionally, the baseline assessment, in conjunction with a riparian restoration plan and a specified set of objectives, provides a basis for determining where, and to some degree how, to conduct riparian restoration projects (Smith and Klimas (2006) and Appendix C of this report).

Background

The term "riparian" has been defined in many ways for various purposes, and over the past 35 years a variety of other terms have been linked to it (e.g., riparian ecosystem, riparian corridor, riparian zone, and riparian area) (Veery et al. 2004). For the baseline assessment of riparian integrity, the following definition of riparian ecotone, originally developed by Ilhardt et al. (2000) and subsequently modified by Veery et al. (2004), was used:

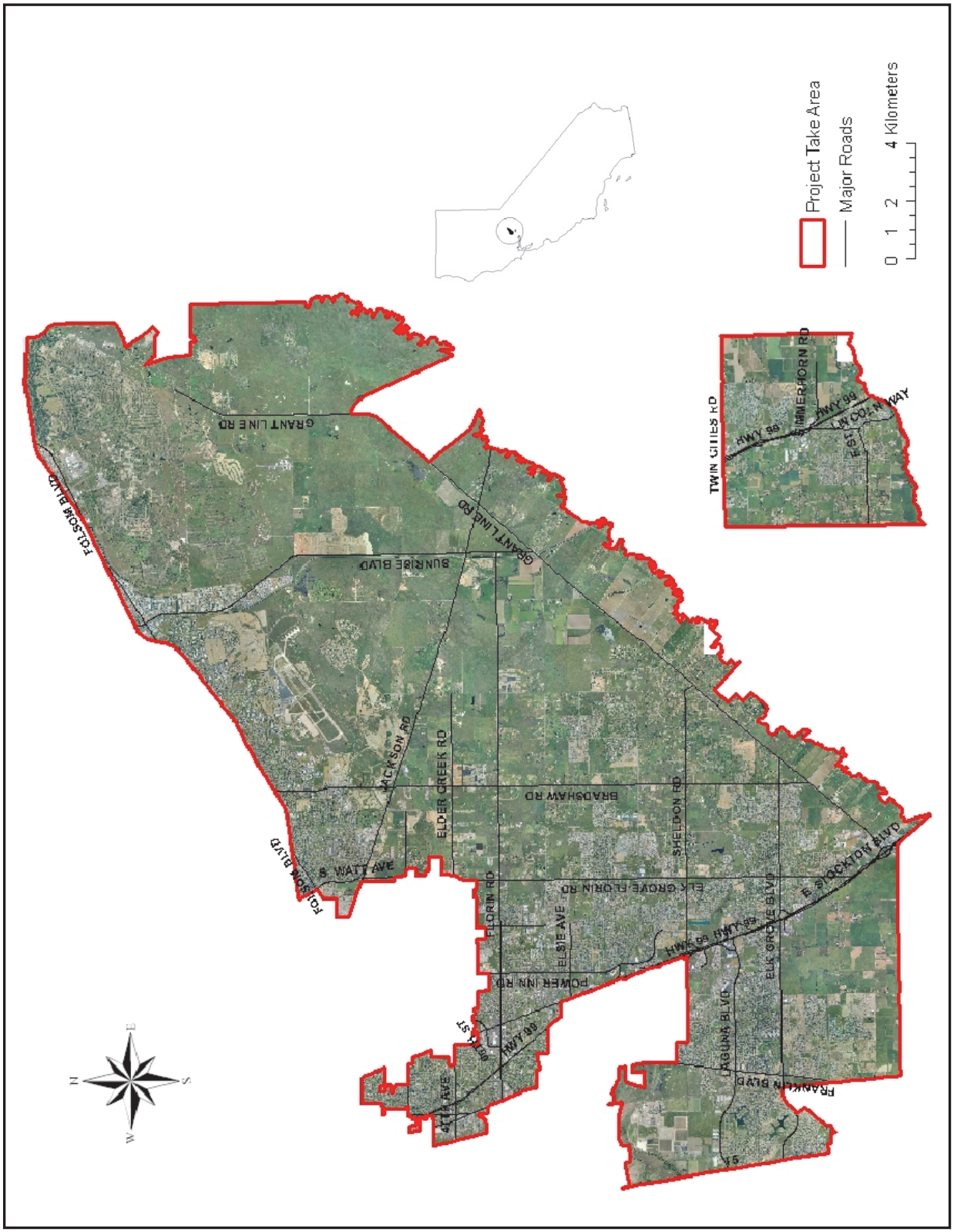


Figure A1. South Sacramento Habitat Conservation Plan project area.

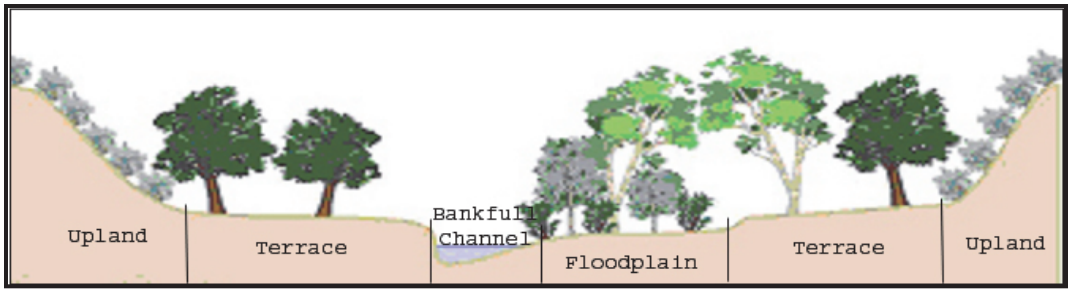
> *Riparian ecotones are a three-dimensional space of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.*

Linking "riparian" with the term "ecotone" in the definition is preferable because of the ambiguity surrounding terms such as riparian corridor and riparian zone, and the fact that the term "ecosystem," like "watershed," has the troublesome characteristic of being applicable at virtually all spatial scales.

Riparian ecotones adjacent to streams, lakes, and estuarine-marine shorelines are characterized by distinct structural attributes, processes, functions, biota, and biophysical gradients that influence the exchange of energy and matter between terrestrial and aquatic ecosystems (National Academy of Sciences 2000, Williams 1978). Riparian ecotones adjacent to ephemeral, intermittent, and perennial streams typically exhibit distinctive geomorphic features and vegetation communities that reflect the hydrologic interactions among the stream, the riparian ecotone, and the adjacent terrestrial areas (Richards 1982, Harris 1987, Kovalchik and Chitwood 1990, Gregory et al. 1991, Malanson 1993, and Goodwin et al. 1997).

The hydrologic interaction between streams and riparian ecotones typically results in two distinct zones, although either area may be narrow and seemingly absent under certain geologic or geomorphic conditions such as V-shaped valleys or broad valleys with low slopes. The first zone (Figure A2) is the active floodplain, which includes those portions of a riparian ecotone that are normally inundated by overbank flooding at a frequency of one to two years, but up to a frequency of five to ten years under certain conditions in arid areas of the western United States (Lichvar et al. 2006, Lichvar and Wakeley 2004). The active floodplain exhibits the fluvial features associated with frequent flooding such as point bars, areas of scour, sediment accumulation, natural levees, debris wrack, and vegetation communities that are either short- lived or adapted to survive the physical effects of frequent flooding.

Figure A2. Generalized cross section of a riparian ecotone.



The second zone includes one or more terraces that are abandoned (i.e., historical) floodplains formed by fluvial processes under historical, and often different, climatic conditions or hydrologic regimes (Knox et al. 1975, Graf et al. 1991, Rumsby and Macklin 1994). Under current climatic conditions and hydrologic regimes, terraces are typically flooded infer-quently during larger magnitude events (Dunne and Leopold 1978). Vegetation communities on terraces normally consist of woody perennials that require the shallow high water table, or bank storage, that is often present in the riparian ecotones, and are adapted to survive, or reestablish after, large flood events.

Reference condition

Much has been written about the integrity and health of ecosystems (Rapport 1989, Costanza et al. 1991, Suter 1993, Scrimgeour and Wicklum 1996, Karr 1999). While the two terms are often used interchangeably, the distinction made by Karr (1996) is instructive and important in terms of interpreting and applying the mandate of the Clean Water Act. "Integrity" refers to the quality, or state of being whole, complete, self -sustaining, and corresponding to a natural or original condition. "Health," on the other hand, refers to a flourishing condition, well-being, or vitality (Guralnik and Friend 1968). Based on these distinctions, a cornfield, pine plantation, commercial nursery, or other intensively managed ecosystem is healthy, but does not have integrity.

In order to assess the integrity of riparian ecotones, a standard of comparison or "reference condition" must be defined (Smith et al. 1995, Brinson and Rheinhardt 1996, Rheinhardt et al. 1999, Rheinhardt and Brinson 1997, Bailey et al. 2004, Egan and Howell 2001). Defining a reference condition serves two purposes. First, it provides an explicit representation, across multiple spatial scales, of the conditions under which a riparian ecotone is considered to have integrity. Second, it provides a basis for defining the

relationship between riparian integrity and the biotic and abiotic factors that are used to assess riparian ecotone integrity.

The reference condition used for the baseline assessment was a "minimally disturbed condition," which Stoddard et al. (2006) defined as the absence of local human disturbance, while recognizing that minimal impacts related to human activities at regional and global spatial scale are ubiquitous (e.g., deposition of atmospheric contaminants below the threshold required to have a measurable impact on an ecosystem). It can be argued that minimally disturbed conditions are difficult to define because few examples of this condition exist. This is due to the widespread existence of grazing, fire suppression, urban development, non-point air pollution, the disruption of historical metapopulation dynamics (Hastings and Harrison 1994), and a host of other factors. Sedell and Luchessa (1981) and Schubauer-Berigan et al. (2000) have shown that it is possible to reconstruct minimally disturbed conditions given adequate time and resources. In addition, it is relatively easy to define minimally disturbed conditions for many of the indicators (see Section titled "Indicators for Assessing Riparian Integrity") used in the baseline assessment. This is due primarily to the indicators selected and the way in which they were defined. For example, in the case of the indicators related to land use, it was reasonable to assume that under the culturally unaltered condition no grazing, agriculture, transportation, or urban development land uses existed. Similarly, in the case of the altered hydrologic conveyance indicator, it was reasonable to assume that under minimally disturbed conditions, stream channels were not straightened, lined, impounded, or piped and buried (Hughes et al. 1986). Finally, while it may not be possible to restore minimally disturbed conditions, it is often feasible to restore some of the larger, isolated, and remote areas to a condition that functionally approximates minimally disturbed conditions given adequate time, resources, and appropriate management strategies.

Indicators for assessing riparian integrity

The objective in selecting indicators to assess riparian integrity was to capture, to the greatest degree possible, the full range of characteristics and attributes, across multiple spatial scales that influence hydrologic, water quality, and habitat integrity of riparian ecotones. Potential indicators were initially gleaned from a review of existing assessment methods (Dinius 1987, Lee et al. 1997, Ladson et al. 1999). Additional potential indicators were based on the literature related to riparian

ecotones, and the collective field experience of the authors and numerous colleagues.

Several factors influenced which assessment indicators were ultimately selected. The first was the ease of measure. Preference was given to indicators that could be measured rapidly and accurately in the field, or through the use of remotely sensed data and GIS analysis. The second factor was indicator sensitivity. In order for an indicator to be useful, it had to be sensitive enough to distinguish relevant differences in riparian ecotones with regard to the characteristic or process being assessed. The third factor was the requirement to develop an open and easily understood approach that would allow participation and input from multiple stakeholders representing a range of perspectives from the development community to federal and state agencies. Ultimately, balancing all of these factors determined which indicators were selected for assessing hydrologic, water quality, and habitat integrity of riparian ecotones.

The relationship between indicators and riparian integrity was defined primarily using an ordinal, linear scale. This assumed that deviation from the reference condition represented an equivalent decrease in the level of riparian integrity in terms of the specific indicator. This approach to scaling was possible because of the way in which indicator metrics were defined and measured (i.e., deviation from the reference condition). Using the Altered Hydraulic Conveyance indicator (below) as an example, the indicator metric was defined as the percent of the main stem channel in the riparian reach with altered hydraulic conveyance. The reference condition was defined as 0% of the riparian reach with altered hydraulic conveyance. If 25% of the main stem channel in a riparian reach exhibited altered hydraulic conveyance, then an indicator metric value of 25 was assigned to the Altered Hydraulic Conveyance indicator for that riparian reach. Similarly, if 100% of the main stem channel in a riparian reach exhibited altered hydraulic conveyance, then an indicator metric value of 100 was assigned to the Altered Hydraulic Conveyance indicator for that riparian reach.

Table A1 summarizes the indicators used to assess riparian hydrologic, water quality, and habitat integrity. In the following sections, each indicator is defined, the relationship between the indicator and relevant integrity indices (i.e., endpoints) is discussed, the metric used to measure the indicator is defined, the method used to assign a metric value to a riparian assessment unit is described, and the reference condition is defined.

Table A1. Indicators used to assess riparian hydrologic, water quality, and habitat integrity.

Indicator Acronym	Indicator Description (Spatial Scale*)	Hydrologic Integrity Index Indicator Weight	Water Quality Integrity Index Indicator Weight	Habitat Integrity Index Indicator Weight
AHC $_{RR}$	Altered Hydraulic Conveyance (RR*)	1.0	1.0	
AHC $_{DB}$	Altered Hydraulic Conveyance (DB)	0.20	0.11	
BUF $_{RR}$	Riparian Buffer (RR)			1.0
IED $_{RR}$	Import, Export, or Diversion (RR)	1.0	1.0	
IED $_{DB}$	Import, Export, or Diversion (DB)	0.20	0.11	
LULCH $_{LD}$	Land Use Land Cover / Hydrocarbons (LD)		1.0	
LULCH $_{DB}$	Land Use Land Cover / Hydrocarbons (DB)		0.11	
LULCN $_{LD}$	Land Use Land Cover / Nutrients (LD)		1.0	
LULCN $_{DB}$	Land Use Land Cover / Nutrients (DB)		0.11	
LULCP $_{LD}$	Land Use Land Cover / Pesticides (LD)		1.0	
LULCP $_{DB}$	Land Use Land Cover / Pesticides (DB)		0.11	
LULCS $_{LD}$	Land Use Land Cover / Sediments (LD)		1.0	
LULCS $_{DB}$	Land Use Land Cover / Sediments (DB)		0.11	
LULCI $_{LD}$	Land Use Land Cover / Impervious Land Surfaces (LD)	1.0	1.0	
LULCI $_{DB}$	Land Use Land Cover / Impervious Land Surfaces (DB)	0.20	0.11	
LULCW $_{LD}$	Land Use / Land Cover Wildlife Habitat (LD)			1.0
* Spatial scales: RR = Riparian Reach LD = Local Drainage DB = Drainage Basin (see Section 3.1)				
MSF $_{RR}$	Modified Stream Flow (RR)	1.0	1.0	
MSF $_{DB}$	Modified Stream Flow (DB)	0.20	0.11	
RCC $_{RR}$	Riparian Corridor Continuity (RR)			1.0
RCC $_{DB}$	Riparian Corridor Continuity (DB)			1.0
RVF $_{RR}$	Riparian Vegetation Floodplain (RR)			0.5
RVT $_{RR}$	Riparian Vegetation Terrace (RR)			0.5
SFI $_{RR}$	Stream / Floodplain Interaction (RR)	1.0	1.0	
SR $_{RR}$	Sediment Regime Index (RR)		1.0	
SWD $_{LD}$	Surface Water Detention (LD)	1.0	1.0	
SWD $_{DB}$	Surface Water Detention (DB)	0.20	0.11	
Minimum / Maximum Integrity Index (non-normalized)		7 / 700	12 / 1200	5 / 500
* Spatial scales: RR = Riparian Reach LD = Local Drainage DB = Drainage Basin (see Section 4.6)				

Altered Hydraulic Conveyance indicator (AHC_{RR} / AHC_{DB})

The Altered Hydraulic Conveyance indicator assesses the degree to which the surface water flow in the main stem stream channel of a riparian reach has been altered as a result of modification of the stream channel. The

engineering techniques involved are usually designed to reduce the frictional resistance (i.e., roughness) caused by channel substrate, vegetation, woody debris, or other objects in the channel (Barnes 1967); reduce the wetted perimeter; or shorten the length of a channel. An increase in the volume and/or velocity of water conveyed by a stream channel can result in significant changes to the hydrologic regime in the riparian reach where it occurs as well as in upstream and downstream riparian reaches. For example, vegetation removal can decrease channel stability and increase erosion by reducing the resistance afforded by the network of plant roots, and by increasing the velocity and consequently the erosive force of water in the channel. A straightened stream reach will typically respond by incising to reestablish a more energy-efficient and stable channel slope (Shankman and Samson 1991). This in turn may result in the initiation of head cuts, bank destabilization, and increased erosion in upstream channels. Downstream of an altered stream channel, the hydrologic regime can also be affected in terms of increased peak discharges, decreased channel stability, and, depending on slope, either increased sedimentation or increased erosion.

The metric for this indicator was defined as the percent of the main stem channel of the riparian reach with altered hydraulic conveyance. At the riparian reach spatial scale, metric values were assigned based on field observation and interpretation of aerial photography. At the drainage basin spatial scale, metrics values were calculated as the weighted average of the percent of Altered Hydraulic Conveyance for all riparian reaches in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[AHC_{RR} * \left(ML_{RR} \Big/ ML_{DB}\right)\right] \quad \text{(A1)}$$

where:

AHC_{RR} = % of main stem in a riparian reach with altered hydraulic conveyance
ML_{RR} = length of main stem channel in a riparian reach
ML_{DB} = length of main stem channel of all riparian reaches in drainage basin

The reference condition was defined as none (i.e., 0%) of the main stem stream channel with altered hydraulic conveyance.

Riparian buffer indicator (BUF_{RR})

The Riparian Buffer indicator assesses the degree to which the Land Use/ Land Cover (LULC) in a 300-ft buffer zone around the main stem stream is suitable for wildlife usage and movement. The LULC in the area adjacent to the riparian ecotone plays an important role in determining the ability of animals to move freely between riparian and adjacent upland ecosystems on a daily or seasonal basis (Petersen et al. 1992, Vought et al. 1994, Statzner et al. 1997, Osborne and Kovacic 1993). Under natural conditions, vegetation in the riparian buffer often gradually transitions to upland vegetation, particularly in higher order streams with larger floodplains. In lower order streams, the interface between the riparian area and uplands can be abrupt. A variety of cultural activities replace these native or naturalized vegetation communities with agriculture, grazing, urban/industrial, transportation corridors, or other types of LULC that reduce the likelihood that wildlife can utilize the riparian buffer, or move freely between the riparian zone and adjacent upland habitats.

The metric for this indicator was defined as the percent of the riparian buffer supporting the type of vegetation communities that would occur under natural conditions. This metric was calculated by delineating a 300-ft buffer around the main stem stream of a riparian reach. The percent of this buffer supporting natural vegetation communities was estimated using aerial imagery from various years and seasons. Portions of the buffer that did not support natural vegetation communities were classified as either 1) altered and not restorable, or 2) altered and restorable. The altered and not restorable class included those areas where restoration of natural vegetation communities would be difficult due to the presence of permanent infrastructure such as roads, urban residential or commercial developments, and industrial areas. The altered and restorable class included those areas where restoration of natural vegetation communities was considered to be both feasible and practical. The reference condition was defined as 100% of the riparian buffer supporting natural vegetation communities.

Import, Export, or Diversion of Surface Water indicator (IED_{RR} / IED_{DB})

The Import, Export, or Diversion of Surface Water indicator assesses the degree to which the hydrologic regime of a riparian reach has been altered as a result of import, export, or diversion of surface water. Inter-basin import and export of surface water and the intra-basin diversion of water

for public water supply, irrigation, and groundwater recharge is common in the arid and semi-arid western United States. The import, export, or diversion of water within and between watersheds has been shown to affect a wide variety of biotic and abiotic processes as a result of changes in the quantity and timing of surface water discharge and other aspects of the hydrologic regime (Taylor 1982, Kondolf et al. 1987, Stromberg and Patten 1990, Petts 1996, Davies et al. 1992).

The metric for this indicator was defined as the percent of the main stem channel in a riparian reach with a hydrologic regime significantly altered due to the import, export, or diversion of surface water. At the riparian reach scale, the metric was based on field observations, USGS 7.5-minute quadrangles, and the interpretation of aerial photography. At the drainage basin spatial scale, the metric was calculated as the weighted average of the percent of the main stem channels in all riparian reaches in the drainage basin with a hydrologic regime significantly altered due to the import, export, or diversion of surface water using the following formula:

$$\sum_{i=1}^{i_n}\left[IED_{RR} * \left(ML_{RR} \Big/ ML_{DB}\right)\right] \quad \text{(A2)}$$

where:

IED_{RR} = % of main stem in a riparian reach with import, export, or diversion of surface water
ML_{RR} = length of main stem channel in a riparian reach
ML_{DB} = length of main stem channel of all riparian reaches in drainage basin

The reference condition was defined as none (i.e., 0%) of the main stem stream channel with a hydrologic regime significantly altered by the import, export, or diversion of surface water.

Land Use / Land Cover indicator ($LULCH_{LD}$ / $LULCH_{DB}$ / $LULCN_{LD}$ / $LULCN_{DB}$ / $LULCP_{LD}$ / $LULCPH_{DB}$ / $LULCS_{LD}$ / $LULCS_{DB}$)

The Land Use/Land Cover indicator assesses how the current LULC in an area influences various physical, chemical, and biological characteristics of riparian ecotones. A number of studies have related LULC to water quality in stream channels. These studies consistently show that water quality

decreases as natural vegetation communities are culturally altered, but the specific relationships and causative factors vary widely. For example, Hunsaker and Levine (1995) found that LULC changes in the watershed had the greatest effect on water quality, while Graf (1998) found that changes in LULC in the surrounding landscape had the greatest effect. The relationship between LULC and quantity and quality of surface water has been documented for a variety of wetland and aquatic systems (Brugam 1978, Ehrenfeld 1983, Kuenzler 1986, Howarth et al. 1991, Ryan 1991, Williamson et al. 1992, Richards and Host 1994, Cooper 1995, Blair 1996, Wilber et al. 1996, Caruso and Ward 1998). In the western United States specifically, livestock grazing, agriculture, and urbanization have often been identified as contributors to increased surface water runoff and non-point sources of sediment, nutrients, and other classes of pollutants (Armour et al. 1991, Sedgwick and Knopf 1991, Charbonneau and Kondolf 1993, Busch and Smith 1995, Rothrock et al. 1998).

Four indicators, representing LULC types with the potential to increase the nutrient loading ($LULCN_{LD}$), pesticide loading ($LULCP_{LD}$), hydrocarbon loading ($LULCH_{LD}$), or sediment loading ($LULCS_{LD}$) in downstream surface waters, were used to measure the impact of culturally altered LULC on water quality integrity. The LULC types in the assessment area are shown in Table A2. In the table, LULC types with the potential to increase nutrients, pesticides, hydrocarbons, or sediments are indicated by a "Yes" in Columns 2-5. For example, the agricultural LULC type does not have the potential to increase hydrocarbon, but it does have the potential to increase nutrients, pesticides, and sediment. The decision of whether or not a LULC type had the potential to increase hydrocarbons, nutrients, pesticides, or sediments was based on review of available literature, and the opinion of the authors. It is easy to think of exceptions to the decision rules listed in Table A2. For example, agricultural lands can, and do, provide food resources for certain wildlife species. However, the decision rules are developed in the context of the reference condition for the suite of wildlife species that would have occupied the native vegetation communities replaced by the current LULC. In the case of grazed LULC, it is assumed that species adapted to ungrazed conditions are replaced by species adapted to grazed conditions, and therefore still provide suitable wildlife habitat (South Sacramento Habitat Conservation Plan (SSHCP) 2005, Table 1).

The metric for these four indicators was defined as the percent of the local drainage of the riparian reach with LULC types having the potential to

increase the nutrient, pesticide, hydrocarbon, or sediment loading in downstream surface waters. At the local drainage spatial scale, the metric was calculated based on a GIS analysis of the LULC types in the local drainage. This involved intersecting the LULC coverage with the local drainage coverage in GIS. The resulting database file of the intersected coverage was exported to a spreadsheet and manipulated with pivot tables and macro tools to create a spreadsheet consisting of local drainages (rows) by percent of LULC types increasing loadings. At the riparian reach spatial scale, metrics were based on GIS calculations of the percentage of "increasing" LULC types in the local drainage of the riparian reach. At the drainage basin spatial scale, metrics were calculated as the weighted average of the percent of "increasing" LULC types in the drainage basin of the riparian reach using the following formula:

Table A2. Land Use / Land Cover (LULC) types and their effect on loadings, impervious surfaces, and wildlife habitat suitability.

LULC Type	LULC Type Increases Hydro-carbon Load	LULC Type Increases Nutrient Load	LULC Type Increases Pesticide Load	LULC Type Increases Sediment Load	>15% Impervious Surfaces	LULC Type Unsuitable for Wildlife Habitat
Aqueducts	No	No	No	No	No	No
Blue Oak Woodland	No	No	No	No	No	No
Cottonwood Woodland	No	No	No	No	No	No
Cropland	No	Yes	Yes	Yes	No	Yes
Disturbed	No	No	No	Yes	No	Yes
Eucalyptus Woodland	No	Yes	Yes	Yes	No	Yes
Freshwater Marsh	No	No	No	No	No	No
High-Density Development	Yes	Yes	Yes	No	Yes	Yes
Irrigated Pasture-Grassland	No	Yes	Yes	Yes	No	Yes
Low-Density Development	Yes	Yes	Yes	No	Yes	Yes
Major Roads	Yes	No	Yes	No	Yes	Yes
Mine Tailings	No	No	No	Yes	No	Yes
Mixed Riparian Scrub	No	No	No	No	No	No
Mixed Riparian Woodland	No	No	No	No	No	No
Open Water	No	No	No	No	No	No
Orchards	No	Yes	Yes	Yes	No	Yes
Recreation/Landscaped	No	Yes	Yes	No	No	Yes
Savannah (Assume Grazing)	No	Yes	Yes	Yes	No	No

LULC Type	LULC Type Increases Hydro-carbon Load	LULC Type Increases Nutrient Load	LULC Type Increases Pesticide Load	LULC Type Increases Sediment Load	>15% Impervious Surfaces	LULC Type Unsuitable for Wildlife Habitat
Seasonal Wetlands	No	No	No	No	No	No
Streams/Creeks	No	No	No	No	No	No
Swale (Assume Grazing)	No	Yes	Yes	Yes	No	No
Valley Grassland (Assume Grazing)	No	Yes	Yes	Yes	No	No
Valley Oak Riparian Woodland	No	No	No	No	No	No
Vernal Impoundment	No	No	No	No	No	No
Vernal Pool (Assume Grazing)	No	Yes	Yes	Yes	No	No
Vineyards	No	Yes	Yes	Yes	No	Yes
Wetland Restoration	No	No	No	No	No	No
Woodland Restoration	No	No	No	No	No	No

$$\sum_{i=1}^{i_n}\left[LULCX_{LD} * \left(ML_{LD} \Big/ ML_{DB}\right)\right] \quad \text{(A3)}$$

where:

$LULCX_{LD}$= % of local drainage with increasing LULC types
ML_{LD} = area of local drainage of the riparian reach
ML_{DB} = area of drainage basin of riparian reach

The reference condition for all four indicators was defined as none (i.e., 0%) of the local drainage of the riparian reach with LULC types having the potential to increase the nutrient, pesticide, hydrocarbon, or sediment loading in downstream surface waters.

Impervious Land Surfaces indicator ($LULCI_{LD}$ / $LULCI_{DB}$)

The Impervious Land Surfaces indicator assesses the degree to which the hydrologic regime of a riparian reach has been altered as a result of the increased surface water runoff from impervious land surfaces. Perhaps the single most dramatic and pervasive impact of urbanization on watersheds is the replacement of the natural surface with pavement and other water-impervious material such as roads, parking lots, driveways, sidewalks, and

rooftops. Impervious surfaces interrupt the hydrologic cycle, alter stream structure, and degrade the chemical profile of the water that flows to streams. These changes affect fish and wildlife in various ways, and are cumulative within watersheds. Research indicates that when total impervious area in a watershed reaches 10%, stream ecosystems begin to show evidence of degradation, and degradation becomes severe when the total impervious area approaches 30% (Arnold and Gibbons 1996, Schueler 1994). Effects that have been associated with increases in impervious area include an increase in stream temperature; changes in the quantity, duration, timing of stream flow; and increased concentrations of pollutants in streams (Klein 1979, Benke et al. 1981, Booth 1991, Evett 1994, Booth and Jackson 1997, Schueler and Holland 2000).

The effects of impervious surfaces are not limited to the tract of land where the change actually takes place. Indirect effects often occur in stream, aquatic resources, and riparian systems that occur down gradient from lands covered by impervious surfaces (Ryan 1991). This is, of course, a result of the fact that water and accumulated or eroded materials move down gradient (i.e. downhill and downstream) in response to gravitational forces. The relationship between changes in Land Use Land Cover (LULC) and the quantity and quality of surface water has been documented for a variety of wetland and aquatic systems in the United States (Brugam 1978, Ehrenfeld 1983, Kuenzler 1986, Howarth et al. 1991, Richards and Host 1994, Cooper 1995, Blair 1996, Wilber et al. 1996, Caruso and Ward 1998).

The metric for this indicator was defined as the percent of the Land Use/Land Cover types with greater than 15% impervious surfaces. This percentage was selected, based on Arnold and Gibbons (1996) and Schueler (1994), as a conservative estimate of the point at which impervious surfaces begin to have a significant downstream impact. At the local drainage spatial scale, the metric was calculated based on a GIS analysis of the LULC types in the local drainage. This involved intersecting the LULC coverage with the local drainage coverage in GIS. The resulting database file of the intersected coverage was exported to an Excel spreadsheet and manipulated with pivot tables and macro tools to create a spreadsheet consisting of local drainages (rows) by percent of LULC types with >15% impervious surfaces. At the drainage basin spatial scale, metrics were calculated as the weighted average of the percent of LULC types with >15% impervious surfaces in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[LULCI_{LD} * \left(ML_{LD} \Big/ ML_{DB}\right)\right]\frac{1}{2} \quad \text{(A4)}$$

where:

$LULCI_{LD}$ = % of local drainage with LULC types with >15% impervious surface
ML_{LD} = Area of local drainage of the riparian reach
ML_{DB} = Area of drainage basin of riparian reach

The reference condition was defined as none (0%) of the local drainage of the riparian reach with LULC types with >15% impervious surfaces.

Wildlife Habitat Suitability indicator ($LULCW_{LD}$)

The Wildlife Habitat Suitability indicator assesses the degree to which the LULC in the local drainage of the riparian reach is suitable for wildlife. The upland areas in the local drainage of the riparian ecotones, like the buffer area adjacent to the riparian reach, are important because of their ability to support various other life requirements of riparian-dependent wildlife species. Under reference conditions, these upland areas consist of native vegetation communities to which wildlife is adapted. A variety of cultural activities replace these native vegetation communities with agriculture, urban, industrial, transportation corridors, and other types of land use.

The metric for this indicator was defined as the percent of the Land Use/Land Cover types suitable for wildlife usage. At the local drainage spatial scale, the metric was based on a GIS analysis of the Land Use/Land Cover types in the local drainage. This involved converting the Land Use/Land Cover polygon coverage to raster coverage with 4-ft-square pixels, and then determining what percent of these pixels represented Land Use/Land Cover types suitable for wildlife usage. At the drainage basin spatial scale, metrics were calculated as the weighted average of the percent of Land Use/Land Cover types suitable for wildlife usage for all riparian reaches in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[LULCW_{LD} * \left(ML_{LD} \Big/ ML_{DB}\right)\right] \quad \text{(A5)}$$

where:

$LULCW_{LD}$= % of local drainage with LULC types suitable for wildlife use
ML_{LD} = area of local drainage of the riparian reach
ML_{DB} = area of drainage basin of riparian reach

The reference condition was defined as 100% of the local drainage of the riparian reach with Land Use/Land Cover types suitable for wildlife use.

Modified Stream Flow indicator (MSF_{RR} / MSF_{DB})

The Modified Stream Flow indicator assesses the degree to which the hydrologic regime of a riparian reach has been altered by a supplementary source of surface water. Supplementary sources of surface water include irrigation (e.g., golf courses, plant nurseries, and residential development) or return water (e.g., storm water and treated sewer water). In arid and semi-arid regions, supplementary surface water can result in the perennialization of a stream that facilitates a shift in plant and animal community composition away from what occurs naturally. In addition, perennialization has the potential to alter the physical and chemical processes in riparian ecotones.

The metric for this indicator was defined as the percent of the main stem channel in a riparian reach with modified stream flow due to supplementary sources of water. At the riparian reach spatial scale, metrics were based on field observation and the interpretation of aerial photographs. The evidence used to identify streams with modified surface flow in the field was the presence of low flow during dry periods; nutrient enrichment based on the presence of blue-green algae and vascular species such as cattails; outfall pipes and other outfall structures entering a reach; residential developments, nurseries, and golf courses in the drainage basin; upstream reservoir leakage; and the lack of evidence of a natural low-flow groundwater discharge.

At the drainage basin scale, metrics were calculated as the weighted average of the percent of streams with modified stream flow for all riparian reaches in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[MSF_{RR} * \left(ML_{RR} \Big/ ML_{DB}\right)\right] \quad \text{(A6)}$$

where:

MSF_{RR} = % of main stem in a riparian reach with modified stream flow
ML_{RR} = length of main stem channel in a riparian reach
ML_{DB} = length of main stem channel of all riparian reaches in drainage basin

The reference condition for the indicator was defined as 0% of the main stem channel in riparian reach with modified stream flow.

Riparian Corridor Continuity indicator (RCC_{RR} / RCC_{DB})

The Riparian Corridor Continuity indicator assesses the degree to which the floodplain and terrace of the riparian reach exhibits vegetation of similar type and extent to reference conditions. Riparian ecotones typically form a relatively continuous corridor along the floodplain and terrace. Intact vegetated corridors allow animals to move to locations throughout a watershed on a daily, seasonal, or annual basis (La Polla and Barrett 1993; Machtans et al. 1996; Naiman et al. 1993). The natural fluvial processes that occur during large-magnitude events can result in gaps in the continuous riparian corridor (Hawkins et al. 1997). However, gaps are more frequently created as a result of cultural alterations such as roads, power and pipeline corridors, grazing, agriculture activities, and urban/industrial development. The reference condition for this indicator varied depending on stream order, soil type, and geologic substrate (Table A3). For example, low order streams on non-alluvial soils probably never supported an extensive tree canopy, and therefore the reference condition for these situations was based on the presence of low shrubs and herbaceous vegetation.

The metric for this indicator was defined as the percent of floodplain and terrace of the riparian corridor exhibiting natural vegetation communities (Table A3). At the riparian reach scale, metrics were determined by estimating the percent of floodplain and terrace of the riparian reach that was occupied by riparian vegetation using field observation and aerial photography. At the drainage basin scale, metrics were calculated as the weighted average of the metric for the Riparian Corridor Continuity indicator for all riparian reaches in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[RCC_{RR} * \left(ML_{RR} \Big/ ML_{DB}\right)\right] \quad \text{(A7)}$$

where:

RRC_{RR} = % of floodplain and terrace of the riparian reach exhibiting vegetation similar in type and extent to reference conditions
ML_{RR} = length of main stem channel in a riparian reach
ML_{DB} = length of main stem channel of all riparian reaches in drainage basin

Table A3. Characteristics of riparian ecotones and associated main stem streams.

Geomorphic Zone	Stream Channel Description	Natural Riparian Ecotone Vegetation	Geologic Formation	Land Form	Typical Soil Map Units
1	First- and second-order streams on eroded remnants of mud and lava flow fans. These channels exhibit narrow floodplains and discontinuous, low terrace fragments, and colluvial fans.	Native forbs and grasses occur on floodplains and low stream terraces. Scattered shrubs in seeps, swales, protected areas, and impounded areas.	Mehrten	High Terraces and hills on eroded remnants of mud and lava flow fans	Hicksville Sandy Clay Loam 0-2% (160) Creviscreek Sandy Loam 0-3% (132)
2	First- and second-order streams meandering on alluvium. Second-order streams usually with a first terrace (T1) present, which in many instances is a remnant of an older paleo-terrace or small fan.	Native grasses, forbs, and scattered shrubs and trees on first-order floodplains and, when present, on the T1 terrace. Nearly continuous corridor of native grasses, forbs, shrubs and trees on second-order floodplains and T1 terraces.	Laguna and South Fork Gravels	High Terraces	Red Bluff Loam 0-1% (191) Red Bluff Loam 2-5% (192) Red Bluff - Redding Complex 2-5% (193) Redding Gravelly Loam 2-8% (198) San Joaquin Silt Loam 0-3% (214)
3	Second- and third-order streams meandering on alluvium, with nearly continuous first terrace (T1) and intermittent second terrace (T2).	Continuous riparian forest on the floodplain and T1; native grassland on T2 with scattered trees and shrubs.	Riverbank Lower, Middle, Upper, and Undivided	Low Terraces	San Joaquin Silt Loam 0-3% (214) San Joaquin Silt Loam 3-8 (215) Galt Clay 0-2% (152)

The reference condition for the indicator was defined as 100% of the floodplain and terrace of the riparian corridor exhibiting natural vegetation communities.

Riparian Vegetation Condition on Floodplain and Terrace indicator (RVF_{RR} / RVT_{RR})

The riparian vegetation condition indicator assesses the condition of riparian vegetation on the floodplain and terrace (when present) portions of a riparian reach. In general, as stream orders increase, widths of the bank-full channel, floodplain, and terraces increase in size along with the extent of the associated riparian vegetation. Thus, the Riparian Vegetation Condition indicator represents a scaled metric that can be applied consistently across different stream orders throughout a watershed.

Riparian vegetation plays a significant role in providing habitat for terrestrial and stream fauna, maintaining bank stability, and intercepting sediments and associated pollutants entering a stream. Much has been written about the importance of native riparian vegetation in the support of specific faunal groups such as amphibians (Brode and Bury 1984), birds (Hendricks and Rieger 1989), and fauna in general (Hubbard 1977; Faber et al. 1989; Knopf et al. 1988). In addition, the condition of vegetation on the floodplain and terrace portions of the riparian buffer can affect the rate at which water, sediment, and nutrients move from uplands through the riparian to the stream channel (Peterjohn and Correll 1984, 1986; Osborne and Kovacic 1993; Barling and Moore 1994).

Ideally, the condition of riparian vegetation is assessed in the field using visual observation (Oregon Water Enhancement Board 1999; Pritchard 1993) or by sampling the structure and composition of existing vegetation (Bonham 1989). Riparian conditions for this project were assessed on the basis of visual estimates using high-resolution aerial photography. Compared to field observation or sampling, this approach results in some uncertainty, due primarily to the difficulty of making accurate visual estimates even when using the high-resolution aerial photography available. In addition, vegetation in riparian areas can vary widely depending on stream order, channel morphology, geology, slope, aspect, anthropogenic disturbance, and a host of other factors. Every attempt was made to assign metrics consistently throughout the watershed, but fieldwork will be required to decrease the uncertainty associated with this indicator.

The metric for this indicator was calculated by subdividing the floodplain and terrace portions of a riparian reach based on vegetation condition, assigning an appropriate vegetation condition coefficient ranging from 1.0 (reference condition) to 0.01 (vegetation absent) to each of the portions,

and then calculating an area-weighted average vegetation condition metric for the riparian reach using the following formula:

$$\left[\left(\sum_{i=1}^{i_n}\left(RVF_{AREA} * RVF_{COEF}\right)+\sum_{i=1}^{i_n}\left(RVT_{AREA} * RVT_{COEF}\right)\right)/2\right] \quad \text{(A8)}$$

where:

RVF_{AREA} = percent of floodplain portion of riparian reach
RVF_{COEF} = floodplain vegetation condition coefficient
RVT_{AREA} = percent of terrace portion of riparian reach
RVT_{COEF} = terrace vegetation condition coefficient

For example, if 100% of the floodplain and 100% of the terrace portion of a riparian reach exhibited natural vegetation communities consistent with the geomorphic zone (Table A3), a vegetation condition coefficient of 1.0 was assigned to both the floodplain and terrace portions of the riparian reach resulting in a vegetation condition metric of 100 for the riparian reach. When a riparian reach exhibited different vegetation conditions in different portions of the floodplain or terrace, separate vegetation condition coefficients were assigned to the different portions. For example, the following conditions would result in a vegetation condition metric of 37.5 for the riparian reach (Equation A7):

- 50% of the floodplain portion of a riparian reach assigned a vegetation condition coefficient of 1.0 (i.e., all natural vegetation communities)
- 50% of the floodplain portion of a riparian reach assigned a vegetation condition coefficient of 0.5 (i.e., half of the natural vegetation communities expected to occur)
- 100% of the terrace portion of a riparian reach was assigned a vegetation condition coefficient of 0.01 (i.e., no natural vegetation present)

The reference condition was defined as the presence of natural riparian vegetation communities consistent with the geomorphic zone (Table A3).

Stream Floodplain Interaction indicator (SFI_{RR})

The Stream Floodplain Interaction indicator assesses the degree to which a normal, overbank surface water connection exists between the stream

channel and the active floodplain. The loss of a connection between the stream channel and the active floodplain is typically the result of channelization, levees, accelerated channel incision, and other activities that remove or disconnect the active floodplain from a stream channel.

Many of the characteristics and processes of riparian ecotones are dependent on the periodic hydrologic interaction between the stream channel and the floodplain (Junk et al. 1989; Naiman and Decamps 1990; Cooper et al. 1999). When the overbank surface water connection is disrupted, the physical and biological characteristics of the riparian ecotones can be significantly modified.

The metric for this indicator was defined as the percent of the main stem stream channel in a riparian reach exhibiting a normal, overbank surface water connection with the adjacent floodplain and not impeded by levees, accelerated channel incision, or channel modification. Historically incised stream channels in which the active floodplain had been reestablished within the incised channel through normal fluvial processes were not considered disconnected (Keller 1972). Metric values were assigned based on visual observations using high-resolution aerial photography. Each side of the stream channel was assessed separately, and together constituted 100% of the main stem stream channel in the riparian reach. For example, if one side of the main stem stream channel was connected to the floodplain and the other side was disconnected from the floodplain, then 50% of the main stem stream channel was considered to be connected. The reference condition for the indicator was defined as 100% of the main stem channel in the riparian reach exhibiting a normal, overbank surface water connection with the adjacent floodplain.

Sediment Regime indicator (SR_{RR})

The Sediment Regime indicator assesses the degree to which the sediment dynamics in the main stem channel of a riparian reach are in equilibrium with the sediment supply from upstream sources and erosion and deposition processes within the channel. A variety of cultural activities can alter sediment dynamics and/or channel geometry. This includes channelization, channel hardening, channel erosion due to physical disturbance, channel incision and head-cutting due to the alteration of slope, sediment aggregation due to flow-impeding structures (i.e., weirs, drop structures, culverts), and irrigation diversions (Kondolf et al. 1987).

The metric of the indicator was assigned by matching visual observations using high-resolution aerial photography with the conditions described in Table A4. The reference condition was defined as exhibiting a sediment regime in equilibrium with respect to supply, erosion, and deposition processes, and was not affected by cultural alteration.

Table A4. Conditions for assigning the Sediment Regime indicator metric value.

Conditions	Metric Value
Movement of sediment in the channel is in equilibrium in terms of supply, erosion, and deposition processes that reflect the ***culturally unaltered condition****.* On higher-order streams there are alternating point bars; bank erosion occurs, but is stabilized and moderated by vegetation; and channel width, form, and floodplain area is consistent through the reach. In low-order streams with bedrock control, some of these indicators may not be apparent, but overall bank and hillslope erosion is moderated by vegetation, and there are no apparent culturally induced catastrophic failures.	100
Movement of sediment in the channel is in equilibrium with the ***current hydrologic regime, as opposed to a culturally unaltered condition****, and exhibits an overall balance in terms of erosion and deposition processes.* On higher-order streams there are alternating point bars; bank erosion occurs, but is stabilized and moderated by vegetation; and channel width, form, and floodplain area are consistent through the reach. In low-order streams with bedrock control, some of these indicators may not be apparent, but overall bank and hillslope erosion is moderated by vegetation, and no culturally induced catastrophic failures are apparent.	75
Sediment disequilibrium is minor and localized within the reach. This includes small, localized areas of bank protection, slumping, or encroachment on the floodplain and channel. This condition class also includes previously disrupted reaches on a recovery trajectory, such as deeply entrenched streams where downcutting has been arrested by structural grade control, and there is sufficient room for lateral channel migration and establishment of a functional floodplain within the incised channel.	50
Sediment erosion and deposition out of equilibrium. Water inflow is sediment rich or poor, or accelerated bank erosion exists. Channel not actively incising, but extensive disequilibrium is evident. Typical indicators include extensive bank slumping (erosion events that exceed any moderating influence of native vegetation), active gullies feeding into the reach from adjacent hillslopes, shoaling of sediments rather than deposition in sorted lateral and mid-channel bars. Apparently stable channels should be placed in this category if there is evidence of regular mechanical disruption, such as bulldozing of the channel bottom and clearing of riparian vegetation to improve flood conveyance.	25
Sediment dynamics within most of the reach are seriously disrupted. This includes reaches where no significant storage or recruitment of sediment occurs (i.e., reaches in underground tunnels/culverts, and reaches hardened with rock or concrete). It also includes reaches that are either actively incising or functioning as sediment traps (e.g., sediment basins). This also includes reaches that have been subject to recent changes likely to induce severe disequilibrium, such as extensive floodplain filling, changes in slope, channel straightening, or other changes that are likely to cause channel downcutting during future high-flow events.	1

Surface Water Detention indicator (SWD_{RR} / SWD_{DB})

The Surface Water Detention indicator assesses the degree to which the hydrologic regime in a riparian reach has been altered as a result of short- and long-term storage of surface water in reservoirs, lakes, sediment basins, retention ponds, or similar surface water storage facilities. Streams in arid and semi-arid regions are disturbance-dominated systems (Resh et al. 1988; Power et al. 1988, 1996; Rood and Mahoney 1990). During flash floods, stream discharge can increase by several orders of magnitude, causing aquatic organism mortality, destruction of riparian vegetation, and changes in channel morphology. The biological components of riparian ecotones have adapted to these episodic cycles of disturbance, and have developed a variety of mechanisms that make it possible to survive and indeed flourish where other organisms cannot. Short- and long-term detention of surface water in storage facilities can significantly alter the characteristic pattern of discharge over the water year (Cushman 1985, Bain et al. 1988, Dynesius and Nilsson 1994, Ligon et al. 1995, Poff et al. 1997, Hadley and Emmett 1998). Most important, it eliminates the low-frequency, high-volume discharges that reset the system (Hawkins et al. 1997). However, it can also lead to perennialization of streamflow, and change the pattern of seed distribution, germination, and survival, as well as a variety of other physical and biological processes necessary to perpetuate the riparian ecotone (Hynes 1975, Warren 1979, Lotspeich and Platts 1982, Frissell et al. 1986, Kondolf et al. 1987, Debano and Schmidt 1990, Stromberg and Patten 1991, Power et al. 1996, Kershner 1997, Kondolf 1997, Richter et al. 1996).

The metric for this indicator was defined as the percent of the drainage basin of riparian reach upstream of reservoirs, dry dams, sediment basins, retention ponds, or similar cultural facilities designed to store surface water from several weeks to months. At the riparian reach spatial scale, the metric was based on visual observations using high-resolution aerial photography. At the drainage basin scale, the indicator was calculated as the weighted average of the percent of surface water detention for all riparian reaches in the drainage basin of the riparian reach using the following formula:

$$\sum_{i=1}^{i_n}\left[SWD_{RR} * \left(ML_{RR} \Big/ ML_{DB}\right)\right] \quad \text{(A9)}$$

where:

SWD_{RR} = % of drainage basin of local drainage without surface water detention
ML_{RR} = area of local drainage
ML_{DB} = area of drainage basin of riparian reach

The reference condition was defined as 0% of the drainage basin of a riparian reach not influenced by sediment detention facilities.

Riparian integrity indices

Assessing riparian integrity is challenging because of the abstract nature of the concept of integrity, and the fact that no single measure encompasses the variety of characteristics and processes that influence riparian integrity across multiple spatial scales. For this project, three indices were selected to represent riparian integrity. They include hydrologic, water quality, and habitat integrity that reflect the mandate in Section 101(a) of the Clean Water Act to "…restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Hydrologic, Water Quality, and Habitat Integrity Indices are discussed in the following sections.

Hydrologic Integrity Index

Under reference conditions, riparian ecotones exhibit the full range of frequency, magnitude, and temporal distribution of stream discharge, and surface and subsurface interaction between the stream channel, floodplain, and terraces, that historically characterized riparian ecotones in the region (Bedford 1996, Poff et al. 1997, Richter et al. 1997). In the arid and semi-arid southwest, this translates into seasonal intermittent, ephemeral, or low flow periods, with annual bank-full discharges superimposed on a background of episodic, and often catastrophic, larger magnitude floods that inundate historical terraces (Graf 1979, 1998; Harris 1987; Fisher et al. 1982; Friedman et al. 1996a, 1996b).

In selecting indicators to assess hydrologic integrity, two groups of characteristics and processes were considered. The first group focused on the factors that influence frequency, magnitude, and temporal distribution of stream discharge. Direct measures of stream discharge are unavailable at the riparian reach scale in these watersheds. Consequently, several indicators were selected at the drainage basin scale with the assumption

that deviation from reference conditions can be indirectly estimated based on changes in specific characteristics and processes of a drainage basin such as interception, infiltration, evapotranspiration, percolation, groundwater flow, and surface water flow overland and in channels. Cultural alteration of the drainage basin alters these characteristics and processes, and consequently, stream discharge. While it is difficult to quantify the exact nature of the relationship between drainage basin characteristics, as represented by the indicators and stream discharge, it can generally be shown that as cultural alterations in watersheds increase, so does the deviation from historical short- and long-term patterns of frequency, magnitude, and temporal distribution of stream discharge.

The second group focused on the factors that influenced the hydrologic interaction between the stream channel, floodplain, and historical terraces. A frequency, magnitude, and distribution of stream discharge that is similar to the historical range of conditions does not alone ensure hydrologic integrity. Hydrologic integrity also depends on maintaining the interaction between the stream channel, floodplain, and terraces of the riparian ecotones through overbank and subsurface flows. This interaction is critical to the maintenance of riparian plant communities, sediment storage, carbon dynamics, biogeochemical processes, and other characteristics and processes of riparian ecotones. These indicators were selected to reflect cultural alterations with the potential to influence stream discharge locally and represent the degree of interaction between the stream channel and the adjacent floodplain and terrace:

The following indicators were used in the Hydrologic Integrity Index:

- Altered Hydraulic Conveyance (RR)
- Altered Hydraulic Conveyance (DB)
- Import, Export, or Diversion of Surface Water (RR)
- Import, Export, or Diversion of Surface Water (DB)
- Land Use Land Cover/Impervious Land Surface (LD)
- Land Use Land Cover/Impervious Land Surface (DB)
- Modified Stream Flow (RR)
- Modified Stream Flow (DB)
- Surface Water Detention (LD)
- Surface Water Detention (DB)
- Stream / Floodplain Interaction (RR)

The Hydrologic Integrity Index indicators were aggregated using the following equation:

$$\begin{bmatrix} AHC_{RR} + IED_{RR} + LULCI_{LD} + MSF_{RR} + SWD_{RR} + SFI_{RR} + \\ \left(\left(AHC_{DB} + IED_{DB} + LULCI_{DB} + MSF_{DB} + SWD_{DB} \right) / 5 \right) \end{bmatrix} / 7 \quad \text{(A10)}$$

where:

AHC_{RR} = % of main stem of riparian reach with altered hydraulic conveyance

AHC_{DB} = % of main stems of drainage basin of riparian reach with altered hydraulic conveyance

IED_{RR} = % of main stem of riparian reach with import, export, or diversion of surface water

IED_{DB} = % of main stems in drainage basin of riparian reach with import, export, or diversion of surface water

$LULCI_{RR}$ = % of LULC types in local drainage with >15% impervious surfaces

$LULCI_{DB}$ = % of LULC types in drainage basin of riparian reach with >15% impervious surfaces

MSF_{RR} = % of main stem of riparian reach with modified stream flow

MSF_{DB} = % of main stems in drainage basin of riparian reach with modified stream flow

SWD_{RR} = % of local drainage of riparian reach behind surface water detention structures

SWD_{DB} = % of drainage basin of riparian reach behind surface water detention structures

SFI_{RR} = % of floodplain isolated from main stem stream channel in riparian reach

Water quality integrity index

Water quality integrity was defined as exhibiting a range of loading in the pollutant categories of nutrients, pesticides, hydrocarbons, and sediments that are similar to those that historically characterized riparian ecotones in the region. Changes in the range of loading in each pollutant category can be assessed directly by comparing data on current loading with data on historical loading when such data are available. While some historical and recent monitoring data are available for a limited number of stations in the watershed, little or no loading data are available at the riparian reach

scale. Consequently, water quality integrity was assessed based on indicators of drainage basin and riparian reach characteristics that have been shown to influence water quality integrity.

Three groups of factors were considered in selecting indicators for the water quality integrity endpoint. The first group focused on whether the changes in land use in the drainage basin had the potential to increase sources of pollution compared to the reference condition. The second group focused on whether the stream channel delivery system had changed in relation to reference conditions in terms of frequency, magnitude, and temporal distribution of stream flow (Kuenzler 1977). The third group focused on whether changes in land use in the areas adjacent to the stream, or the loss of a hydrologic connection between the stream channel and the floodplain, had decreased the likelihood of pollutants being physically captured or biogeochemically processed compared to reference conditions. A number of studies have shown that cultural alteration of these factors can lead to increased loading in one or more pollutant categories (Allan and Flecker 1993; Hunsaker and Levine 1995; Perry and Vanderklein 1996; Richards et al. 1996; Allan et al. 1997; Bolstad and Swank 1997; Johnson et al. 1997; Wang et al. 1997; Miltner and Rankin 1998; Trimble 1997; Basnyat et al. 1999).

The following indicators were selected to reflect how the condition of land use in the drainage basin influenced water quality integrity:

- Land Use/Land Cover – Nutrient Increase (LD)
- Land Use/Land Cover – Nutrient Increase (DB)
- Land Use/Land Cover – Pesticide Increase (LD)
- Land Use/Land Cover – Pesticide Increase (DB)
- Land Use/Land Cover – Hydrocarbon Increase (LD)
- Land Use/Land Cover – Hydrocarbon Increase (DB)
- Land Use/Land Cover – Sediment Increase (LD)
- Land Use/Land Cover – Sediment Increase (DB)

The following indicators were selected to reflect the condition of the stream system that transports pollutants:

- Altered Hydraulic Conveyance (RR)
- Altered Hydraulic Conveyance (DB)
- Modified Stream Flow (RR)

- Modified Stream Flow (DB)
- Surface Water Retention (RR)
- Surface Water Retention (DB)
- Import, Export, or Diversion of Surface Water (RR)
- Import, Export, or Diversion of Surface Water (DB)

Indicators selected to reflect the condition of the riparian reach in terms of its ability to physically capture and biogeochemically process pollutants and thereby influence water quality included:

- Floodplain Interaction (RR)
- Sediment Regime (RR)
- Riparian Vegetation Condition Floodprone Area (RR)

The Water Quality Integrity Index indicators were aggregated using the following equation:

$$\left[\begin{array}{l} AHC_{RR} + IED_{RR} + LULCH_{LD} + LULCN_{LD} + LULCP_{LD} + LULCS_{LD} + \\ LULCI_{LD} + MSF_{RR} + SWD_{RR} + SFI_{RR} + SR_{RR} + \\ \left(\left(\begin{array}{l} AHC_{DB} + IED_{DB} + LULCH_{DB} + LULCN_{DB} + LULCP_{DB} + \\ LULCS_{DB} + LULCI_{DB} + MSF_{DB} + SWD_{DB} \end{array}\right) / 9\right) \end{array}\right] / 12 \quad \text{(A11)}$$

where:

AHC_{RR} = % of main stem of riparian reach with altered hydraulic conveyance

AHC_{DB} = % of main stems of drainage basin of riparian reach with altered hydraulic conveyance

IED_{RR} = % of main stem of riparian reach with import, export, or diversion of surface water

IED_{DB} = % of main stems in drainage basin of riparian reach with import, export, or diversion of surface water

$LULCH_{RR}$ = % of LULC types in local drainage increasing hydrocarbons

$LULCH_{DB}$ = % of LULC types in drainage basin of riparian reach increasing hydrocarbons

$LULCN_{RR}$ = % of LULC types in local drainage increasing nutrients

$LULCN_{DB}$ = % of LULC types in drainage basin of riparian reach increasing nutrients

$LULCP_{RR}$ = % of LULC types in local drainage increasing pesticides
$LULCP_{DB}$ = % of LULC types in drainage basin of riparian reach increasing pesticides
$LULCS_{RR}$ = % of LULC types in local drainage increasing sediments
$LULCS_{DB}$ = % of LULC types in drainage basin of riparian reach increasing sediments
$LULCI_{RR}$ = % of LULC types in local drainage with >15% impervious surfaces
$LULCI_{DB}$ = % of LULC types in drainage basin of riparian reach with >15% impervious surfaces
MSF_{RR} = % of main stem of riparian reach with modified stream flow
MSF_{DB} = % of main stems in drainage basin of riparian reach with modified stream flow
SFI_{RR} = % of floodplain isolated from main stem stream channel in riparian reach
SR_{RR} = sediment regime index for riparian reach
SWD_{RR} = % of local drainage of riparian reach behind surface water detention structures
SWD_{DB} = % of drainage basin of riparian reach behind detention structures

Habitat integrity index

Riparian ecotones with habitat integrity exhibit the quality and quantity of habitat necessary to support and maintain a balanced, integrated, adaptive biological system having the full range of characteristics, processes, and organisms at the site-specific, landscape, and watershed scales that historically characterized riparian ecotones in the region. The following factors were considered in selecting indicators of habitat integrity including the spatial extent and quality of riparian habitat, the "connectedness" of riparian habitats at the riparian reach and drainage basin scales, and the spatial extent and quality of upland habitat in the landscape adjacent to riparian ecotones:

- Riparian Vegetation Condition - Floodplain Area (RR)
- Riparian Vegetation Condition - Terrace (RR)
- Riparian Corridor Continuity (RR)
- Riparian Corridor Continuity (DB)
- Culturally Altered Land Use / Land Cover in 300-ft Buffer (RR)
- Wildlife Habitat (LD) (RR)

The Habitat Integrity Index indicators were aggregated using the following equation:

$$\left(BUF_{RR} + LULCW_{LD} + RCC_{RR} + RCC_{DB} + \left(\left(RVF_{RR} + RVT_{RR}\right)/2\right)\right)/5 \qquad \text{(A12)}$$

where:

RCC_{RR} = Riparian Corridor Connectivity of main stem in riparian reach
RCC_{DB} = Riparian Corridor Connectivity in drainage basin
RVF_{RR} = Vegetation Condition on floodplain
RVT_{RR} = Vegetation Condition on terrace
WH_{LD} = Wildlife Habitat in local drainage
BUF_{RR} = Alterations to 300-ft Buffer

Methods

Identification of riparian reaches

Due to the large project area, inherent variability of riparian ecotones, and differential nature of historical impacts to riparian ecotones, the initial task was to subdivide the project area into appropriate spatial units for assessing riparian integrity. These spatial units, or "riparian reaches," were defined as a segment of main stem stream (see below) and the adjacent riparian ecotone that was relatively homogenous with respect to geology, geomorphology, soils, channel morphology, hydrologic regime, vegetation communities, and cultural alterations (Olson and Harris 1997).

The first step in identifying riparian reaches was to develop a geographical information system (GIS) theme for streams in the project area. Several sources of information were used to develop the stream themes, including: 1) themes provided by the Sacramento County Planning and Community Development Department, which appeared to be based on USGS National Hydrography Data (http://nhd.usgs.gov/), 2) USGS 7.5-minute quad digital raster graphics (DRGs), 3) 10.0-m resolution 2005 aerial photographs from the National Agricultural Information Program (http://new.casil.ucdavis.edu/casil/remote_sensing/naip_2005/), 4) 1.0-m resolution 2004 color infrared aerial photographs, and 5) 0.6-m resolution, recent (undated) aerial photographs from Air Photo USA.

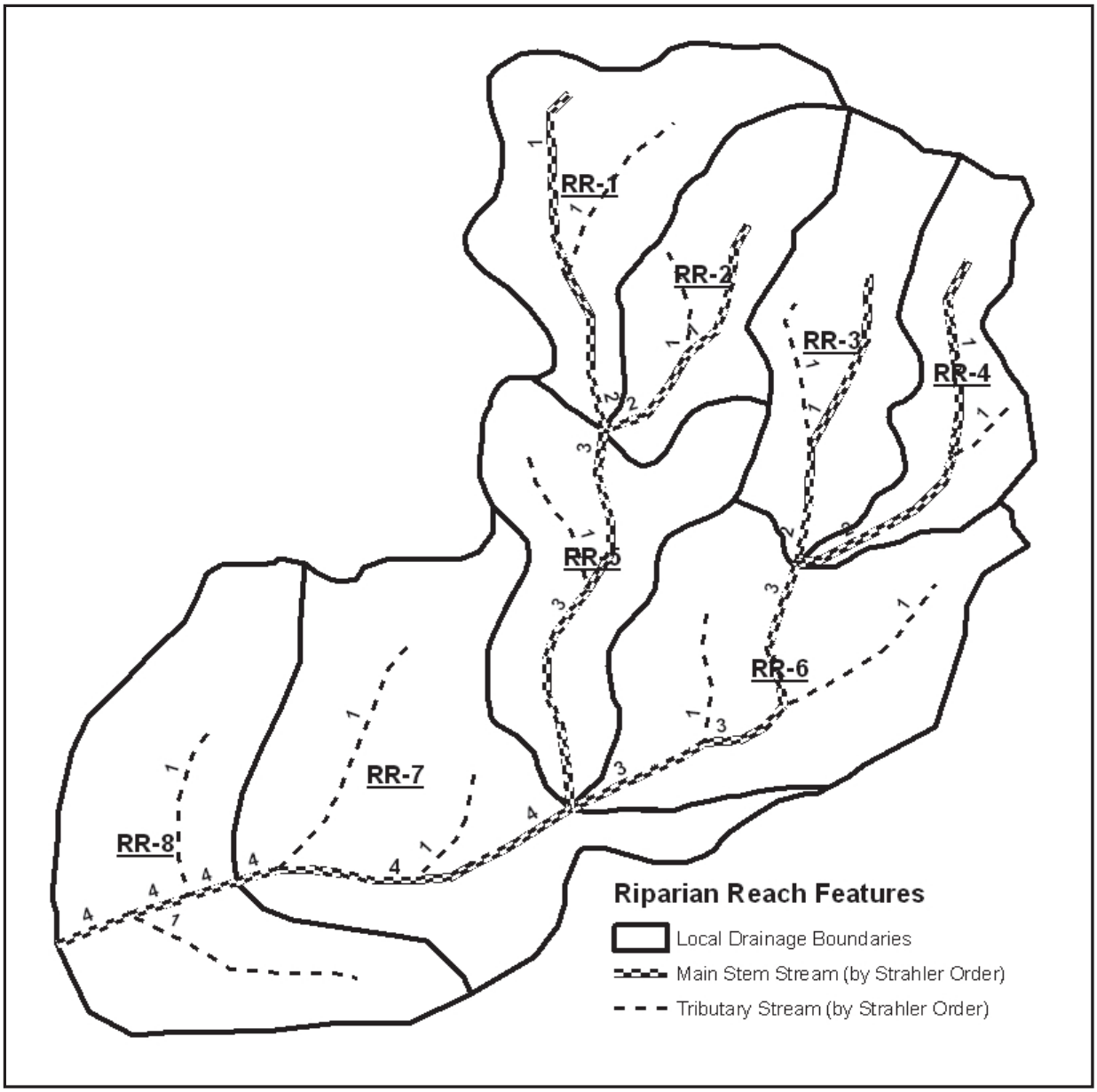
The stream GIS theme was developed by modifying the existing theme provided by the Sacramento County Planning and Community Develop-

ment Department based on the DRGs and aerial photography. The modifications included the addition of missing stream channels, updating the location of re-routed stream channels in developed areas, and matching stream channel vectors to the thalweg of the stream channel as depicted in the aerial photographs. During the development of the stream theme, specific stream segments were categorized as engineered, reservoir, or natural. Stream segments that had been straightened, dredged, hardened, or similarly altered were assigned to the engineered category. Stream segments that were flooded due to the presence of a permanent dam were assigned to the reservoir category. All other stream segments were assigned to the natural category. Headwater streams were assigned a Strahler (1957) stream order of "1." Subsequent downstream streams were assigned a stream order consistent with Figure A3. The theme of the completed streams closely approximated the blue line streams mapped on USGS 7.5-minute quadrangles.

The stream's theme was then used as the basis for delineating initial riparian reach boundaries using a second-order stream "rule of thumb." Moving downstream from the upstream end of a headwater stream, a downstream riparian reach boundary was established at the point where the selected stream, after having achieved second-order status, joined with a second- or higher-order stream. For example, in Figure A3, the confluence of the second-order streams in the riparian reaches labeled as RR-1 and RR-2 represents the downstream boundary of these two riparian reaches. Moving downstream, the confluence of the third-order streams in the riparian reaches labeled RR-5 and RR-6 represents the downstream boundary of these two riparian reaches. Throughout the delineation process additional riparian reaches were established where geologic or geomorphic changes occurred, or where significant changes in Land Use/Land Cover occurred. For example, in Figure A3, the downstream boundary of riparian reach RR-7 is due to a significant change in geology, geomorphology, or land use and not the confluence with another second-order, or higher, stream.

Several features were identified in association with each riparian reach. These included the "main stem stream," "tributary stream(s)," "local drainage," and "drainage basin" (Figure A3). Main stem streams were the primary streams used to delineate riparian reach upstream and downstream boundaries. Tributary streams were streams tributary to main stem streams and wholly within the local drainage of the riparian reach. Local drainages

Figure A3. Schematic of riparian reach features.



were the area from which surface water drained directly to the main stem stream of the riparian reach. The boundaries for local drainages were digitized using the "contours_5ft_detailed" theme provided by the Sacramento County Planning and Community Development Department, and USGS 7.5-minute quad DRGs. Drainage basins included the local drainage of a specific riparian reach in addition to the local drainages of all upstream riparian reaches. Figure A3 explicitly illustrates all of these features except the drainage basin. In Figure A3, the drainage basin of riparian reach RR-1 is the same as the local drainage of riparian reach RR-1, since in this case there are no upstream riparian reaches. The drainage

basin of riparian reach RR-5 consists of the local drainage of riparian reach RR-5 and the local drainages of all upstream riparian reaches (i.e., RR-1 and RR-2).

Assigning indicator metric values to riparian reaches

Metric values were assigned to indicators for each riparian reach based on visual interpretation of the high-resolution aerial photographs and site visits. Several days were spent in the field prior to assigning indicator metric values in order to calibrate visual interpretation to ground conditions. In addition, several days were spent in the field to resolve questions that arose during the process of assigning indicator metric values to riparian reaches. The general strategy was to begin at the downstream end of a riparian reach and conduct a remote visual reconnaissance of the main stem channel and its riparian ecotone to the upstream end of the riparian reach. Following this initial visual reconnaissance, a decision was made to either retain the initial riparian reach boundaries, or divide the riparian reach into two or more additional riparian reaches. Metric values for indicators were initially entered into the streams theme attribute table, and subsequently exported to a spreadsheet for use in the calculation of hydrologic, water quality, and habitat integrity indices. Metric values for all indicators ranged from 0 to 100, but depending on the indicator, the reference condition was assigned a metric value of either 0 or 100.

Calculation of riparian integrity indices

Riparian integrity indices were calculated by aggregating the metric values of specific indicators for hydrologic, water quality, and habitat integrity indices (Section titled “Riparian integrity indices”). Metric values were imported from the GIS to a spreadsheet where indicators with a reference condition of 0 were converted so that the reference condition for all indicators was 100. Indicators were then aggregated in the spreadsheet for hydrologic, water quality, and habitat integrity indices. At this point the hydrologic integrity index ranged from a possible 7-700, the water quality integrity index ranged from a possible 12-1200, and the habitat integrity index ranged from a possible 5-500. These integrity indices were then normalized to a scale of 0.0 to 1.0 to give the final hydrologic, water quality, and habitat integrity indices.

Results

Riparian ecotones in the project area

Many of the riparian ecotones in the project area have been significantly altered from their culturally unaltered reference condition. The alterations are a result of cattle grazing, agriculture, mining, modification of streams through straightening and impounding, and urbanization. Natural vegetation has been removed from many riparian ecotones in the project area as a result of grazing and mechanical removal. Isolated patches of natural vegetation remain in some riparian ecotones. Stream banks, floodplains, and alluvial terraces are, for the most part, vegetated with the same suite of non-native, primarily annual, grasses and forbs that blanket the upland slopes. Review of aerial photos dating back to the 1940s documents that this condition has existed for at least 60 years, and historical accounts from elsewhere in the Central Valley suggest that wholesale changes in the landscape probably began nearly two centuries ago.

Cattle operations and other agricultural activities, which began in the Central Valley in the early 19th century, initiated a process of conversion from a landscape dominated by native perennial forbs and grasses to annual grasslands made up of exotic species. In the middle 1800's the gold rush brought thousands of immigrants to the region, and farming began on a large scale, first in the river valleys, and then on the terraces and alluvial fans. All of these changes tended to adversely impact woody riparian vegetation, specifically because of tree cutting for firewood and mine timbers, disruption of stream flow, and changes in shallow groundwater storage associated with farming, land leveling, and heavy browsing by cattle.

Because of the long history of intensive pressure on natural vegetation in the region, reconstruction of the pre-settlement distribution of plant communities is difficult. However, based on field assessments of remnant plant populations and individuals in the project area and elsewhere in the region, it is clear that distinctive combinations of geology and geomorphic settings and soils are predictive of channel configuration and the potential occurrence of woody riparian plant communities (Smith and Verrill 1998; Clifford et al. 1996) (Table A3). In particular, it is likely that nearly all of the higher order streams in Holocene alluvial settings were originally occupied by meandering channels flanked by floodplain and terrace

deposits. The relatively fine-grained and deep alluvial soils in these settings would have been appropriate for the establishment of woody plants. Lower order streams on high terraces and volcanic mud and lava flows with coarser alluvial soils would have supported native annuals and grasses with a scattering of shrubs and trees in more mesic situations. In the modern landscape, persistent, heavy cattle browsing for more than a century, along with mining activity, agriculture, and more recent urbanization, has removed the native plant cover and prevented its re-establishment in most of the settings where it once grew.

Riparian reaches

The project area included 184 identified riparian reaches (Figures A4a-A4c). Several of these riparian reaches occurred outside of the project area and were identified for the purpose of analyzing the influence of upstream areas on riparian reaches inside the project area. The average area of riparian reach local drainages was 281 ha, with a range of 9 ha to 3135 ha. Riparian reach main stem streams are displayed in Figure A5. The average length of the main stem stream in riparian reaches was 2320 m, with a range of 365 to 9301 m. Table A5 provides a breakdown, by category, for main stem streams. The wide ranges exhibited in the size of local drainages and the length of main stem channels reflect the significant difference that exists between developed areas and more natural landscapes in terms of the longitudinal homogeneity of vegetation cover, engineering, and other types of disturbance that occur along stream channels and their associated riparian ecotones.

Geomorphic zones

Each riparian reach was assigned to a geomorphic zone based on predominant geologic formations (Figure A6) and soil map units (Figure A7). Figure A8 displays the geomorphic zones assigned to each riparian reach displayed in the context of main stem streams. Zone 1 first- and second-order streams occur primarily in the northern portion of the project area on the high terraces and hills associated with mud and lava flows of the Mehrten formation. The natural vegetation in riparian ecotones in this zone consists of the native forbs and grasses that occur on floodplains and low stream terraces, with scattered shrubs in seeps, swales, protected areas, and impounded areas. Zone 2 first- and second-order streams occur primarily in the eastern and southern portions of the project area on the high terrace alluvium associated with the Laguna and South Fork Gravel formations. The

Figure A4a. Riparian reaches in the project take area.

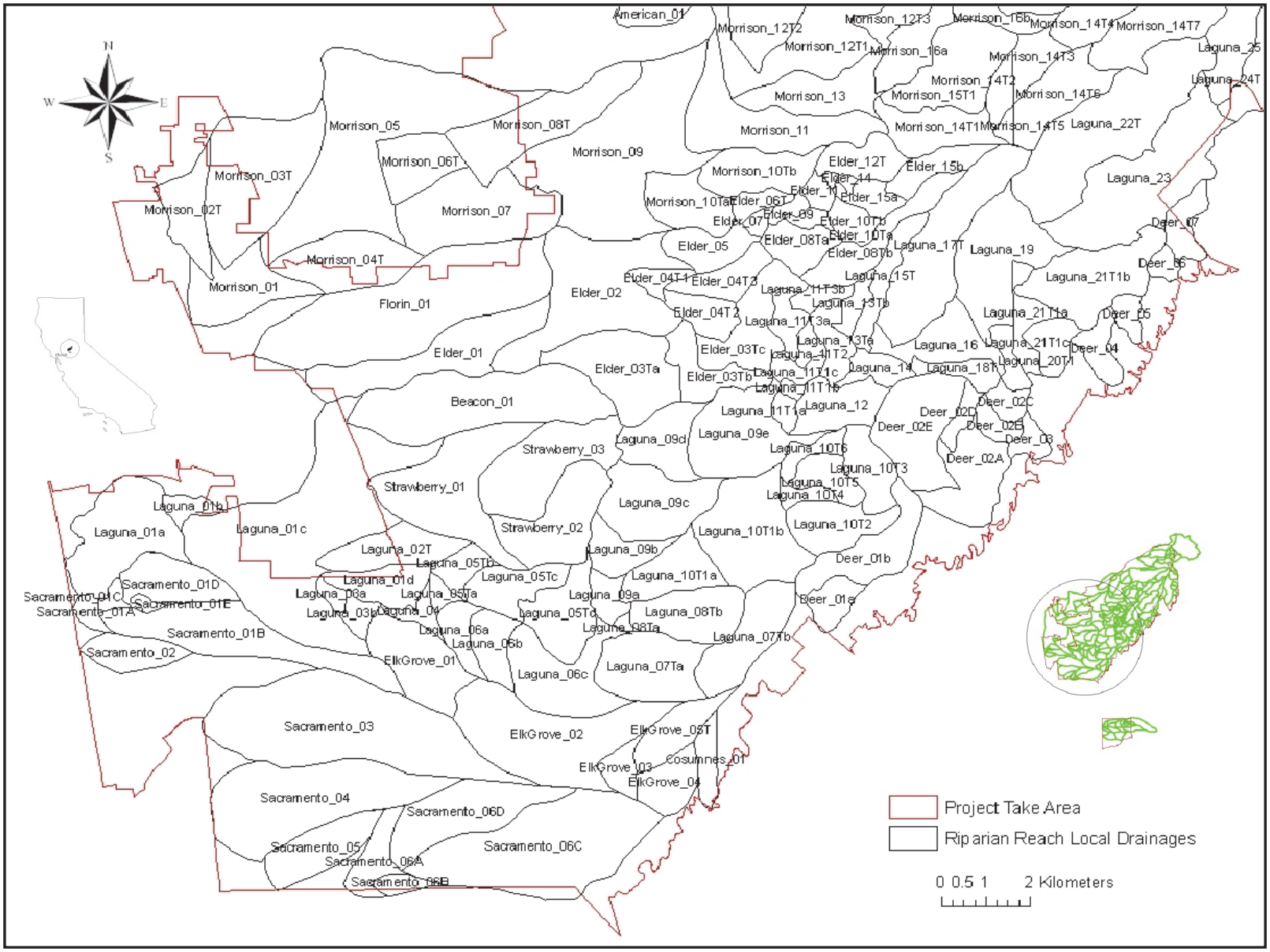


Figure A4b. Riparian reaches in the project take area.

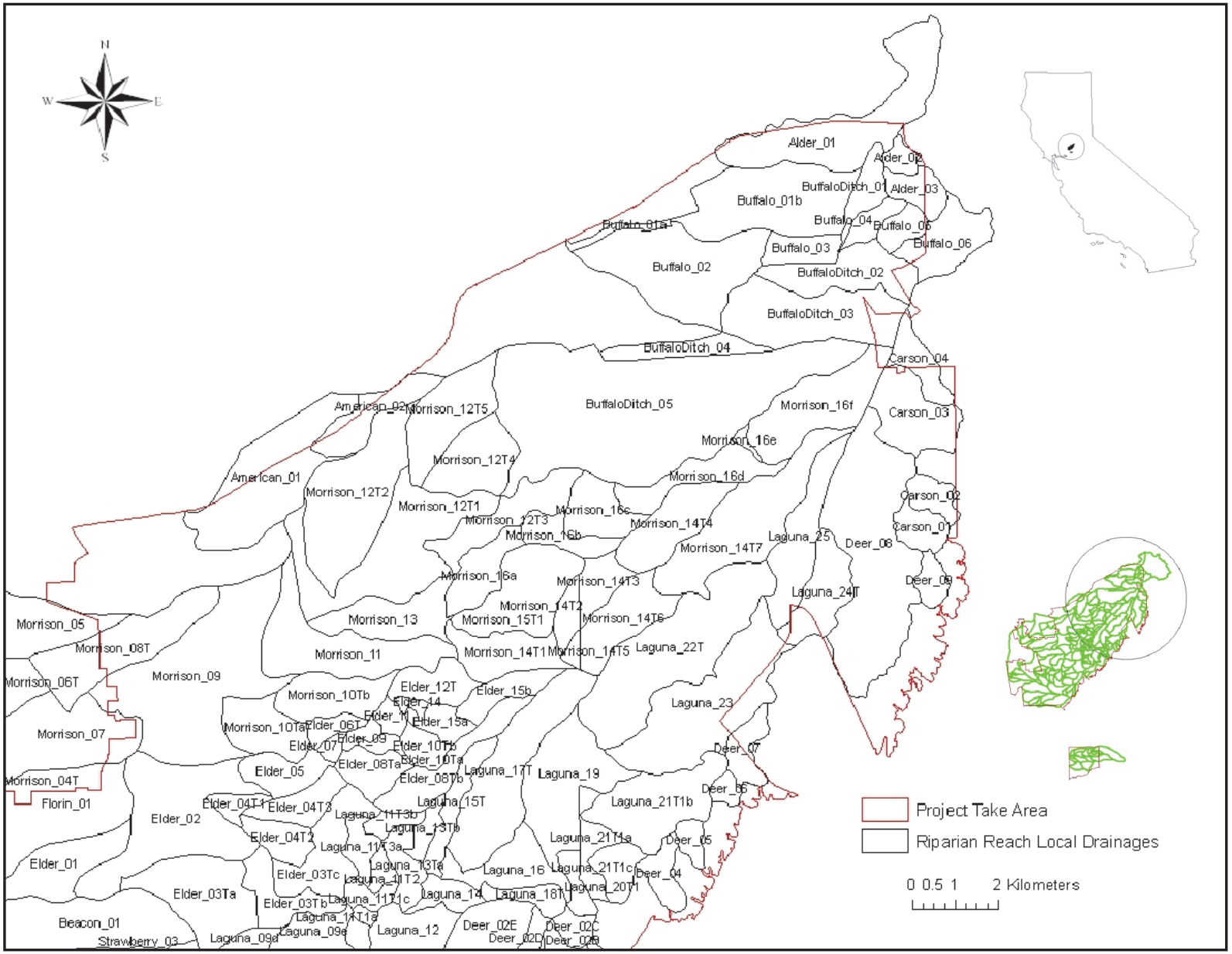


Figure A4c. Riparian reaches in the project area.



Figure A5. Riparian reach main stem streams by category.

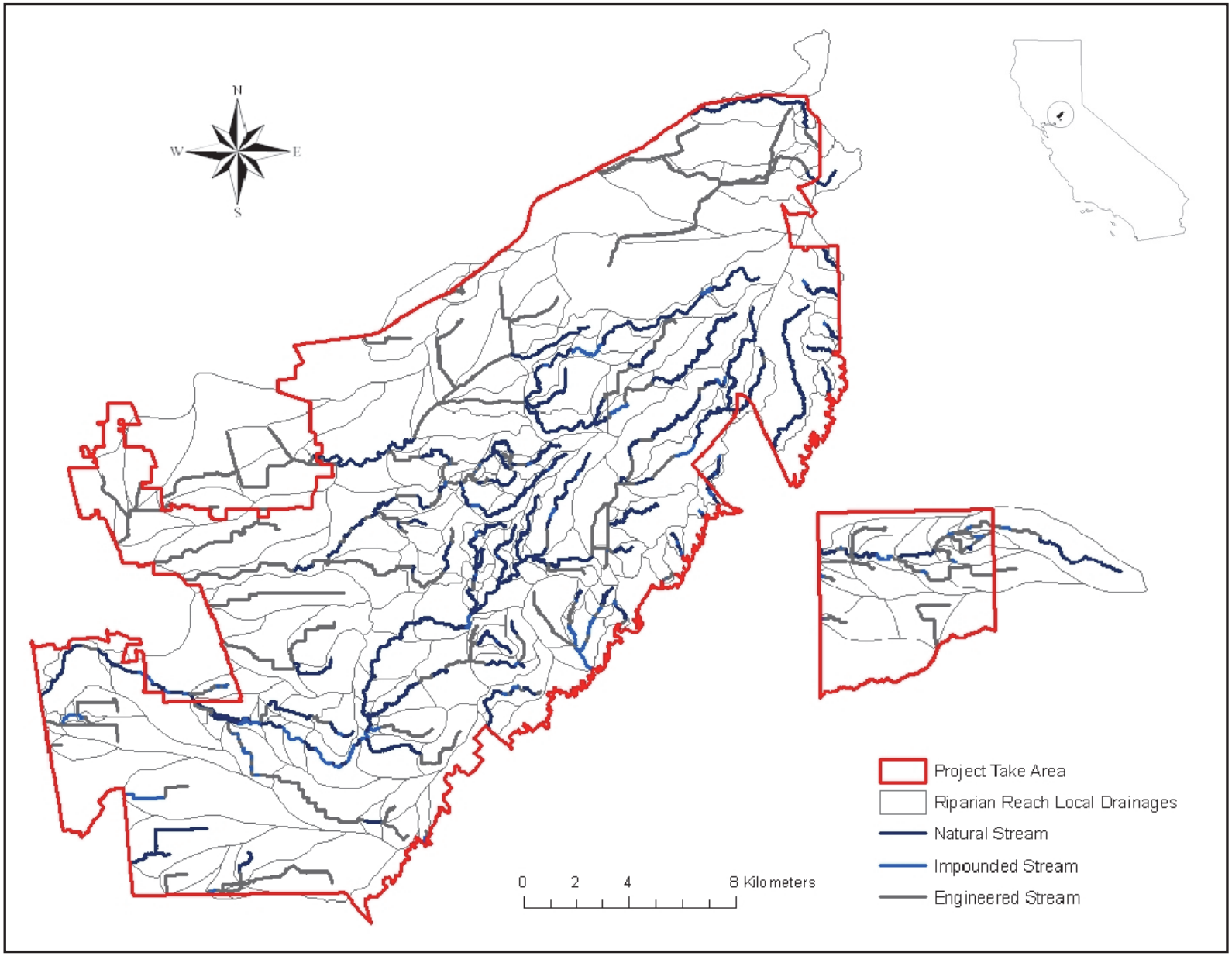


Table A5. Meters of main stem stream, by category.

Stream Channel Category	Length (Meters)
Main Stem - Natural	201,363
Main Stem - Engineered	25,832
Main Stem - Impounded	197,392
Total	424,587

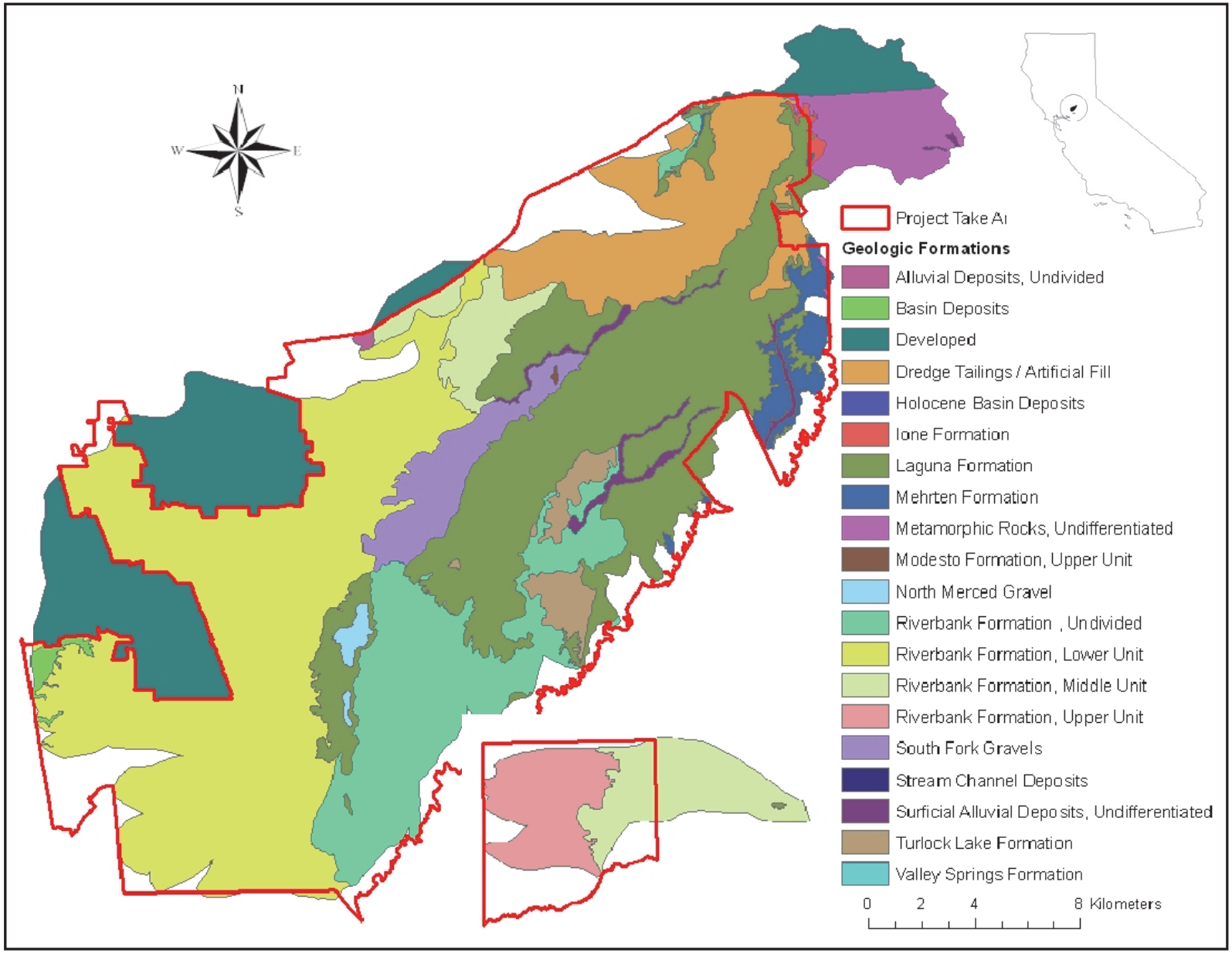
natural vegetation in the riparian ecotones of first-order streams in this zone consists of native grasses, forbs, and scattered shrubs and trees on floodplains and, when present, on the first terrace. Natural vegetation of second-order streams consisted of a nearly continuous corridor of native grasses, forbs, shrubs, and trees on floodplains and first terraces. Zone 3 second- and third-order streams occur primarily in the southern portion of the project area on the low terrace alluvium associated with Riverbank formation. The natural vegetation in the riparian ecotones of first- and second- order streams in this zone consists of a continuous riparian forest on the floodplain and first terrace, with native grassland and scattered trees and shrubs on the second terrace. Geomorphic zones were used to predict the type of natural vegetation that could be expected to occur under reference conditions (Table A3).

Riparian integrity indices

The minimum, maximum, and mean indicator metric values, and the frequency of occurrence of indicator metrics within the indicator metric value ranges of 0-24, 25-49, 50-74, and 75-100 for riparian reaches within the assessment area, are shown in Table A6. Figures A9, A10, and A11 show the distribution of normalized hydrologic, water quality, and integrity indices for riparian reaches in the project area. The range of values for the normalized index of hydrologic integrity was 0.51 to 1.00, with a mean of 0.81. The range of values for the index of water quality integrity was 0.36 to 0.81, with a mean of 0.61. The range of values for the habitat integrity index was 0.00 to 0.87, with a mean of 0.49.

In general, the integrity indices exhibited a relatively wide and even spread across the possible range of values. These results can be interpreted as evidence that the indicators were scaled appropriately, and were sensitive enough to distinguish varying degrees of hydrologic, water quality, and habitat integrity. The results are also consistent with the mental perception of riparian integrity in the watershed accumulated during field work and visual reconnaissance. Ultimately, the only way to increase confidence in the

Figure A6. Geologic formations in the project take area.



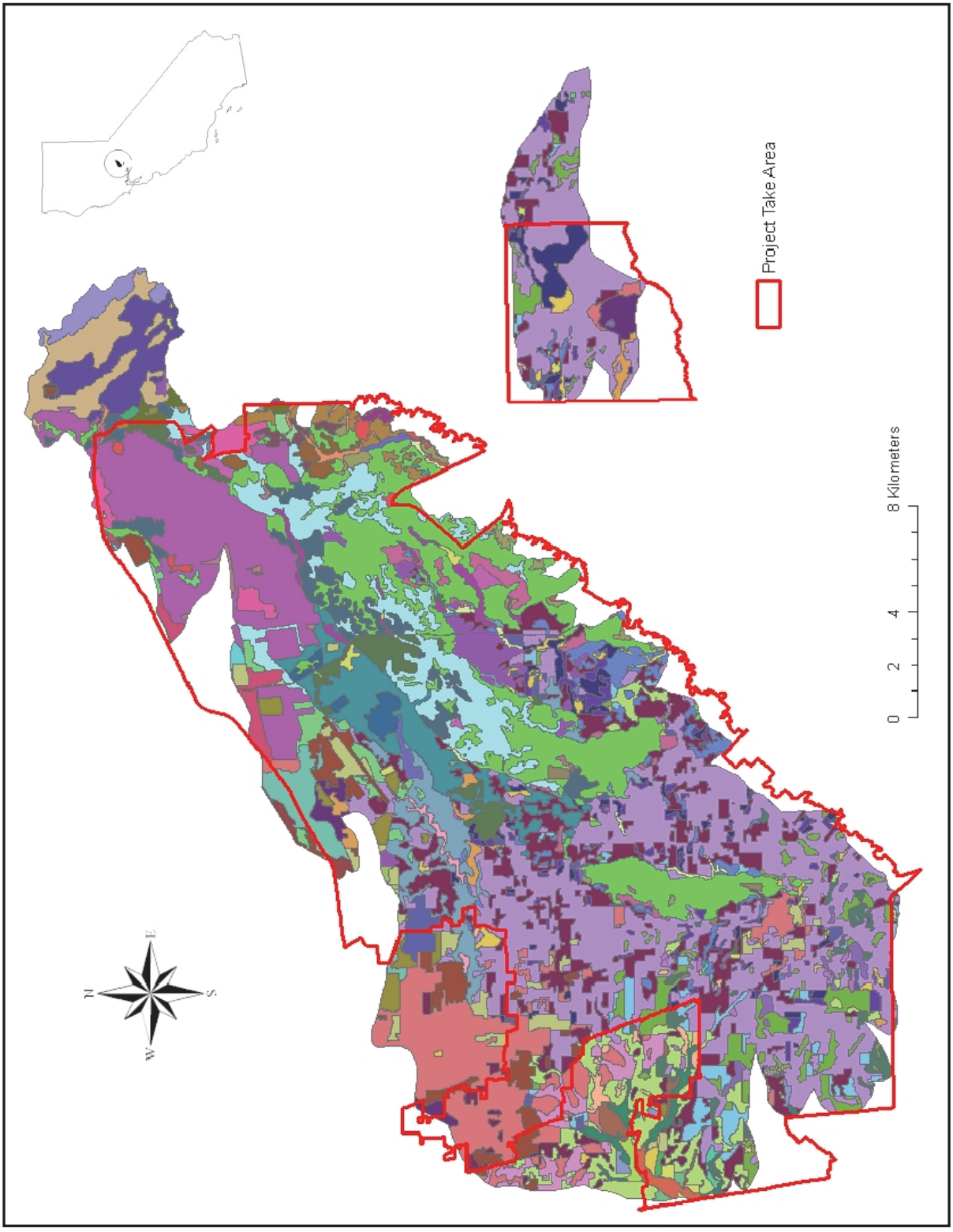


Figure A7. Soil map units in the project take area (continued).



Figure A7. (concluded).

Figure A8. Riparian reach geomorphic zones.

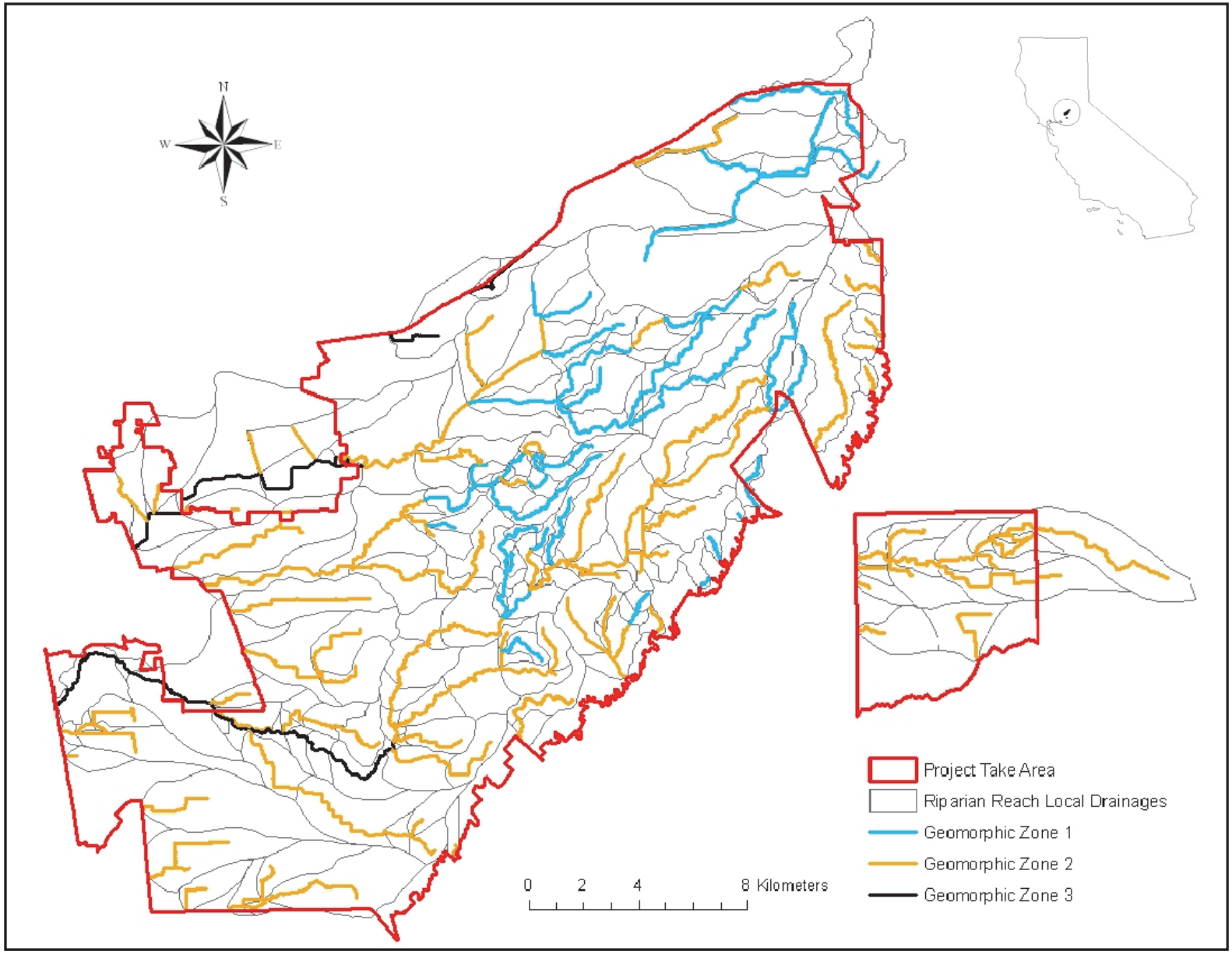


Table A6. Descriptive statistics for indicator metric values.

Indicator Acronym	Minimum Metric Value	Maximum Metric Value	Mean Metric Value	Number of Occurrences within Metric Value Ranges			
				0-24	25-49	50-74	75-100
AHC $_{RR}$	0	100	43	90	11	19	64
AHC $_{DB}$	0	100	28	123	11	12	38
BUF $_{RR}$	0	100	13	161	19	2	2
IED $_{RR}$	0	100	100	0	0	0	184
IED $_{DB}$	0	100	100	0	0	0	184
LULCH $_{LD}$	0	100	82	5	12	32	135
LULCH $_{DB}$	0	100	84	1	10	26	147
LULCN $_{LD}$	0	100	11	161	10	7	6
LULCN $_{DB}$	0	100	9	170	6	7	1
LULCP $_{LD}$	0	100	10	162	9	7	6
LULCP $_{DB}$	0	100	8	171	5	7	1
LULCS $_{LD}$	0	100	39	79	31	39	35
LULCS $_{DB}$	0	100	33	91	44	30	19
LULCI $_{LD}$	0	100	66	30	27	30	97
LULCI $_{DB}$	0	100	71	18	27	29	110
LULCW $_{LD}$	0	100	47	60	45	34	45
MSF $_{RR}$	0	100	99	2	0	1	181
MSF $_{DB}$	0	100	97	3	1	2	178
RCC $_{RR}$	0	100	33	110	25	16	33
RCC $_{DB}$	0	100	18	145	17	8	14
RVF $_{AVG}$	0	100	55	44	36	58	46
RVT $_{AVG}$	0	100	30	93	67	15	9
SFI $_{RR}$	0	100	85	24	1	2	157
SR $_{RR}$	0	100	37	94	31	56	3
SWD $_{LD}$	0	100	99	0	3	0	181
SWD $_{DB}$	0	100	98	3	1	0	180

integrity indices is to compare them to mechanistic approaches that quantitatively model the characteristics and processes that influence hydrologic, water quality, and habitat integrity. In this regard, integrity indices like those used during this project have been shown in other studies to be highly correlated with results produced by independent, quantitative models of hydrology and habitat integrity (Smith 2006).

Figure A9. Range of normalized Hydrologic Integrity Indices for riparian reaches.

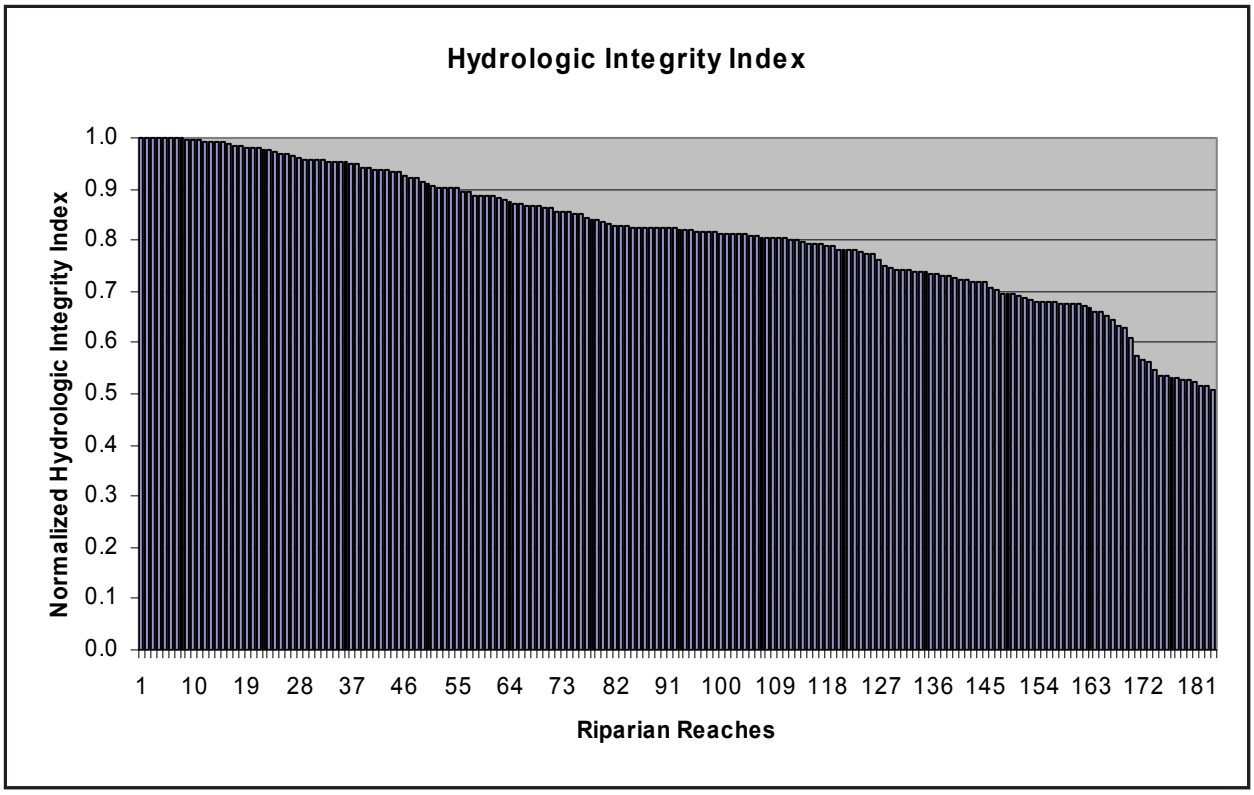


Figure A10. Range of normalized Water Quality Integrity Indices for riparian reaches.

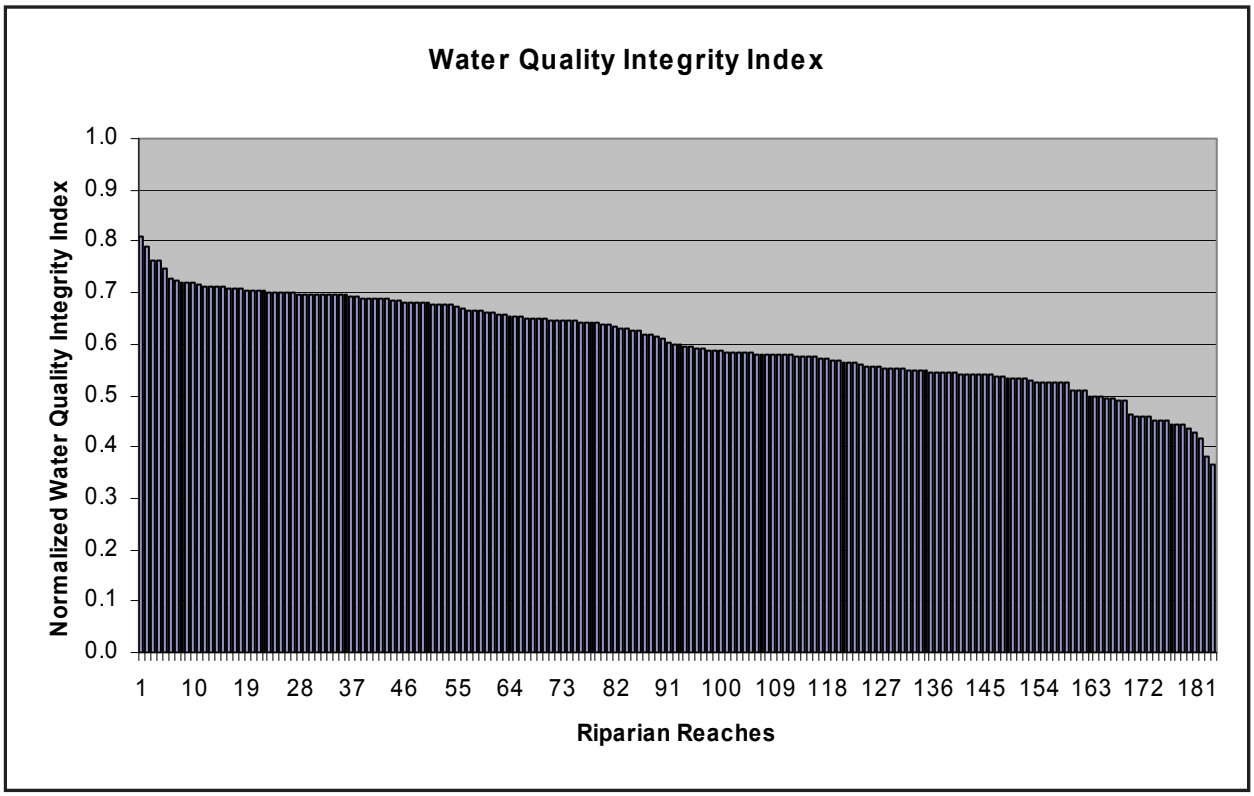
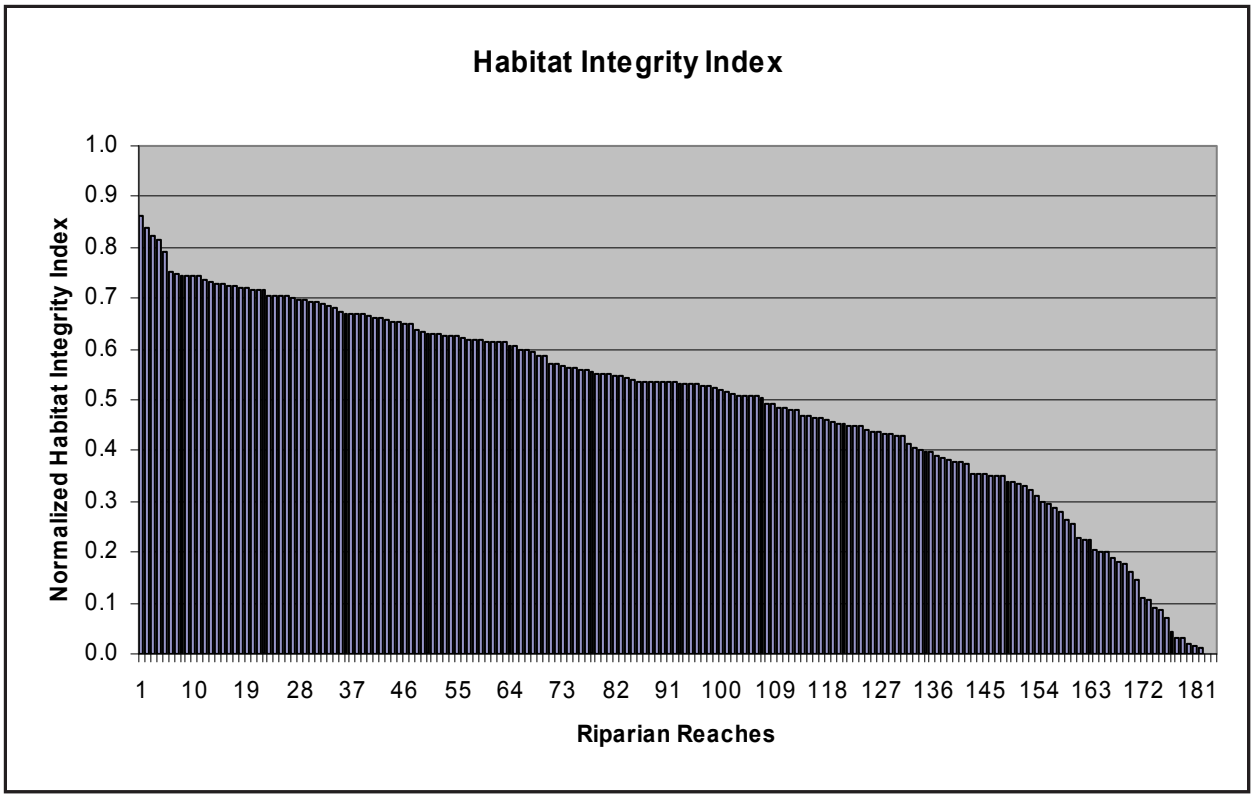


Figure A11. Range of normalized Habitat Integrity Indices for riparian reaches.



It is possible to make generalizations concerning which indicators have a significant influence on the integrity index of riparian reaches in the assessment area. However, care must be taken in applying these generalizations because each riparian reach represents a unique combination of indicators whose influence may be inconsistent with the generalizations. Consequently, the following generalizations should always be verified before applying them to a specific riparian reach.

Figure 12 displays the Hydrologic Integrity Index for riparian reaches in the project area. Riparian reaches tended to cluster into three groups. The first group had a normalized Hydrologic Integrity Index greater than 0.8 (Figure A12). These riparian reaches occurred primarily in areas of higher elevation that were not impacted by mining, agriculture, and urbanization. The primary impact in these areas was grazing, which tends to have minimal impact on hydrologic integrity. The second group of riparian reaches had a normalized Hydrologic Integrity Index between 0.6 and 0.8. The primary impacts in these areas were mining and agriculture, which tend to reduce the indicator metric values for the Altered Hydraulic Conveyance, Modified Stream Flow, and the Sediment Regime indicators at the riparian reach spatial scale and drainage basin scale. The third group had a

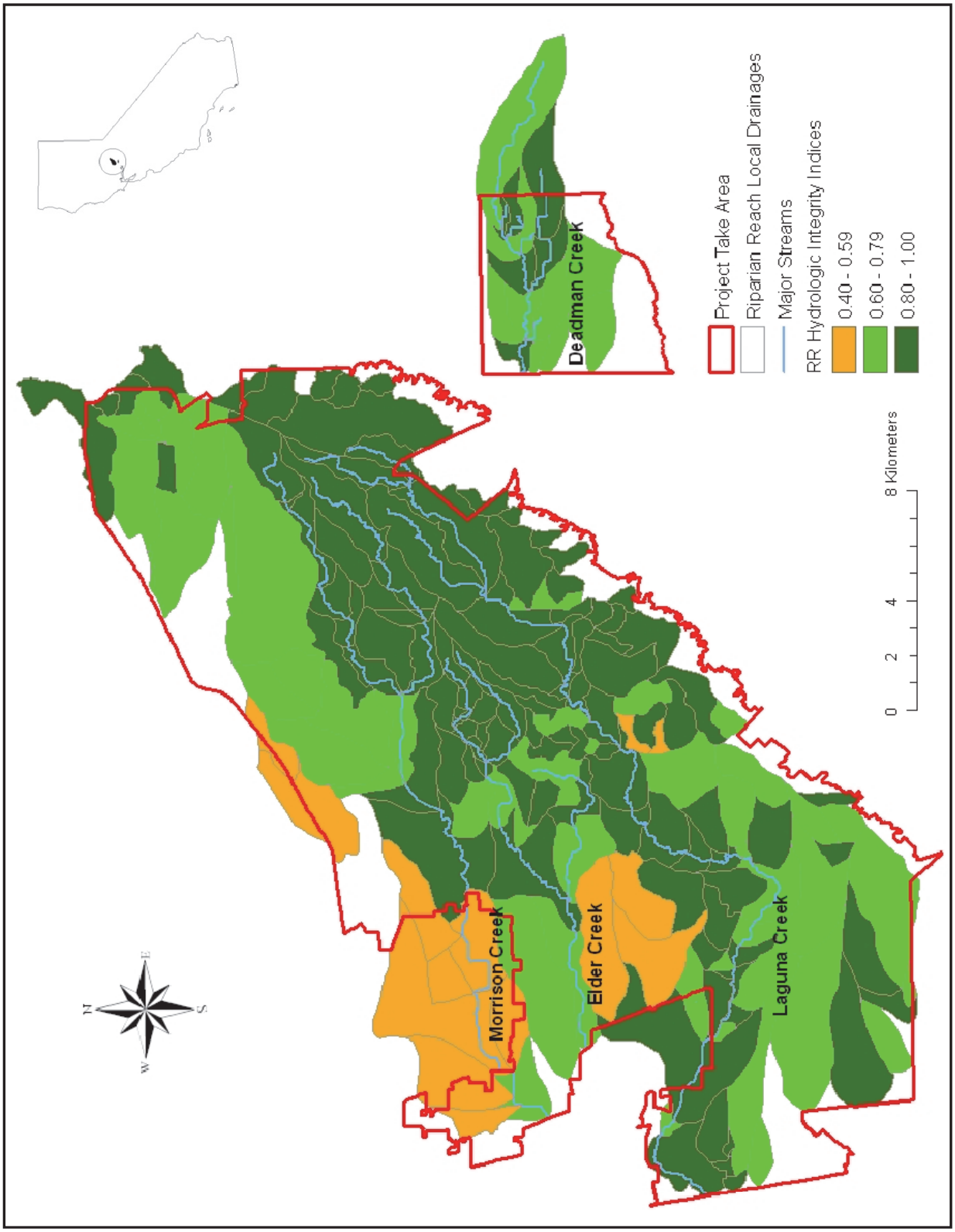


Figure A12. Hydrologic Integrity Indices for riparian reaches in the project take area.

normalized Hydrologic Integrity Index between 0.4 and 0.6. These riparian reaches are impacted by urbanization, which tends to reduce the indicator metric values for the Altered Hydraulic Conveyance, Modified Stream Flow, Stream Floodplain Interaction, and Sediment Regime at the riparian reach spatial scale and Surface Water Detention at the local drainage and drainage basin spatial scales.

Figure A13 displays the Water Quality Integrity Indices for riparian reaches in the project area. Water Quality Integrity Indices are generally lower than the Hydrologic Integrity Indices for the same reaches primarily due to the extensive alteration of land use due to grazing and the significant role of land use indicators at the local drainage scale in this integrity index. Riparian reaches tended to cluster into two groups. The first group had a normalized Water Quality Integrity Index between 0.6 and 0.8. As with the Hydrologic Integrity Index, these riparian reaches occurred primarily in areas of higher elevation in the eastern portion of the assessment area, and in other areas where alterations of the stream channels and grazing extent are minimal. The indicators that most significantly affect the water quality integrity of this category of riparian reaches, in decreasing order of significance, include Land Use/Land Cover – Nutrient Increase, Land Use/Land Cover – Pesticide Increase, Land Use/Land Cover – Sediment Increase at local drainage and drainage basin spatial scale, Sediment Regime at the riparian reach spatial scale, and Surface Water Detention at the local drainage and drainage basin spatial scales.

The second group of riparian reaches had a normalized Water Quality Integrity Index between 0.4 and 0.6. These riparian reaches occurred primarily in areas impacted by mining, agriculture, and urbanization. The indicators that most significantly affect water quality integrity of this group of riparian reaches, in decreasing order of significance, include Land Use/Land Cover – Nutrient Increase, Land Use/Land Cover – Pesticide Increase, Land Use/Land Cover – Sediment Increase at local drainage and drainage basin spatial scale, Sediment Regime, Altered Hydraulic Conveyance, and Modified Stream Flow at the riparian reach spatial scale.

Figure A14 displays the Habitat Integrity Index for riparian reaches in the project area. Habitat Integrity Indices are generally lower than the Hydrologic and Water Quality Integrity Indices for the same reaches primarily due to direct impacts to riparian ecotones, as well as grazing, agriculture, and mining impacts. Riparian reaches tended to cluster into

four groups. The first group had normalized Habitat Integrity Indices between 0.6 and 1.0. These riparian reaches had relatively intact riparian ecotones, local drainages, and drainage basins. They exhibited high to moderate metric values for the Riparian Vegetation Floodplain/Terrace, Riparian Buffer at the riparian reach spatial scale, and Land Use/Land Cover – Suitable Wildlife Habitat at the local drainage spatial scale. The second group had a normalized Habitat Integrity Index between 0.4 and 0.6. These riparian reaches had moderately impacted riparian ecotones, local drainages, and drainage basins, due primarily to agriculture. They exhibited moderate metric values for the Riparian Vegetation Floodplain/ Terrace, Riparian Buffer at the riparian reach spatial scale, and Land Use/Land Cover – Suitable Wildlife Habitat at the local drainage spatial scale. The third group had a normalized Habitat Integrity Index between 0.2 and 0.4. These riparian reaches had moderately to heavily impacted riparian ecotones, local drainages, and drainage basins due to urbanization and/or agriculture. They exhibited moderate to low metric values for the Riparian Vegetation Floodplain/Terrace, Riparian Buffer at the riparian reach spatial scale, and Land Use/Land Cover – Suitable Wildlife Habitat at the local drainage spatial scale. The fourth group of riparian reaches had a normalized Habitat Integrity Index between 0.0 and 0.2. These riparian reaches had heavily impacted riparian ecotones, local drainages, and drainage basins due to urbanization or mining. All the indicators received low metric values for this group.

Figure A13. Water Quality Integrity Indices for riparian reaches in the project take area.

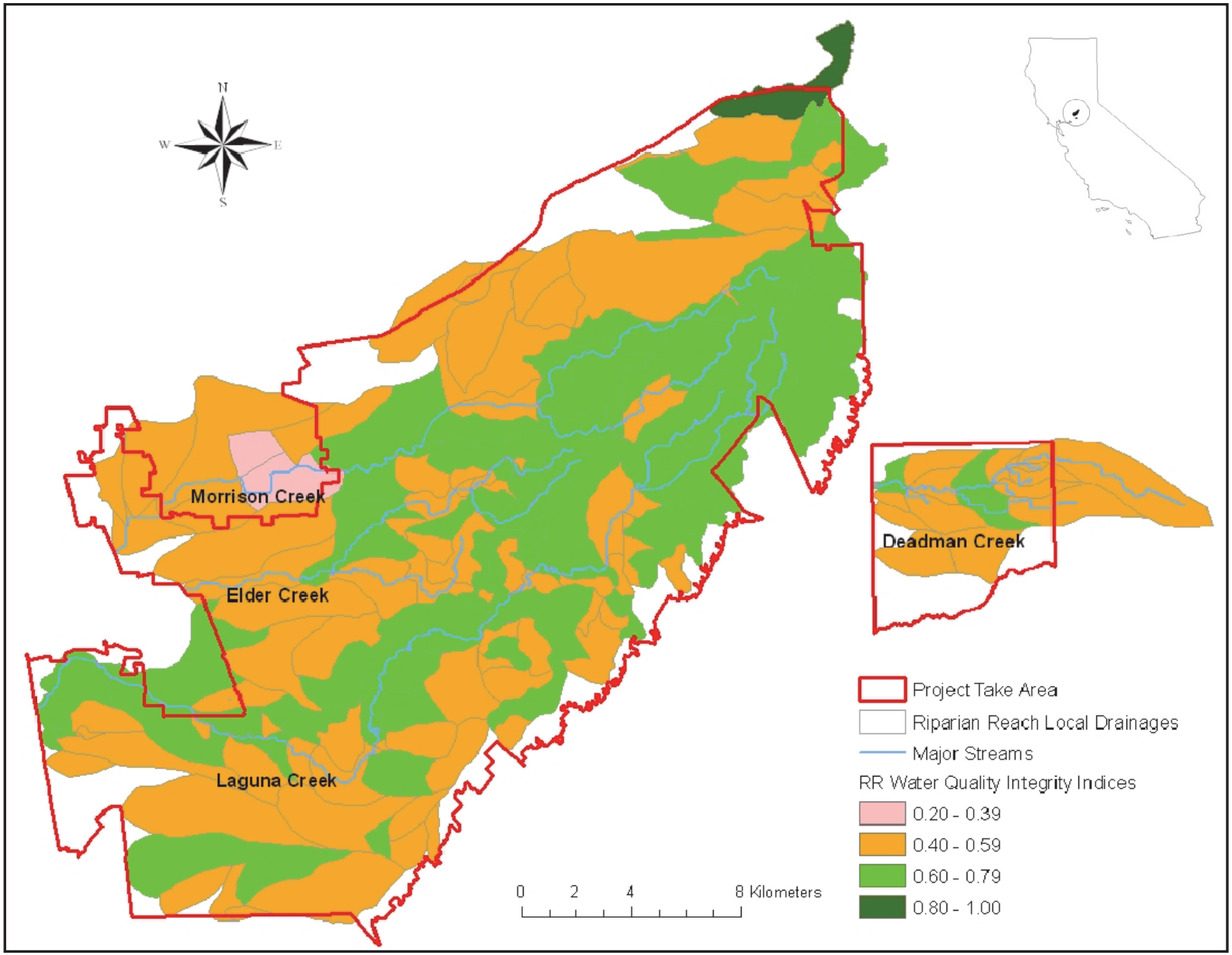
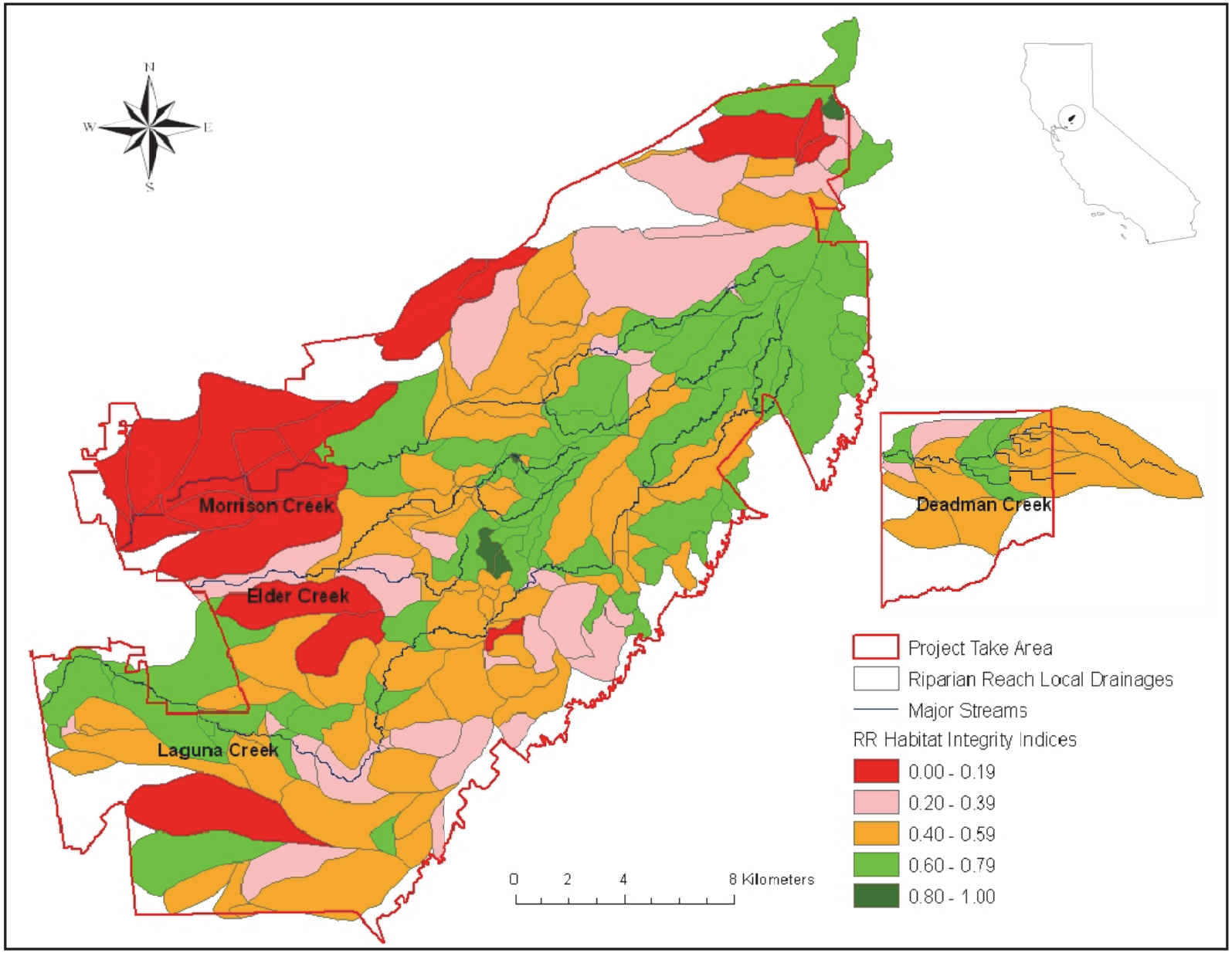


Figure A14. Habitat Integrity Indices for riparian reaches in the project take area.



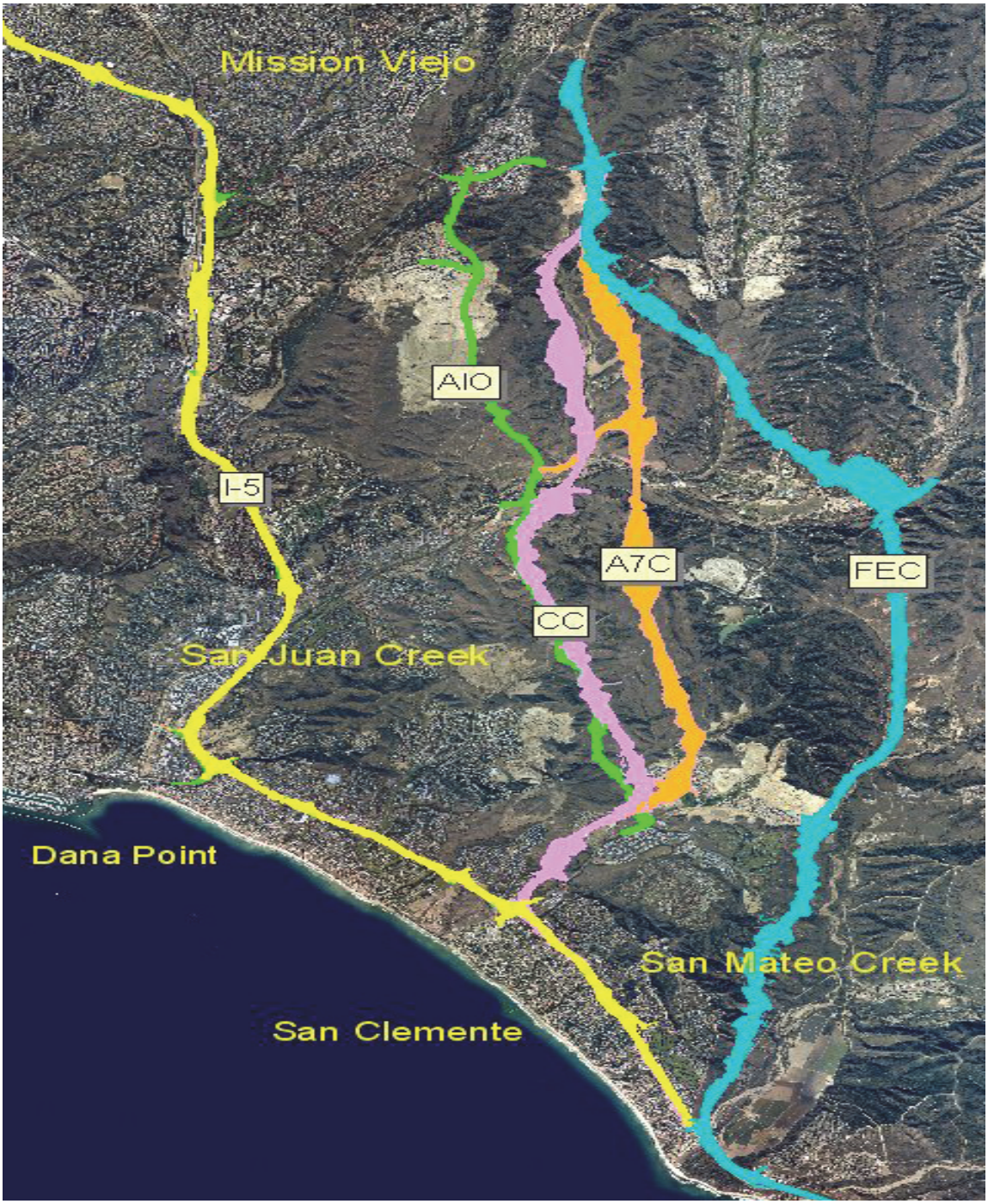
Appendix B: Alternatives Analysis Case Study

This case study describes an alternatives analysis completed for a transportation infrastructure improvement project proposing 23 alternative transportation corridor alignments in the San Juan Creek and San Mateo Creek watersheds in southern California (Figure B1). A baseline assessment of riparian ecosystem conditions had previously been completed for the two watersheds, similar to the one described in Appendix A. The objective of the alternatives analysis was to determine the potential direct and indirect impact of each alternative corridor alignment on riparian ecosystems in terms of several ranking criteria including: 1) linear distance of stream channel directly impacted, 2) acres of riparian ecosystem directly impacted, and 3) impacts to riparian ecosystem condition in terms of hydrologic, water quality, and habitat integrity.

Under the previously completed baseline assessment, the location of stream channels, upstream and downstream watershed assessment area (WAA) boundaries, local drainage boundaries, drainage basin boundaries, and riparian ecosystems had been accomplished. In order to calculate direct impacts to stream channel and riparian ecosystems, a geographic information system (GIS) was used to overlay the grading footprint of each alternative corridor alignment on the stream channel vectors and riparian ecosystem polygons established during the baseline assessment. Polygons and vectors intersecting the grading footprint of each alternative corridor alignment were clipped, and the total linear distance of stream channel and acres of riparian ecosystem was summed for each alternative corridor alignment in terms of each WAA.

In order to calculate the change in hydrologic, water quality, and habitat integrity indices for each alternative corridor, the grading footprint of each alternative was overlain on the riparian ecosystem in each WAA and riparian reach and local drainage basin indicators were reevaluated based on the changes that could be expected to occur as a result of the alternative corridor alignment construction. For example, if a grading footprint directly impacted a portion of the riparian ecosystems in a WAA, changes could be expected to occur in the metric value of several indicators at the riparian reach and local drainage basin scale, including Altered Hydraulic Conveyance, Floodplain Interaction, Area of Native Riparian Vegetation,

Figure B1. Study area showing major alternative corridor alignments.



Riparian Corridor Connectivity, Land Use/Land Cover at Riparian Ecosystem Boundary, and Land Use/Land Cover in Upland Buffer. Indirect impacts to a WAA were accounted for by simulating metric values for the drainage basin scale indicators. For example, if the grading footprint crossed upstream WAAs, changes could occur that would have an indirect impact on downstream WAAs. Based on these simulations, metric values

were recalculated, indicator scores were revised, and hydrologic, water quality, and habitat integrity indices were recalculated for each WAA. Integrity units were calculated by multiplying the integrity indices by the acres of riparian ecosystem in each WAA. The impact of each alternative corridor alignment was expressed in two ways: first, as the difference in the hydrologic, water quality, and habitat integrity indices between baseline assessment conditions and post-alternative corridor alignment conditions; and, second, as the difference in integrity units.

The results for the direct impacts to stream channels and riparian ecosystems (ranking criteria 1 and 2) are shown in Figures B2 and B3, respectively. Total miles of stream channel directly impacted varied among alternatives from about 2.3 to 15.2 miles. The percentage of stream miles impacted within each stream order category also varied widely across different alternative corridor alignments. Total acres of riparian ecosystem directly impacted varied across different alternative corridor alignments from approximately 10 to 275 acres.

The results for the impacts to riparian ecosystem condition in terms of the change in hydrologic, water quality, and habitat integrity indices and units also varied widely. The loss of hydrologic integrity units ranged from 3 to 27.5 units (Figures B4-B6).

Figure B2. Ranking Criterion 1: Directly impacted stream channels by Strahler order for alternative corridor alignments.

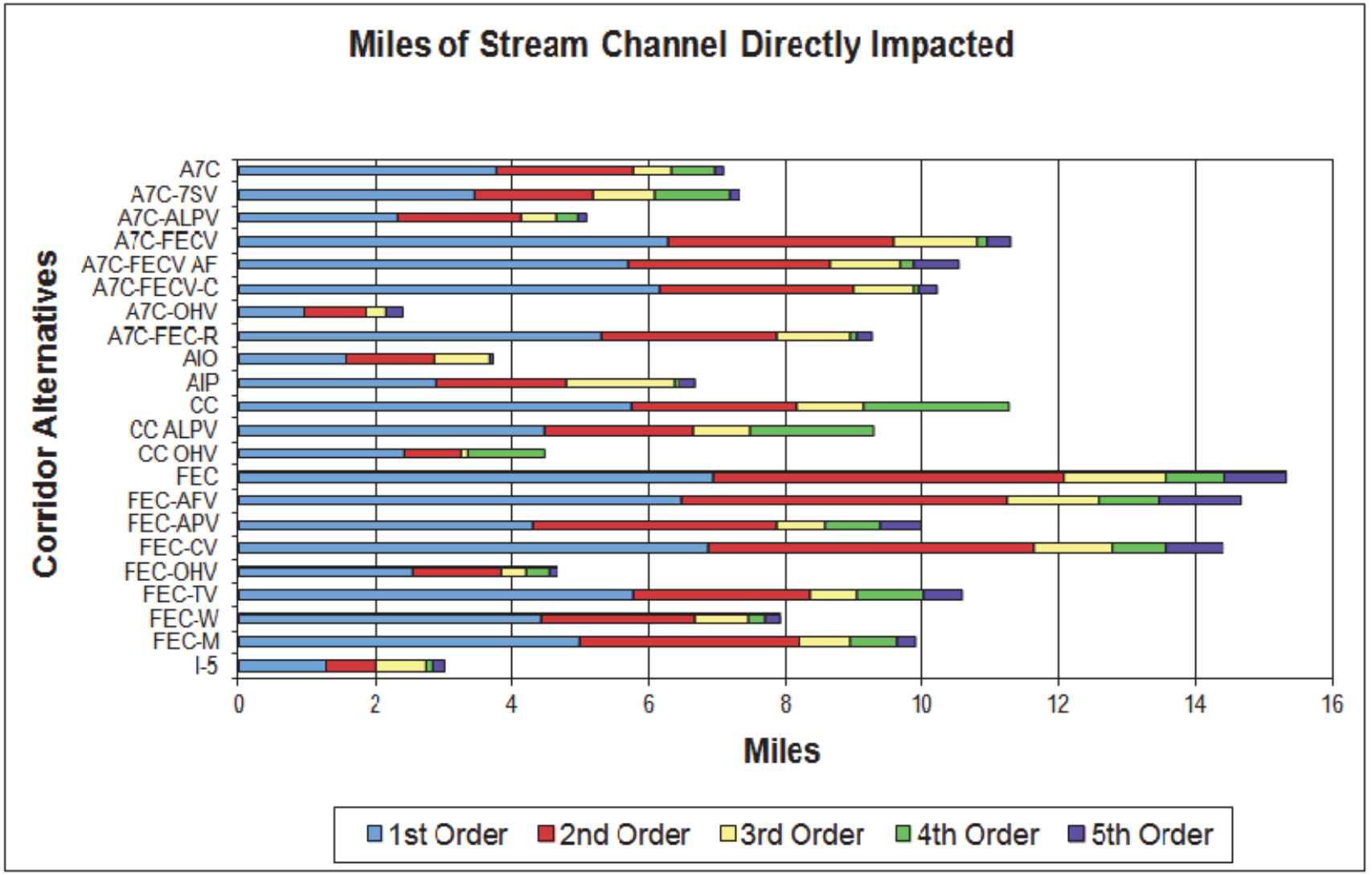


Figure B3. Ranking Criterion 2: Acres of riparian ecosystem directly impacted by alternative corridor alignments.

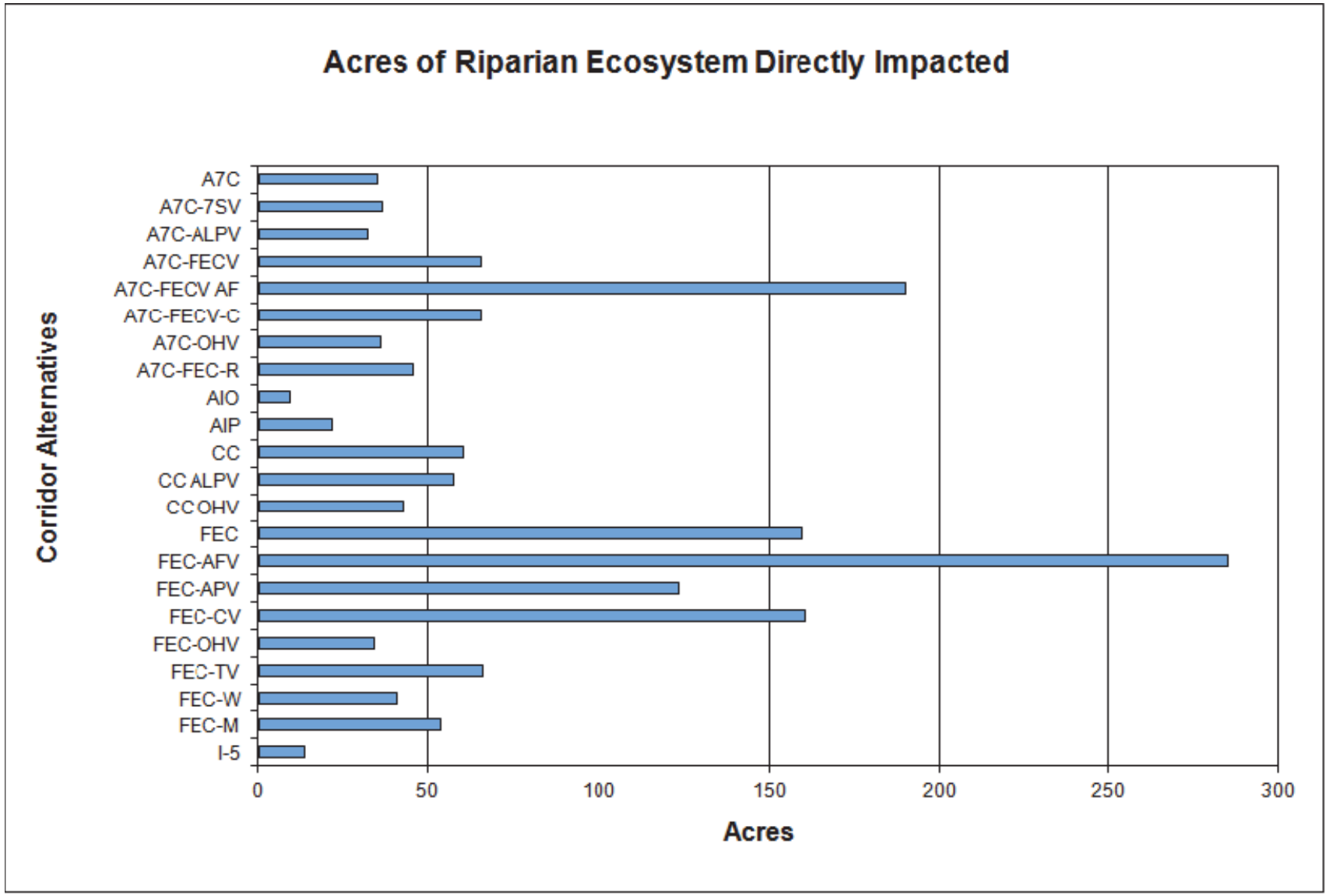


Figure B4. Ranking Criterion 3a: Total loss of hydrologic integrity units for all WAAs under each alternative corridor alignment.

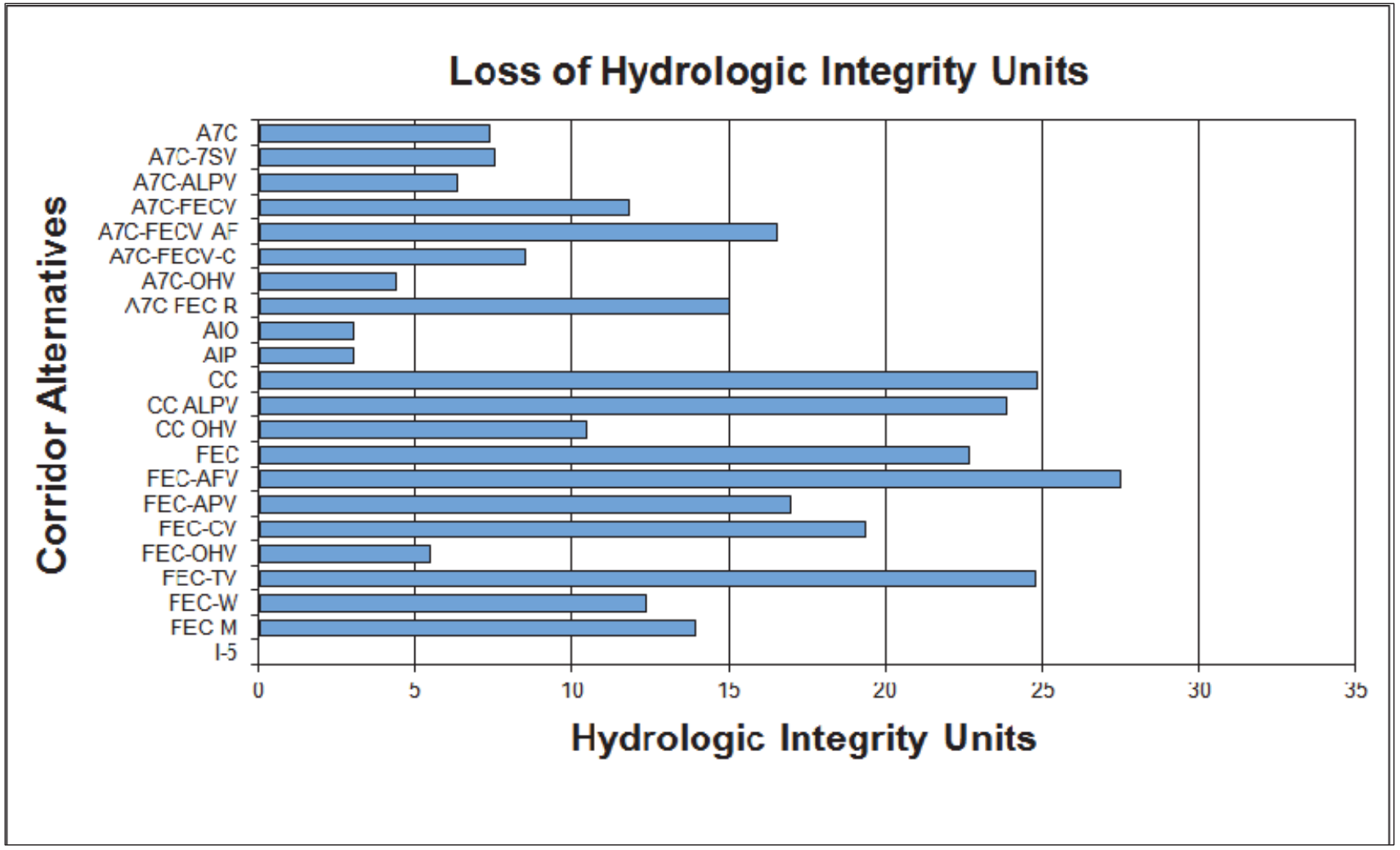


Figure B5. Ranking Criterion 3a: Total loss of water quality integrity units for all WAAs under each alternative corridor alignment.

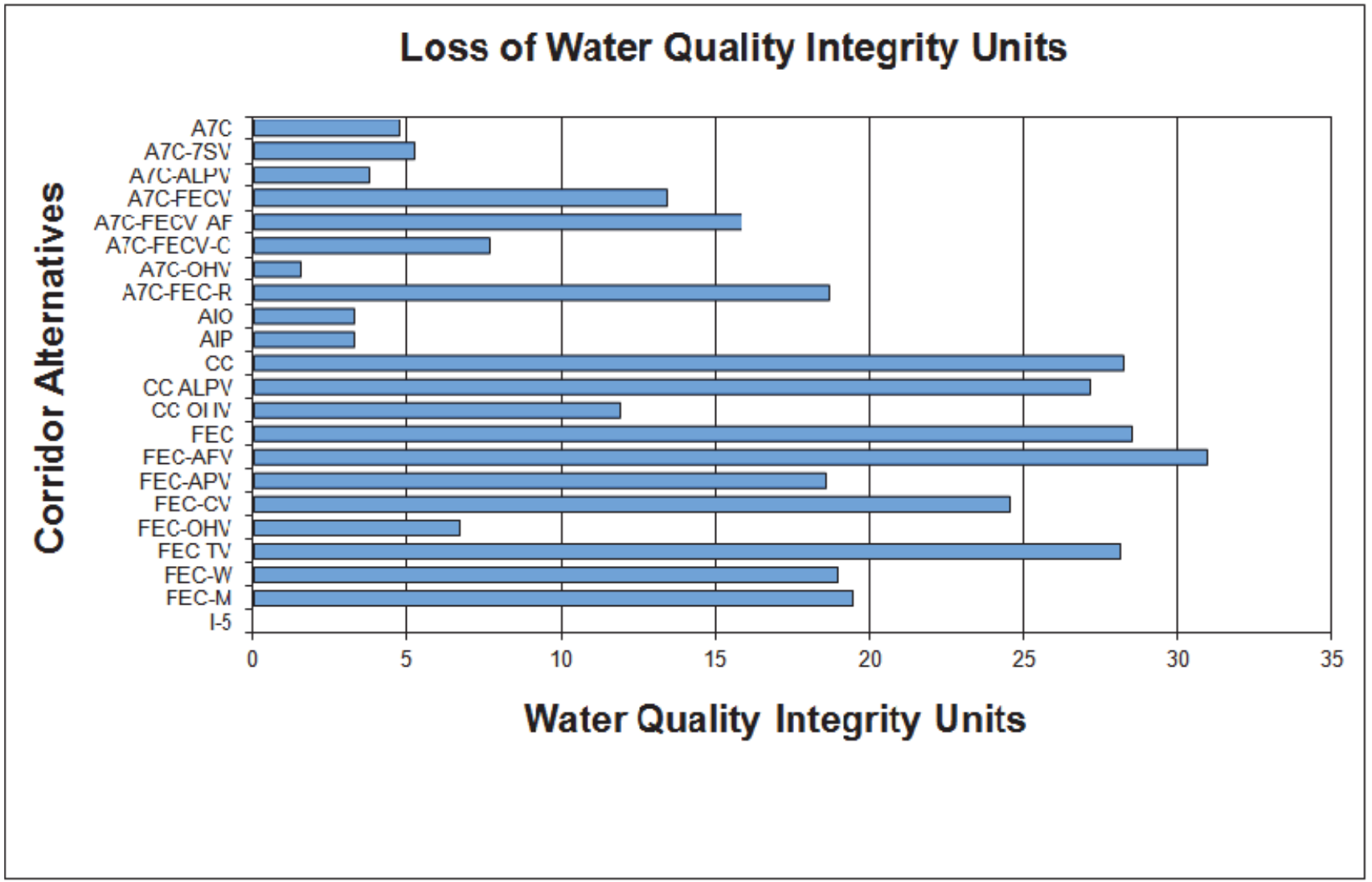
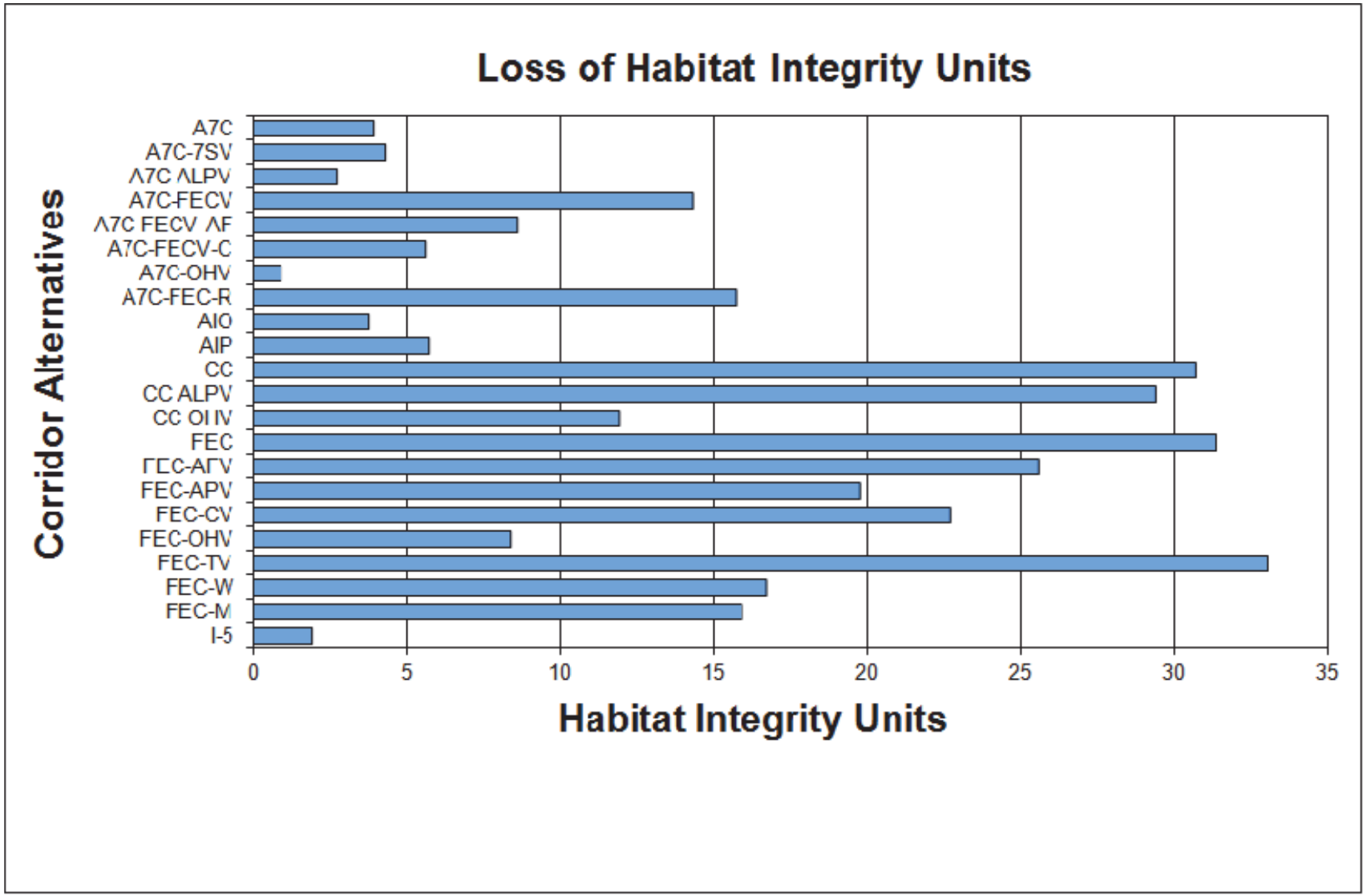


Figure B6. Ranking Criterion 3c: Total loss of habitat integrity units for all WAAs under each alternative corridor alignment.



Appendix C: Restoration Scenario Assessment Case Study

Introduction and background

Objectives and assumptions

The watershed assessment procedure described in the first part of this report is designed to allow testing of multiple impact scenarios, such as alternative highway alignments, to identify the options that will be least detrimental to ecosystem integrity across multiple scales, from the reach to the watershed level. Planners can use that information, along with construction cost data, to identify the least cost-least impact alternatives. However, any impact to wetland or riparian resources will require compensatory mitigation of lost ecosystem functions, which must be included in the cost analysis. Therefore, a method for testing multiple alternative restoration scenarios to identify options that will offset project impacts is a major component of the assessment process. Such a method will also provide an indication of the relative cost likely to be associated with each of those options. Like the baseline assessment procedure (Appendix A), this method is designed to feed directly into an alternatives analysis conducted across multiple scales, such as the example presented in Appendix B. In addition to alternatives testing for impact mitigation, this approach can also be used for developing the most effective and efficient approaches for accomplishing ecosystem restoration and management independent of any impact assessment. In that context, it is a watershed planning tool that can be deployed for a variety of purposes, such as prioritizing and guiding natural area rehabilitation and protection.

The example application of the assessment procedure presented here was developed for application in the Otay River watershed in Diego Counties, California, for the Los Angeles District Corps of Engineers. The District was in the process of developing a Special Area Management Plan (SAMP) for the watershed, and this and the baseline assessment (Smith 2004) were among several supporting studies.

The restoration application involves two separate procedures. The first is an assessment of the restoration potential of each riparian reach in the study area, and the level of effort required to meet that potential. The second is

the assessment of the change in riparian ecosystem integrity that is expected to occur under various restoration scenarios. The second procedure is accomplished by using the baseline assessment approach to re-assess riparian ecosystem integrity using input parameters (i.e. indicator metrics) that reflect the postulated restored condition of riparian reaches. This approach relates reach-specific changes to riparian ecosystem function at multiple scales, and allows estimation of the basin-wide and sub-basin effects of a restoration action undertaken in a single reach.

Approach

The basic steps in the restoration assessment approach are designed to be transferrable to any watershed. However, the individual components must be based on the ecology of the particular ecosystem and the types of data available. Just as the baseline assessment approach involves extensive fieldwork and the assembly of multiple GIS data layers, the restoration module requires the development or adaptation of general ecological models that describe the major landscape settings and natural vegetation communities of the system as well as the human alterations to those conditions that have taken place. These in turn are used to develop a set of restoration templates for various parts of the watershed and various levels of landscape alteration, and to characterize the degree of effort (reflecting relative cost) that would be required to implement that restoration. Like the baseline assessment tool, developing all of these components of the restoration “module” requires a significant investment of resources and the involvement of persons with specialized expertise. However, watershed planning and the vetting of multiple possible planning scenarios are complex tasks that cannot be overly simplified without losing credibility and utility; a significant investment in the development of the required planning tools is unavoidable.

In order to develop a practical planning tool that can be used as described above, it is necessary to devise specific categories of "restoration potential" and "level of effort" that can be applied consistently throughout the target watershed. Restoration potential refers to the level of restoration that is practical under existing conditions. It is defined in the context of extant, stable, and naturally functioning riparian ecosystems in the region, and focuses primarily on the geomorphic features and processes that determine the extent to which natural patterns of vegetation composition, structure, and diversity can be reestablished and sustained.

General restoration guidelines that reflect a variety of specific practical considerations were developed in the context of restoration potential. For example, it was assumed impractical to consider restoration options that involve carving new channels through non-alluvial substrates, or using fill material to build terrace systems within extensively eroded valley bottoms. However, manipulation of natural alluvial substrates to improve channel alignment or floodplain and terrace configurations is considered reasonable and feasible in most cases. Similarly, underground drainage systems and large concrete channels through heavily developed areas are generally regarded as impractical to restore, but some exceptions are made where these engineered features are small or non-functional, and traverse agricultural or recreational land. In no case is removal of roads or buildings considered as a restoration option; however, changes in land use from rangeland and agriculture to natural vegetation is included as a potential restoration tool.

In addition to "restoration potential," a simple relative index of the resources required to restore a riparian ecosystem to its full potential was also developed. This "level-of-effort" index is included as an additional planning tool based on the assumption that there will be limited resources available for restoration, or limited potential sites available to offset certain types of impacts. Under these circumstances, it may be useful to consider cost as a factor in the event that a variety of potential scenarios must be assessed for feasibility and efficacy. To that end, a level-of-effort estimate is assigned to each stream segment as a crude surrogate of construction and planting costs per unit area within the immediate riparian zone. The level-of-effort estimates do not include consideration of land purchase costs, the costs of upland restoration (e.g. conversion of rangeland to native vegetation), or unusual circumstances and unforeseen factors that could significantly change the estimates.

This approach allows consideration of restoration effectiveness at several scales (reach, local drainage, and drainage basin). It also provides a mechanism for testing the effectiveness of various combinations of restoration actions, such as concentrating restoration efforts on all degraded reaches in a drainage basin, versus giving priority to restoration of reaches where the greatest functional improvement can be attained per unit effort.

All of the options for testing and analyzing restoration options and scenarios are designed for application in the context of a geographic

information system and spreadsheets. Thus, the information presented here constitutes a flexible planning tool that is adaptable to changes in on-the-ground conditions, data quality, project priorities, and similar eventualities.

Study area

The 145-square-mile Otay River watershed is located in San Diego County in southern California (Figure C1). Topography of the watershed ranges from rugged peaks typical of the Peninsular Range through rolling foothills, plateaus, and broad drainages flanked by alluvial terraces, to a flat coastal plain. The total elevation range is nearly 4000 ft. The mountains are primarily granitic, but the lower basin is dominated by marine terraces that range from flat to highly dissected, and the major stream valleys often have extensive alluvial terraces flanking the modern floodplain. Both the coastal terraces and the alluvial terraces are often partly buried by alluvial fan deposits (Strand 1962, Aspen Environmental Group 2004).

A Mediterranean climate of warm dry summers and mild winters predominates in the study area. Precipitation patterns vary with elevation and distance from the coast. The coastal zone receives about 13 in. of rain annually, and the average precipitation within the mountains is about 25 in. Most rainfall and periods of high runoff occur between November and April, and many streams are dry during the summer and fall (Bowman 1973). Storm systems capable of delivering large amounts of rainfall occur periodically, and more than a dozen major floods were recorded in the region during the 20th century (Aspen Environmental Group 2004).

Natural plant communities of the uplands in the Otay watershed are predominantly coastal sage scrub and chaparral, which occur throughout the foothills and on most mountain slopes. Native grasslands, once fairly extensive along the Otay River valley and lower hill slopes, have largely been displaced by non-native annual grasses and forbs. Oak woodlands occur on north-facing slopes and in ravines throughout the watershed, and on some alluvial terraces and colluvial fans. Conifer forests are limited in distribution, but include fairly extensive stands of Tecate cypress on Otay Mountain in the southeastern portion of the watershed (Miles and Goudey 2003, Aspen Environmental Group 2004).

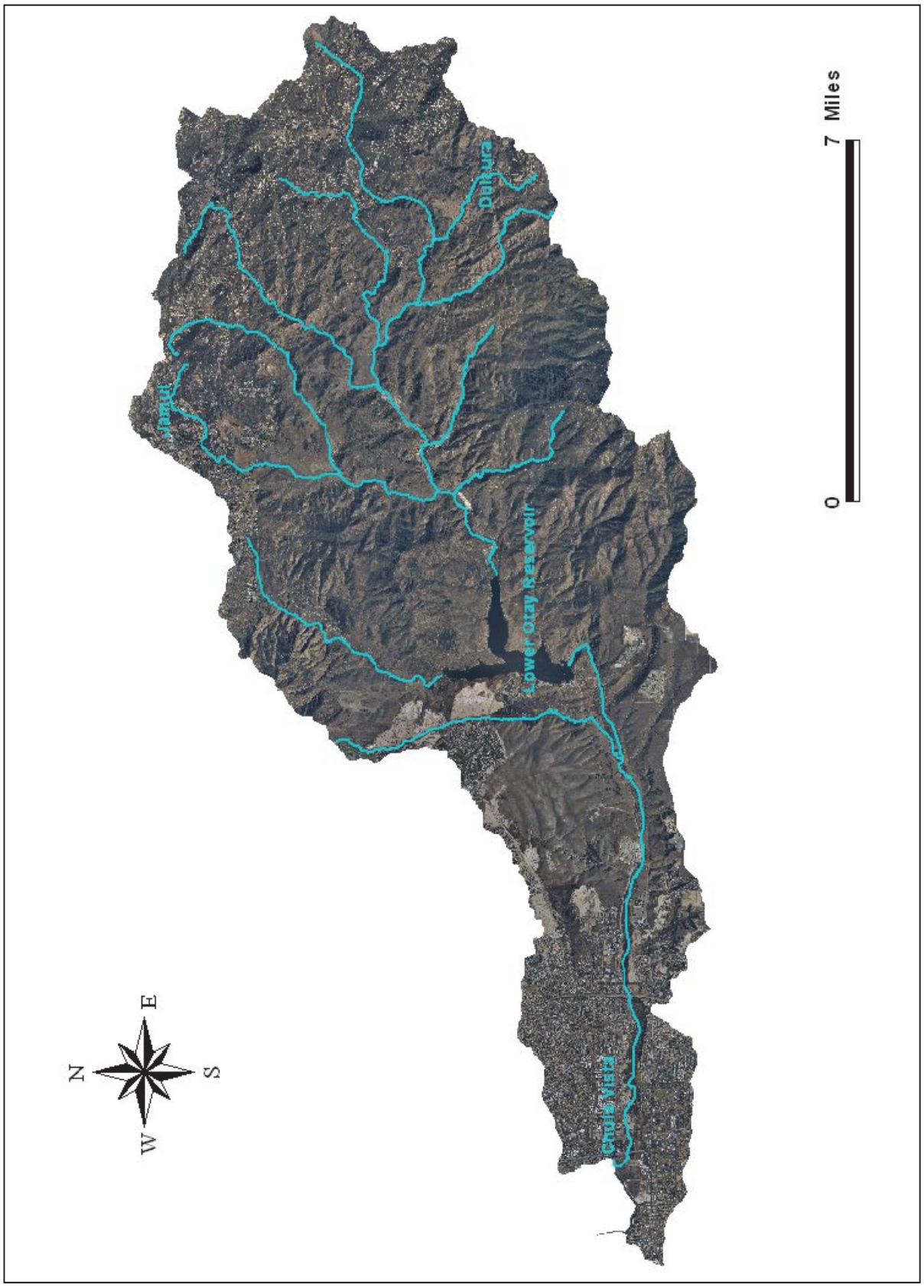


Figure C1. Study area boundaries in the Otay River watershed.

Wetland and riparian communities are quite variable within the study area. Wetlands include salt marsh and estuarine marsh on the coast, freshwater marshes within impoundments such as the Upper and Lower Otay Lakes, and scattered small wet meadows, vernal pools, and seeps. Riparian woodlands of sycamore and alder occur in mountain and foothill valleys with boulder and cobble substrates, and are frequently flanked by discontinuous oak woodlands on terraces and colluvial slopes. Larger valley bottoms and canyons include cottonwoods as an important component, along with sycamore and various willow species. Small sandy or steep channels and many areas where native canopy trees have been removed characteristically support thickets of willow and mulefat. Exotic species, particularly tamarisk, are commonly present in disturbed riparian areas and are dominant on many sites.

Periodic wildfire is an important factor in the maintenance of community structure and diversity in all upland habitat types in the region, particularly chaparral. There is considerable uncertainty regarding how fire patterns (frequency, intensity, and size of fires) may have changed during historic times, but fire continues to be a major influence on natural systems within the study area (Stephenson and Calcarone 1999, Keeley 2002).

The modern landscape of the Otay River watershed reflects extensive human influences. Early Spanish explorers observed that the Native American tribes in the region actively burned shrublands, but otherwise the indigenous people presumably had minimal impact. However, with the establishment of Spanish missions and large ranches, wholesale changes to native vegetation and ecosystem processes began, and they have continued to the present. The Spanish introduced irrigation, exploited timber resources, and cleared native vegetation mechanically and with fire to establish grazing lands. They also introduced European plant species to the landscape, and in particular replaced native grasslands with non-native species (California Coastal Conservancy 2001).

After the area became part of the United States in 1848, the human population increased rapidly as a result of land booms and gold rushes. Over the following decades, the city of San Diego and its port and rail facilities attracted new residents, industries, and military bases that spread over much of the former ranch and farm land in the lower watershed. Development continued through the 20th century, with a concurrent reduction in agricultural land (Aspen Environmental Group 2004).

One of the major concerns in the region since the arrival of European farmers has been the availability of water. Two water supply reservoirs, the Upper and Lower Otay Lakes, currently provide water to San Diego. The Otay River and the Sweetwater River to the north were historically the principal sources of fresh water for San Diego Bay, but dams and extensive groundwater use have reduced their input by 76%. Changes in surface and subsurface water flows have likely reduced the potential extent of riparian plant communities and promoted the expansion of populations of invasive exotic species.

Today, approximately 20% of the Otay watershed is urban or residential. While population growth has been concentrated in the coastal region, residential development in more remote areas has been increasing rapidly.

Methods

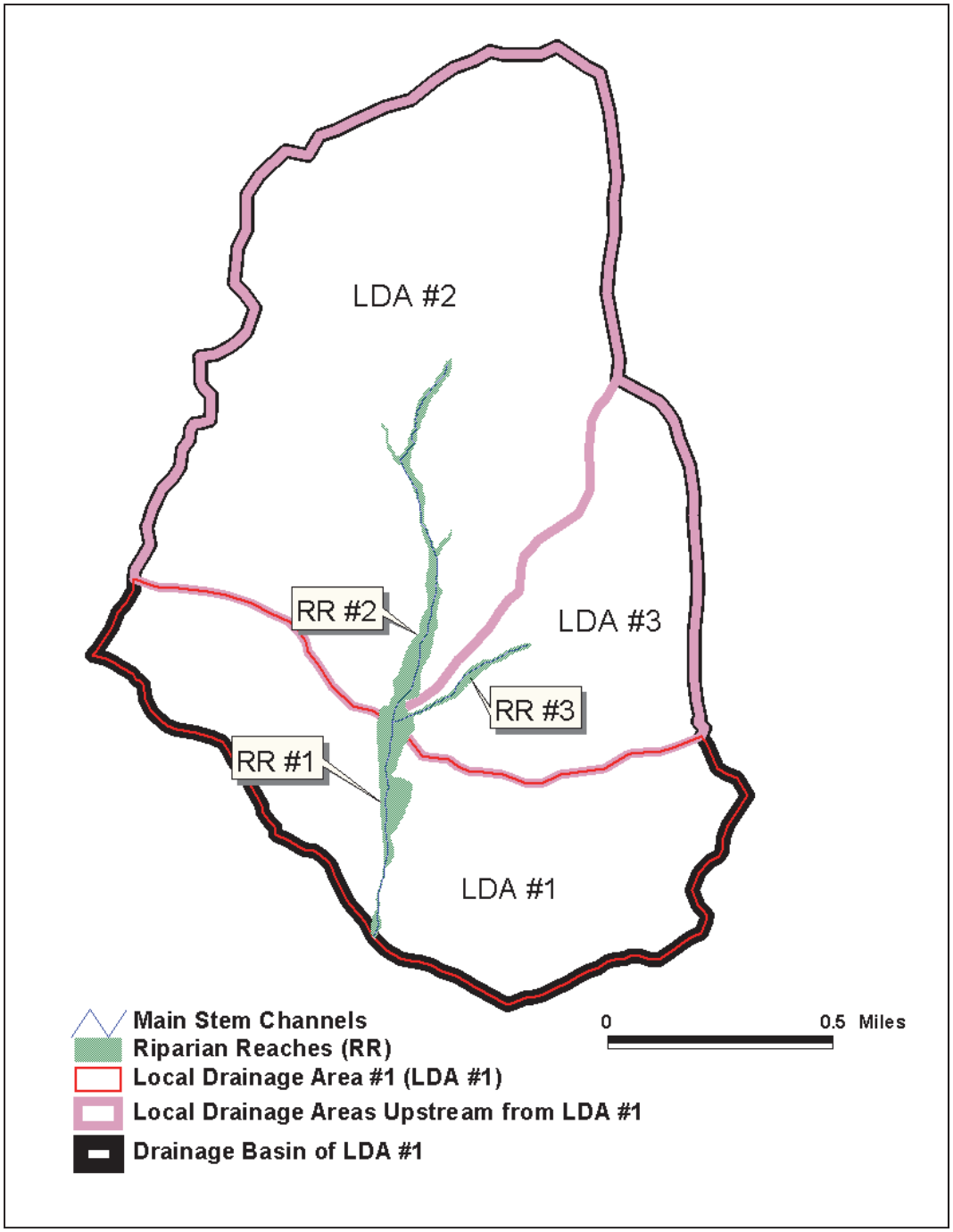
General approach and definitions

The assessment units used in this study were the riparian reaches designated during the baseline assessment of riparian ecosystems. By adopting the riparian reaches as the units of evaluation, the effects of proposed restoration on riparian ecosystem integrity could be assessed using the same methods and criteria employed during the baseline assessment. This method also allowed use of the extensive database of reach characteristics collected during the baseline assessment. A total of 269 riparian reaches were identified in the Otay watershed.

Riparian reaches were defined as discrete, relatively homogenous segments of main stem stream channel and adjacent riparian ecosystem, with respect to geology, geomorphology, channel morphology, substrate type, vegetation communities, and cultural alteration (Figure C2). Associated with each riparian reach was a local drainage, which consisted of the area from which surface water drained directly to the riparian reach, and a drainage basin, which consisted of the local drainages of all upstream riparian reaches. Land use and hydrologic characteristics were recorded for each of the local drainage areas as part of the baseline assessment.

In order to assess restoration potential, each riparian reach was classified in terms of its “geomorphic zone,” reflecting fundamental geomorphic characteristics under equilibrium conditions; a "restoration template," reflecting the extent to which the fundamental equilibrium condition could

Figure C2. Relationships of riparian reaches, local drainage areas, and drainage basins.

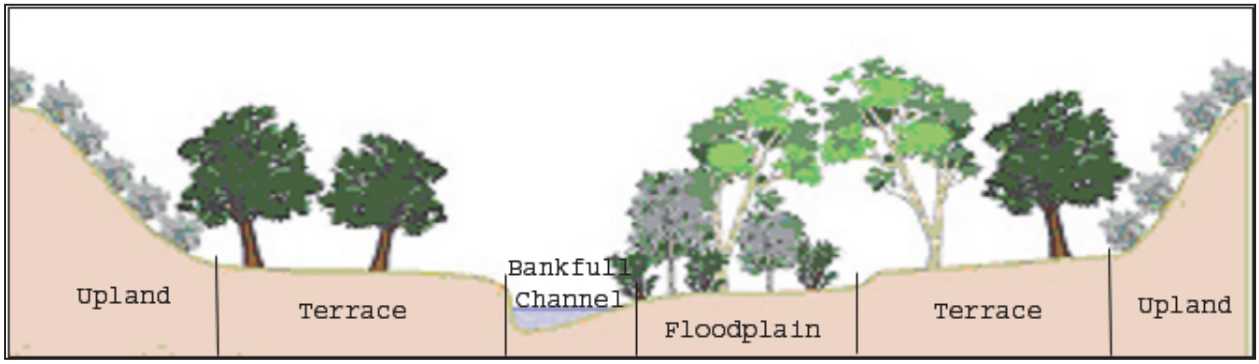


be re-established; and the “level of effort" necessary to achieve the conditions defined by the restoration template. The zone, template, and effort designations were made based on field characterizations of specific reach cross sections supplemented by aerial photography and the detailed reach data collected during the baseline assessment study.

The terms used to describe geomorphic settings and restoration templates are defined below and largely reflect the usage of Dunne and Leopold (1978) and Rosgen (1996). However, some definitions have been framed in terms specific to the Otay River watershed and the objectives of this study.

Bank-full channel: The active stream channel is defined as the area inundated when the stream is at bank-full stage, which corresponds to the discharge at which most channel-forming processes occur (Figure C3). For most streams, this discharge has a recurrence interval of approximately 1.5 years.

Figure C3. Riparian ecosystem geomorphic surfaces.



Floodplain: Technically, the floodplain is the valley floor level corresponding to the bank-full stage, but in fact various "floodplains" (e.g. 5-year, 10-year, etc.) include surfaces inundated at flow depths or frequencies that are of interest in a particular situation. For the purposes of this study, the floodplain corresponds to the "floodprone area" as defined by Rosgen (1996), minus the area of the bank-full channel. This is the area above the bank-full channel that is flooded when maximum channel depth is twice the maximum depth at the bank-full stage. The floodprone area usually includes most or all of the point bar deposits below the scarp rising to the lowest distinct terrace.

Terraces: Terraces are usually defined as former floodplains, although they also include flat surfaces carved by flowing waters, or the wave-cut surfaces of marine terraces. For the purposes of this study, terraces (other than marine deposits) are alluvial features originally deposited as floodplains, but which are now situated above the floodprone area. Multiple terraces may be associated with some stream reaches, usually identifiable as distinct steps along the channel, but sometimes the lowest terrace is contiguous with the floodplain, and is identifiable only with measurements based on the bank-full stage.

Riparian ecosystem: The riparian ecosystem is a linear corridor of variable width along perennial, intermittent, and ephemeral streams. Intact riparian systems exhibit distinctive geomorphic features and vegetation communities that reflect long-term stream processes as well as the ongoing periodic exchange of surface and groundwater between the stream channel and adjacent areas.

Flood channel: In a developed environment, protection of life and property usually requires that containment of floodwaters be a part of the design criteria for stream systems. The design templates presented here generally specify the dimensions of channel, floodplain, and terrace features appropriate to sustain a riparian community characteristic of a particular geomorphic zone, based on reference data from streams in the basin and region. The actual configuration of a restored riparian area will depend in part on the work of hydrologists calculating the overall "flood channel" size (channel, floodplain, and terraces) needed to contain a major flood.

Geomorphic zones

Eight geomorphic zones were defined based on field investigations, topographic maps, maps and descriptions provided in the county soil survey (Bowman 1973), and the geologic map of the region (Strand 1962). Figure C4 is a generalized representation of the landscape position of each geomorphic zone. Each riparian reach was assigned to a geomorphic zone using aerial photography, baseline assessment data, and field evaluations. The following sections describe the typical condition of each of the seven geomorphic zones in terms of geomorphology and vegetation structure. The accompanying block diagrams and photographs illustrate the usual geomorphic features, landscape setting, and plant communities found in relatively intact examples of each zone. The specific composition of the plant communities that occur in each zone varies with elevation, aspect, soils and other factors, as described in publications such as Barbour and Major (1977), Warner and Hendrix (1984), Stephenson and Calcarone (1999), Californian Coastal Conservancy (2001), and Miles and Goudey (2003).

Geomorphic Zone 1: Riparian areas in V-shaped valleys with predominantly bedrock control

Stream channels in Geomorphic Zone 1 (Figure C5) are primarily high-gradient systems within the mountains, and first-order streams in the

foothills. Soil and geologic mapping (Bowman 1973, Strand 1962) usually indicate no Quaternary alluvial deposits, although small terrace fragments may be present. Generally, streambanks are carved directly into adjacent hillslopes, and riparian vegetation is restricted to the channel edges and banks. Hill slope vegetation, usually coastal sage scrub, extends to the top of the bank. Riparian vegetation has been grazed heavily along many Zone 1 streams, but channel incision is generally minimal due to bedrock control.

Figure C4. Generalized representation of landscape settings associated with geomorphic zones.

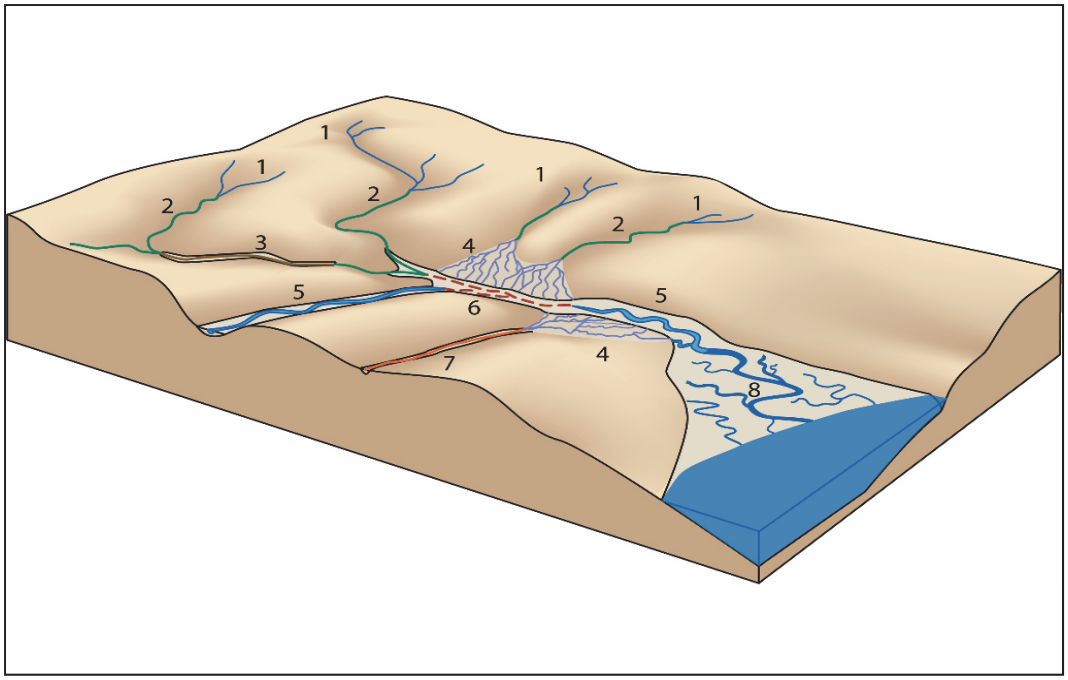
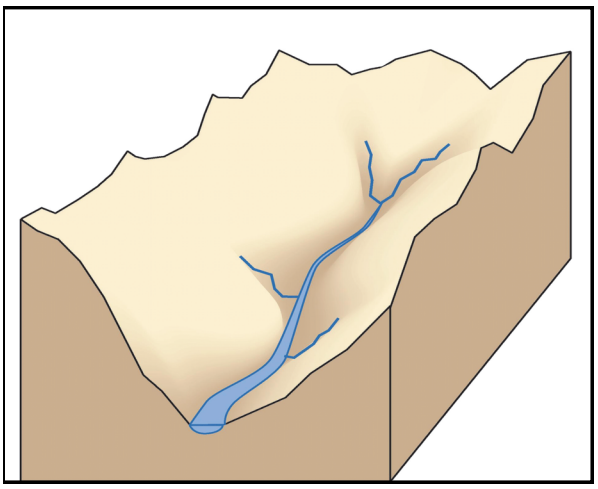


Figure C5. General form of Geomorphic Zone 1 and view of typical reach.

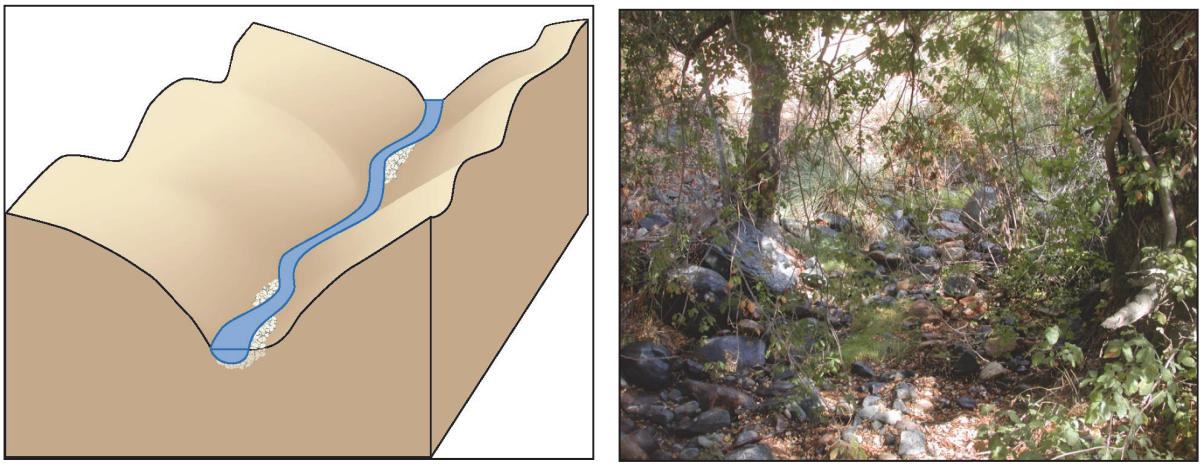




Geomorphic Zone 2: Small floodplains and terrace fragments in mountain and foothill valleys

Stream channels in Geomorphic Zone 2 (Figure C6) have a sinuous, meandering appearance on topographic maps and aerial photos, but in fact are winding between alternating fan, colluvium, or boulder bar deposits. Streams in this zone have narrow floodplains, and narrow, discontinuous terraces. Riparian vegetation dominated by sycamore, willows, and mulefat is restricted to the floodplains and terraces, usually forming narrow strips along the channel through fan and colluvial sections. In sheltered locations, the adjacent colluvial slopes and fans may be occupied by oak woodlands, but in most locations the alluvial zone is directly bordered by the predominant upland vegetation type (most commonly coastal sage-scrub or chaparral). On many streams, particularly within the mountains and deep canyons, large boulder bars occur at intervals along the channel, and often appear to be the result of landslides immediately upslope. These bars may develop thin soils, and have the appearance of terraces more typical of meandering-stream segments. However, the boulder-bar terraces are relatively unsorted material, with uneven, hummocky surfaces. The boulder bars are typically well-drained, and support a mix of riparian and upland plant species.

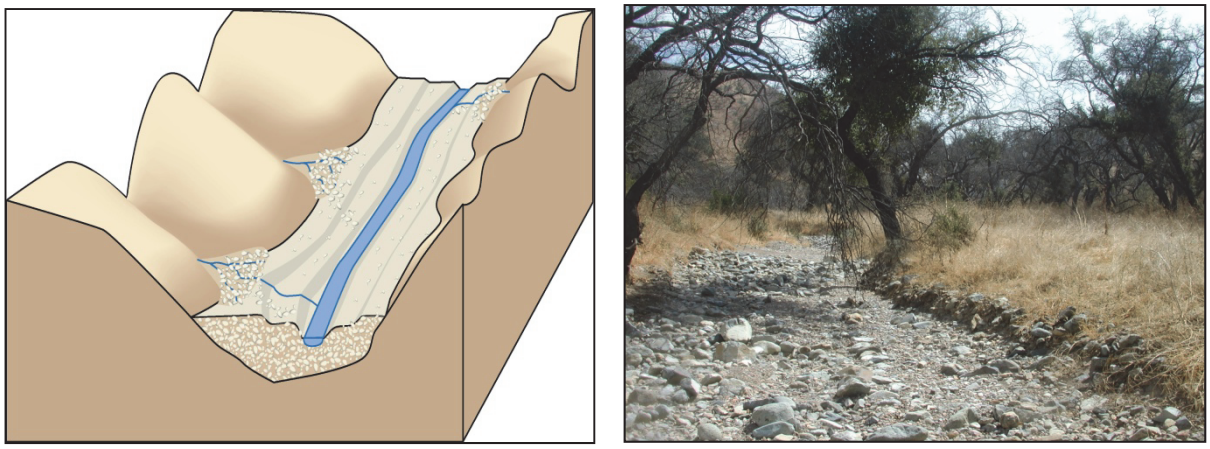
Figure C6. General form of Geomorphic Zone 2 and view of typical reach.



Geomorphic Zone 3: Boulder-dominated floodplain and terrace complexes

Geomorphic Zone 3 (Figure C7) is characterized by deep, extensive accumulations of boulders and cobble that extend from valley wall to valley wall (as opposed to the discontinuous boulder bars that occur in Geomorphic Zone 2). These areas usually are mapped as Quaternary Alluvium (Strand 1962).

Figure C7. General form of Geomorphic Zone 3 and view of typical reach.



Zone 3 reaches occur at and below the confluence of high-gradient tributary streams with larger channels. The steep tributaries deliver coarse, unsorted materials, which are distributed downstream. Usually, the main channel runs across bare cobbles and boulders, while the slightly higher adjacent terraces will have a shallow soil that fills between the rocks and forms a rough, but fairly level surface. Because the terraces consist of very coarse material, they typically support upland shrubs. Oaks and sycamores are often present but usually as scattered individuals. Overall, however, continuous riparian communities are restricted to the immediate vicinity of the stream channels. Very few reaches were designated as Geomorphic Zone 3, but where it occurs, it is distinctive.

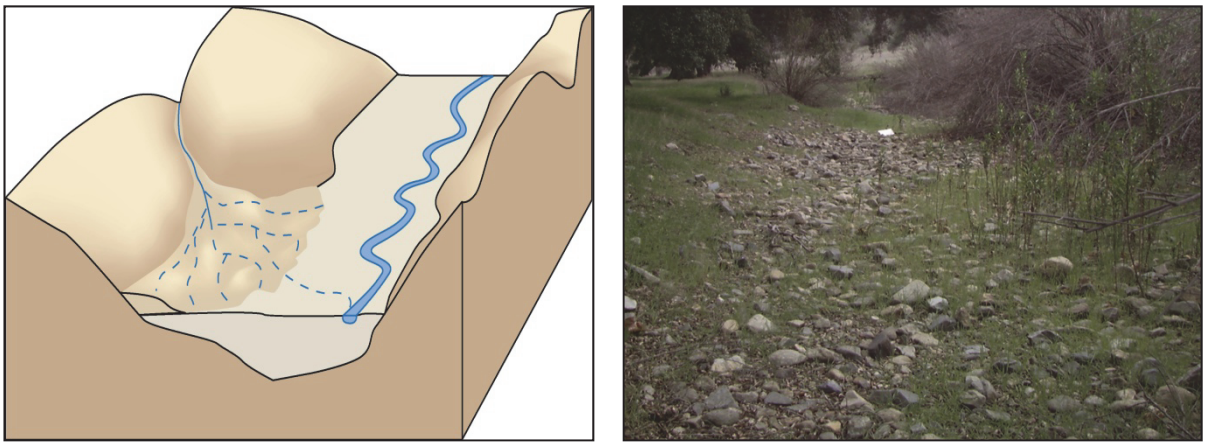
Geomorphic Zone 4: Steep alluvial fans

Where tributary streams enter larger valleys in mountainous terrain, fairly steep, truncated alluvial fans occur (Figure C8). These typically consist of coarse material (boulders and cobbles) where the channel exits from the confinement of the tributary valley walls, and they become more fine-textured as the fan descends and widens to merge with the larger valley floor. Channel systems often change form as they traverse a fan, and different patterns are displayed among fans in seemingly similar settings. Often, a distinct, single-thread channel exits the canyon mouth, then suddenly takes on a braided pattern as it crosses the coarse materials at the apex of the fan.

These channels all tend to be indistinct, and only storm runoff is carried as surface flows. The majority of the time the channels are dry, and any water emanating from the tributary valley mouth tends to travel through the fan

subsurface. A more stable, well-developed channel typically occurs at the base of the fan where groundwater discharges and moves to the main valley floor. Because there is little or no water at or near the surface most of the time, typical riparian species such as oaks, willows, and cottonwood occur only along the channels at the top and bottom of lateral fans. The vegetation along the majority of the channel system across the face of the fan is similar to the surrounding upland community (typically chaparral).

Figure C8. General form of Geomorphic Zone 4 and view of typical reach.



Geomorphic Zone 5: Alluvium of meandering streams in low-gradient valleys

Geomorphic Zone 5 (Figure C9) is characterized by sinuous channel systems that meander widely across the valley floor, have well-developed floodplains with alternating bars, and have one or more broad terraces that dominate the remainder of the valley bottom. The dynamic nature of this system promotes maintenance of a compositionally and structurally diverse plant community. Channel migration continually removes and creates substrates, ensuring patchy distribution of pioneer communities (such as mulefat and willows) in multiple age classes. Low terrace communities include long-lived canopy trees such as sycamores and ash, as well as tall shrubs such as elderberry and mulefat. High terraces and colluvial slopes or fans that overlie the edges of the alluvial terraces support oak woodlands, transitional riparian species, or shrub communities.

Geomorphic Zone 6: Valley fill

Some reaches of the major stream valleys have been filled with deep, well-drained sediments that show only trace channel systems and little or no

terrace development (Figure C10). These areas may slope somewhat toward the valley walls, but do not appear to be created by distinctive lateral fans such as those characteristic of Zone 4. Rather, the valley fill material in Zone 6 has the appearance of having originated higher in the main valley, and was likely deposited in a braided or widely meandering flow environment. As a result, the valley floor is relatively flat, and usually lacks distinctive continuous terraces. In some areas, most flows pass through the subsurface of these reaches. Where farming or grazing occurs, the channel system may be obliterated completely. However, remnant strips of riparian species (cottonwood, mulefat) suggest that, where subsurface water is available, riparian communities can be established. Re-establishment of a channel system, with particular attention to springs and shallow groundwater areas, may allow restoration of fairly continuous riparian corridors through Zone 6 reaches.

Figure C9. General form of Geomorphic Zone 5 and view of typical reach.

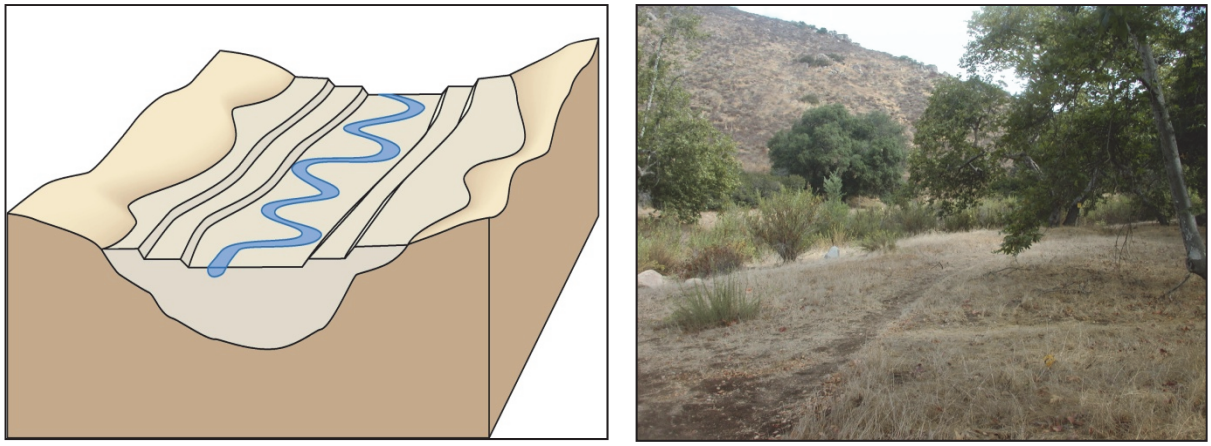


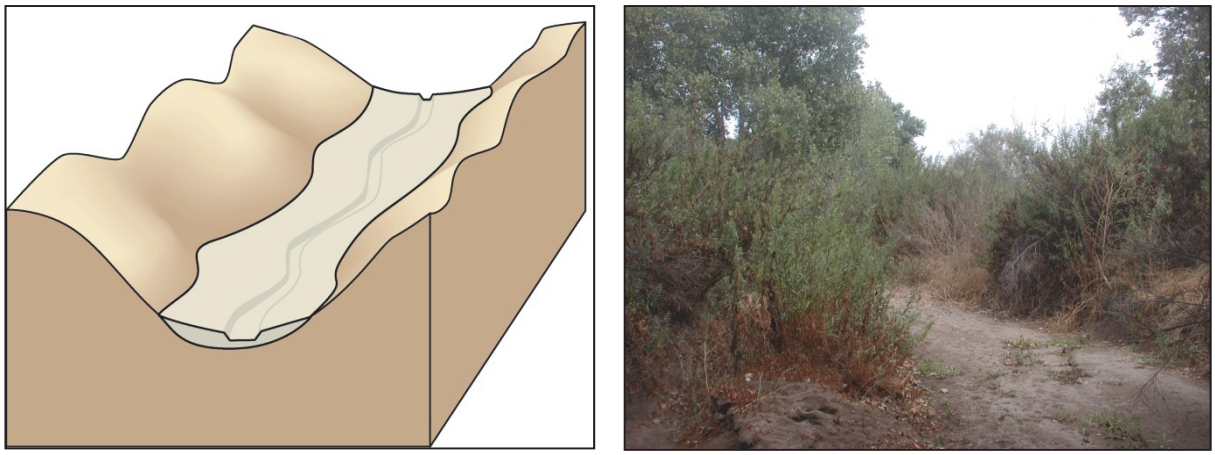
Figure 10. General form of Geomorphic Zone 6 and view of typical reach.



Geomorphic Zone 7: Sandy wash

A distinctive sandy wash channel type occurs in a limited number of small valley settings in the foothills. In the Otay watershed, this type exists only as short segments within reaches designated as predominantly other geomorphic zones. The type consists of a relatively narrow, flat-bottomed channel with low, distinct banks that give way to gently sloping alluvial and/or colluvial deposits (Figure C11). The alluvial deposits flanking the channel do not include any significant terrace systems, but instead are occupied by upland vegetation. The form of the valleys where these systems occur suggests that the coarse alluvial deposits are not deep. Riparian vegetation consists mostly of scattered, sparse stands of mulefat within the channel, but occasional isolated oaks, cottonwoods, and sycamores indicate that a relatively continuous riparian corridor might be reestablished within Zone 7 reaches through land use changes and limited supplemental planting. The distinctive channel, with well-established banklines, the sloping deposits flanking the channel, and the apparent frequent (but brief) occurrence of surface flows distinguish this zone from the valley fill type (Zone 6), where identification of shallow groundwater areas is a more critical restoration factor.

Figure C11. General form of Geomorphic Zone 7 and view of typical reach.

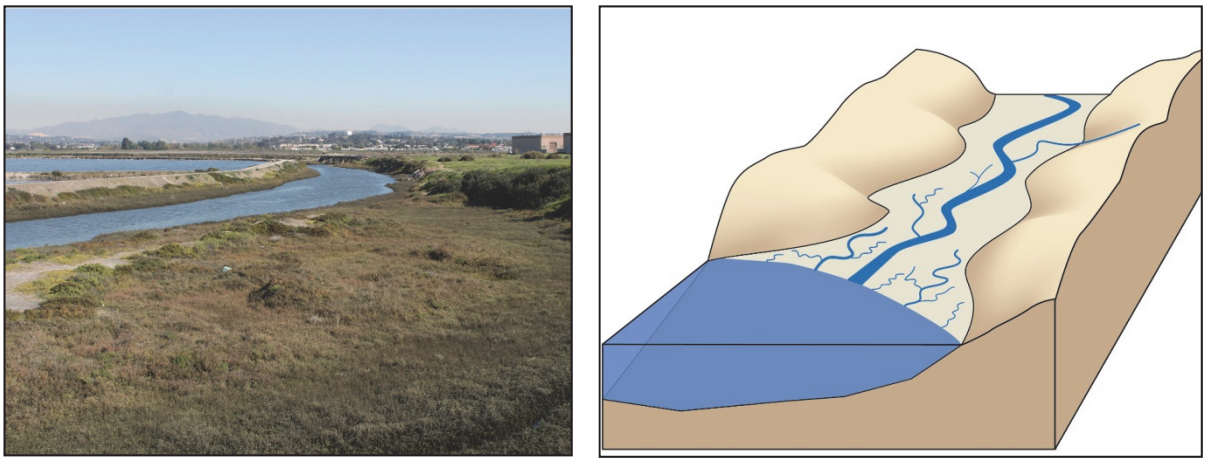


Geomorphic Zone 8: Tidal reaches

Below Interstate 5, the lower Otay River passes through an intertidal zone before discharging to San Diego Bay. The stream and associated wetlands in this zone have been highly modified by fill and channelization, and much of the area has been converted to salt evaporation ponds. Only small remnants of the native marsh system remain (Figure C12). The natural form of the channel system is entirely modified; the channel form and

pattern illustrated in Figure C12 are based on more intact systems in similar settings in the region. While restoration of this reach will clearly require channel realignment and reconfiguration in addition to fill removal, no specific restoration template is offered in this document. If restoration opportunities occur, the specific design will depend on the land available, and a detailed analysis of the potential to reestablish the main stem channel as well as tidal channels within the space available.

Figure C12. General form of Geomorphic Zone 8 and view of typical reach.



Restoration Templates

Potential Restoration Templates were developed for riparian ecosystems in various states of cultural alteration, applicable across all Geomorphic Zones. Each riparian reach was analyzed to establish specific restoration criteria in terms of channel cross section and form, the scale of terraces present, and dominant vegetation types appropriate to each of the Restoration Templates. Using aerial photography, baseline assessment data, knowledge of each riparian reach acquired during baseline assessment field sampling, and field verification, one of six restoration templates was assigned to each riparian reach based on the condition of the channel, riparian vegetation, and surrounding land uses. The assigned restoration template was intended to represent the best possible restoration target, given the potential natural patterns expected for the Geomorphic Zone, as described above. The objective of each template is to reestablish, to the extent possible, all of the vegetation zones present under natural conditions, and in relative proportions approximately corresponding to the extent of the geomorphic surfaces found in relatively intact reference reaches. In some cases, riparian reaches were divided and a different Restoration Template was assigned to each riparian reach. For example, where the upstream or downstream end of a

riparian reach consisted of a short segment of engineered channel (i.e., culvert under a road), a different Restoration Template was assigned.

All templates were assigned based on the potential to establish natural plant communities with composition, structure, and overall diversity characteristic of the geomorphic zone. Analyses of habitat requirements for animal species of concern in the region indicate that complex and diverse riparian plant communities are among the key determinants of habitat quality (e.g Franzreb 1989, Finch and Stoleson 2000). In order to reestablish such conditions, floodplains, terraces, and adjacent uplands must be available for restoration, and those surfaces must be restored to appropriate relative elevations (height relative to bank-full stage) to establish self-sustaining plant communities.

All templates include a zone of native upland vegetation as part of the overall riparian corridor, in addition to the riparian vegetation associated with the channel and terrace systems. For the purposes of assigning a restoration template, it was necessary to estimate whether sufficient upland area was available to form an adequate buffer. What constitutes an "adequate" upland buffer is a complex question that is beyond the scope of this project. For the purposes of this study, a minimum of 30 m of space adequate to support native upland vegetation is required on each side of the riparian vegetation corridor. This is consistent with generalizations that have been published regarding minimum buffers for a wide variety of avian species (Fischer and Fishenich 2000). As noted, this is a minimum figure – final restoration designs should incorporate recommendations from resource agencies, because specific regional and local conservation priorities may dictate wider buffers.

Finally, it is important to recognize that the restoration templates presented below are intended to be just that - general templates structured specifically to determine the feasibility of restoring individual reaches, and to prioritize restoration actions based on the functional benefits likely to be realized. Although final restoration designs are expected to resemble these templates and associated relative dimensions, site-specific restoration designs will have to be developed that include grading plans and specify planting stock, planting densities, irrigation practices, and similar requirements.

Many stream reaches in the study area, though degraded in various respects, still support dense native riparian vegetation in the immediate

vicinity of the channel. In order to avoid adverse impacts to mature, native riparian vegetation present at a restoration site, the restoration templates may need to be adapted. As appropriate, modifications to the restoration templates may include limiting the planting activities to terraces and adjacent lower hill slopes without excavation of alluvial material.

The six restoration templates are described below. Note that these are general descriptions applicable across all Geomorphic Zones.

Natural Template

The Natural Template (Figure C13) is assigned where channel, floodplain, and terrace morphology and vegetation, as well as an upland buffer of native vegetation, can be restored to a condition approximating the estimated undisturbed condition for the zone and site-specific conditions. Some stream incision is acceptable in this category, providing it has not caused a complete and irreversible shift in vegetation distribution. Generally, the designation of the Natural Template applies to reaches with sufficient room for a floodplain and terraces with hydrologic conditions required to sustain characteristic vegetation. In the Otay basin, channel incision, groundwater withdrawal, and surface water storage and diversion may preclude application of the Natural Template in many areas. However, most reaches in Geomorphic Zone 1, and a large percentage of Zone 2 reaches, were assigned to the Natural Template, indicating that they can be fully restored, or are already fully functional. In such cases, restoration is largely a matter of localized reestablishment of native vegetation, and control of exotic species, as illustrated for a typical Zone 2 reach in Figure C13. Some excavation and reconfiguration of alluvial material may be appropriate in cases where a stream is moderately incised, channelized, buried, or re-routed, but can be fully restored.

Incised Channel Template

The Incised Template (Figure C14) was applied to channels that had been incised or laterally scoured such that the existing condition did not fall into the normal range for channel, floodplain, or terrace dimensions, but where the full variety of community types expected for the Geomorphic Zone could be reestablished in proportions generally reflecting the undisturbed condition. In many cases, some reconfiguration of existing alluvium is feasible, allowing reestablishment of appropriate channel and floodplain dimensions to help arrest excessive erosion. In certain instances, some sculpting of terraces is possible. In situations where the

Incised Template is assigned but no opportunity exists for significant earthmoving, it indicates that all surfaces (terraces, floodplain, etc.) are present to a sufficient extent that all native plant communities can be re-established, though perhaps not to their full pre-disturbance extent. Most reaches assigned to the Incised Template are in Geomorphic Zones 2 or 5. Figure C14 illustrates a typical Zone 5 incised condition, and the proposed restoration approach, which includes reconfiguration of surfaces, removal of exotic vegetation, and extensive native plantings.

Figure C13. Typical pre- and post-restoration conditions of the Natural Template.

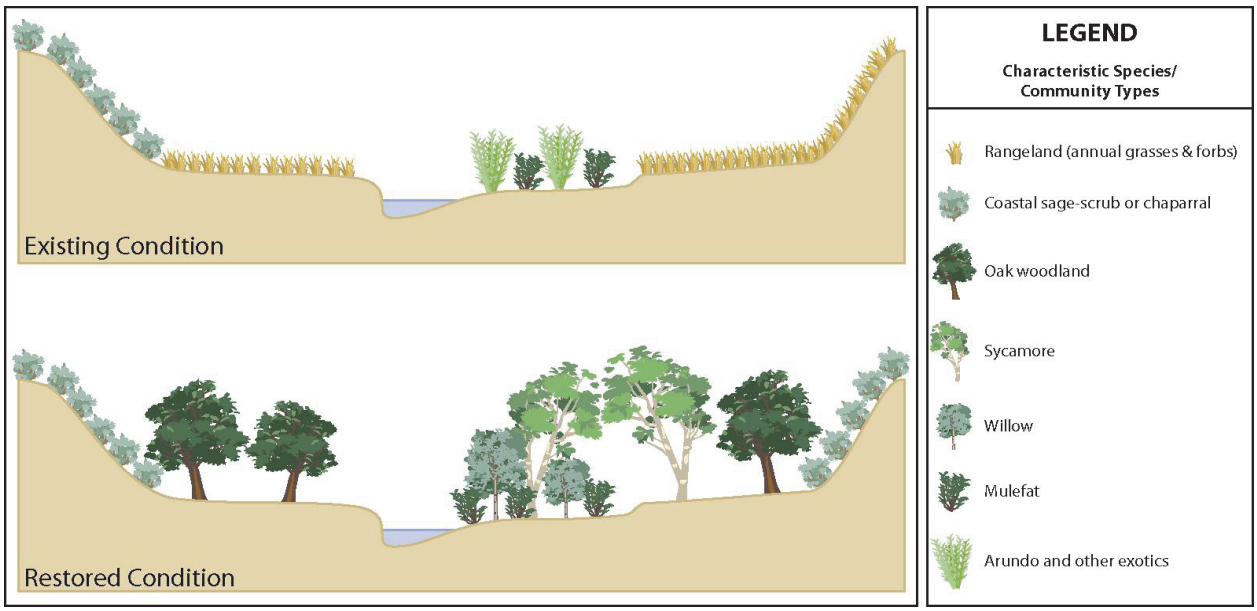
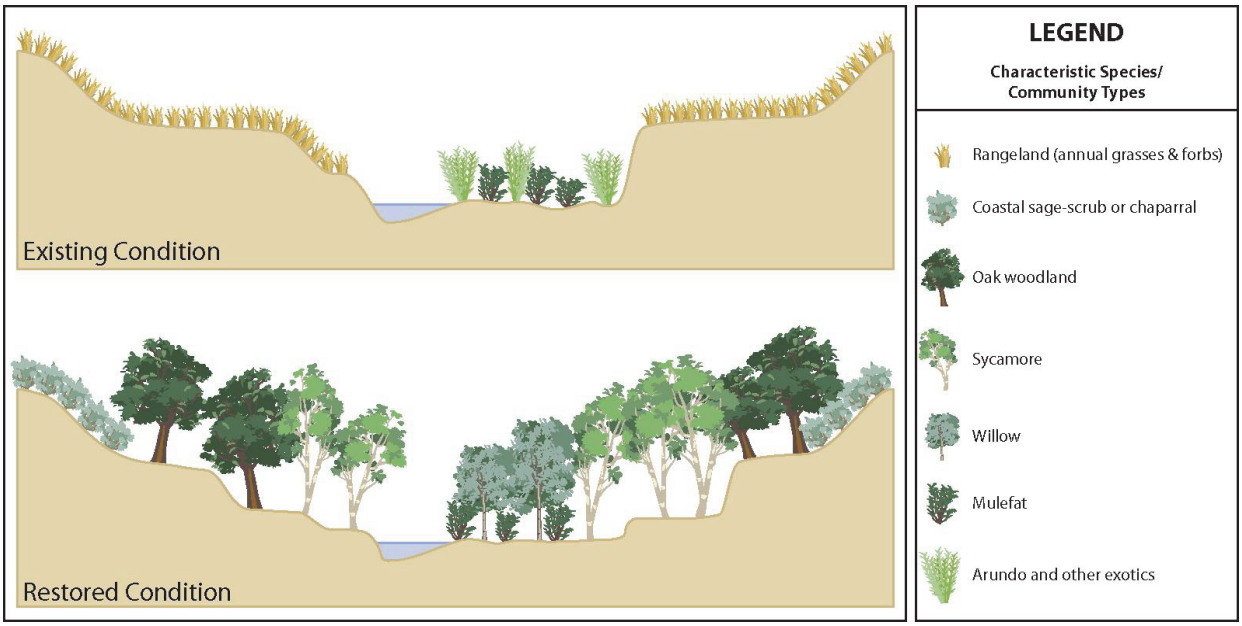


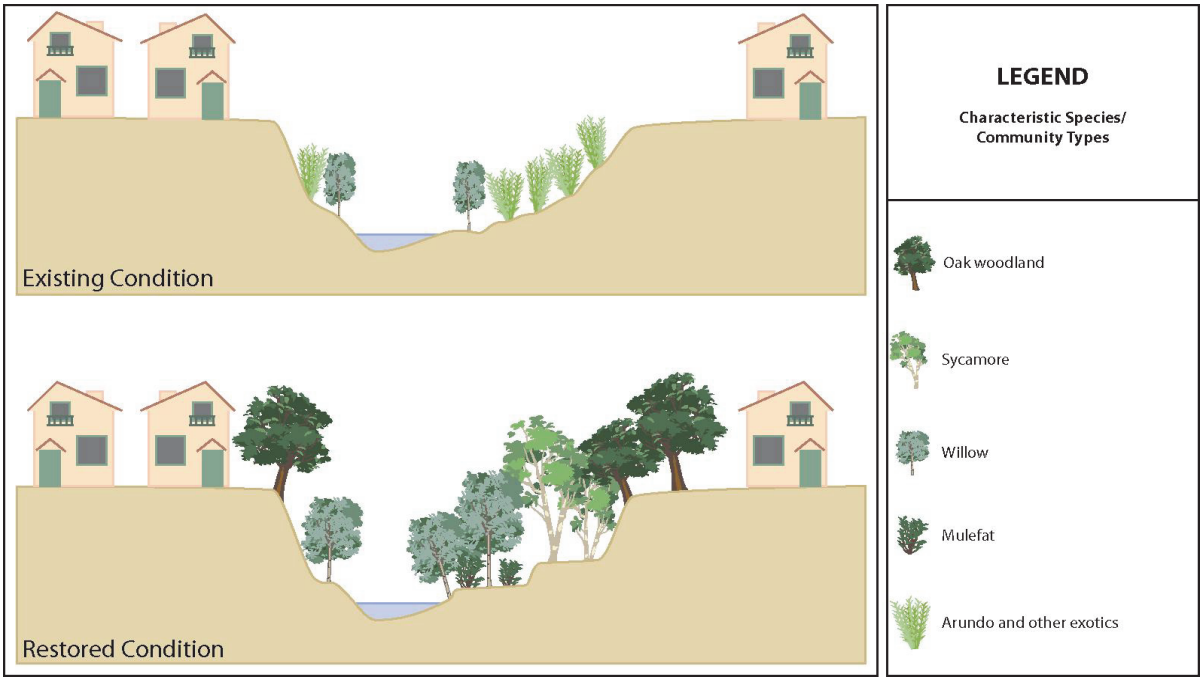
Figure C14. Typical pre- and post-restoration conditions of the Incised Template.



Constrained Channel Template

The Constrained Template (Figure C15) was assigned to channels that would otherwise be included within the Incised Template, except that the immediately adjacent landscape prevents the restoration of one or more components of stream corridor geometry (e.g., floodprone width, sinuosity, terrace configuration) to normal ranges. This template was typically applied where surrounding infrastructure (roads, buildings) irreversibly crowds the incised channel. In these cases, field evaluation indicated that sufficient room would be present to establish functional, and presumably stable (equilibrium) channels and floodplains, but that room to establish terraces and upland buffers would be inadequate to approximate conditions found in reference systems. Thus, stream segments restored based on the Constrained Template have all vegetation communities present, but one or more of those communities is substantially reduced in extent from the normal reference condition. A constrained system, i.e., one without room to adjust to extreme events, is expected to be less functional in various ways than more complete systems, making successful restoration efforts more uncertain, as compared with less constrained systems. The Constrained Template was assigned primarily to Zone 2 and 5 stream reaches. Figure C15 illustrates a typical application, where minor substrate reconfiguration is used to create surfaces sufficient for establishing narrow zones of different communities across a range of elevations relative to the stream channel.

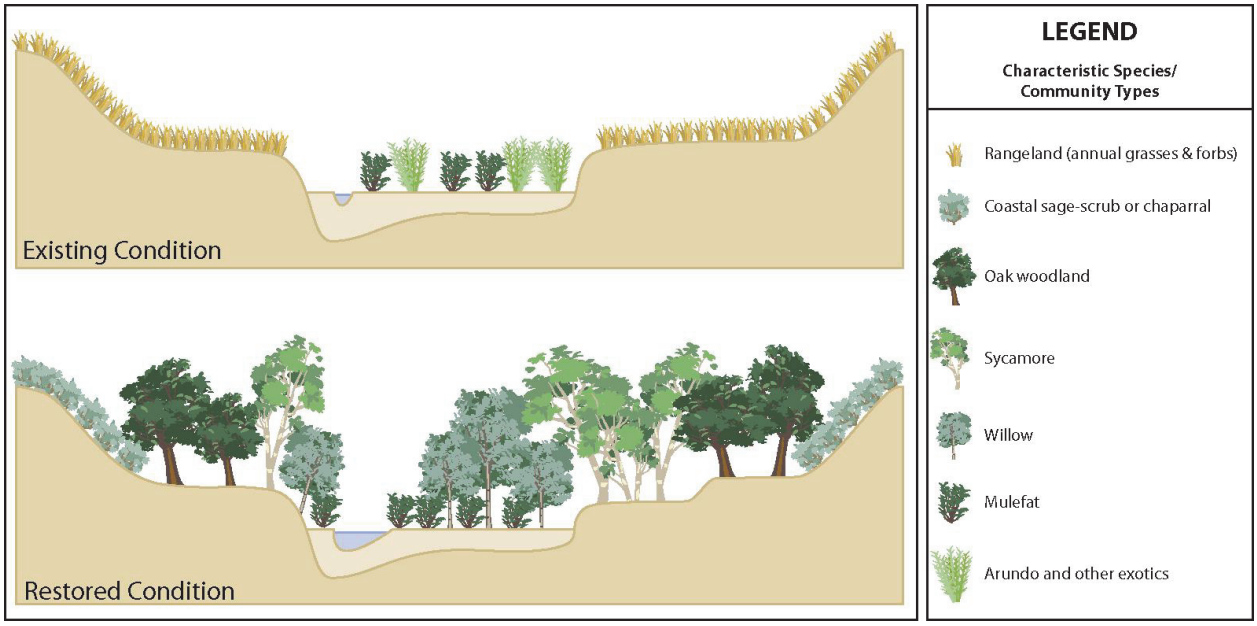
Figure C15. Typical pre- and post-restoration conditions of the Constrained Template.



Aggraded Channel Template

Numerous stream reaches within the study area show signs of having received excess sediment in historic times, but in most cases these areas have adjusted by changing channel size and configuration, which is accounted for in the other templates described above. The Aggraded Template is applied only to stream reaches that are affected by large amounts of recent sedimentation such that there is no distinct organization of surfaces. In the Otay basin, this situation is limited to relatively few sites. In each case, only minor channel reconfiguration (or none at all) would be appropriate. However, most aggraded sites require fairly extensive establishment of native plant communities on one or more riparian surfaces, as illustrated in Figure C16.

Figure C16. Typical pre- and post-restoration conditions of the Aggraded Template.

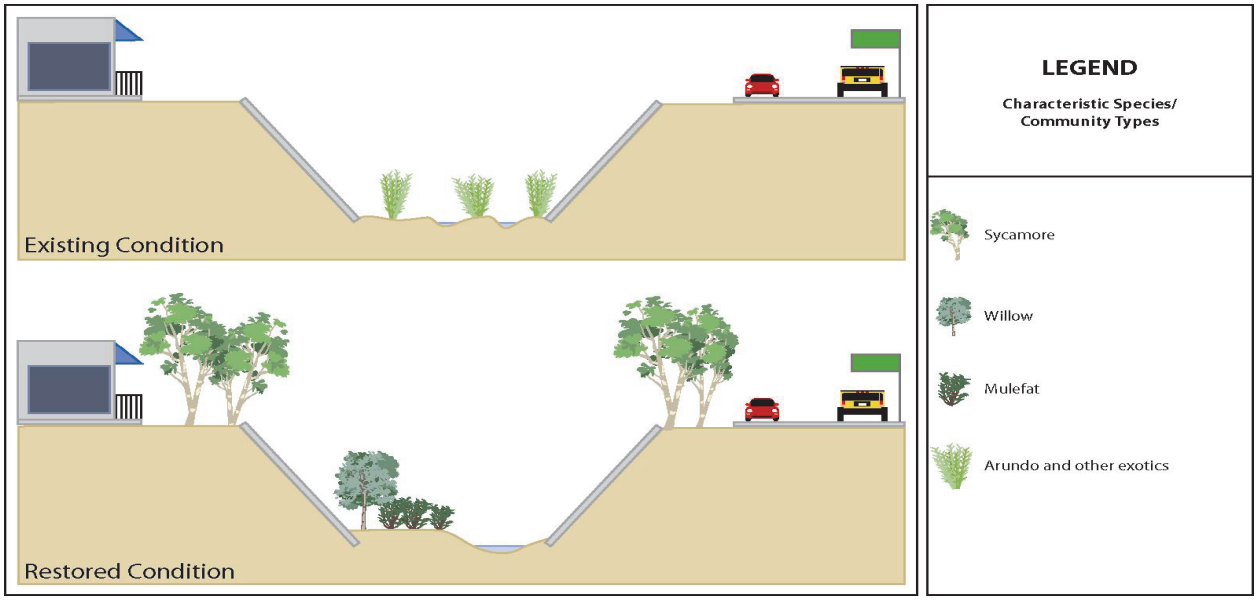


Engineered Channel Template

Stream segments that are confined within concrete or riprap "banks" and which must remain so due to flood conveyance and safety concerns, or because only very limited recovery of ecological benefits is feasible, are assigned to the Engineered Template (Figure C17). Through minimal restoration of native vegetation, this template may provide some, albeit limited, improvement in ecosystem function such as slowing the spread of exotic plant species, and establishing a movement corridor (primarily for avian species) between more functional riparian areas up- and down-stream. Although some concrete-walled channels have natural

channel materials in the bottom (rather than concrete) and are designed to accommodate some native vegetation within the channel, others may be adaptable to a change in management, or can even be modified to replace one of the engineered banks with a natural bank and native vegetation. Certain concrete channels may not be candidates for any change in design or management, and can only be retrofitted with a narrow strip of vegetation on the upland edge of the concrete wall. In any of these cases, the potential for significant restoration of a suite of functions is very limited, and the Engineered Template is intended only to address some specific deficiencies and thereby improve functionality of more complete riparian areas elsewhere in the basin. The Engineered Template is applicable primarily to Geomorphic Zones 2 and 5.

Figure C17. Typical pre- and post-restoration conditions of riparian reaches assigned to the Engineered Template.



Restoration Impractical Template

This template is applied to stream segments where there is no practical way to address the deficiencies present, within the general guidelines adopted for this study that preclude recommending fundamental changes to major roads and developed areas, or massive excavations. Thus, stream segments that pass under highway corridors within culverts, and lengthy stream segments that have been converted to the underground storm drain system through residential areas are assigned the Restoration Impractical designation (template), which means that no action is recommended. Should planners determine that restoration of a stream segment in this category is feasible, then the segment can be assigned to

the appropriate template and the action reassessed. Note that not all underground or engineered stream segments are rated "impractical" to restore, particularly if they pass through agricultural areas or greenways, where daylighting or channel reconfiguration would not disrupt existing infrastructure.

Other design considerations

As noted previously, site-specific restoration design is beyond the scope of this document, and specifications for features such as channel meander patterns, species composition, and the dimensions of geomorphic surfaces will have to be developed for each individual restoration site. However, in the course of conducting field studies the dimensions of geomorphic surfaces throughout the watershed were recorded across a range of geomorphic zones and levels of disturbance. Table C1 presents ranges and average values for channel, floodplain, and terrace dimensions in each geomorphic zone (except the tidal Zone 8), as determined from field measurements in a sample of the least-disturbed reaches remaining in the study area or region. These data may be used in conjunction with the previously presented restoration templates to estimate the general characteristics likely to be desirable for a proposed restoration area. For example, Zones 3, 5, and 6 normally have one or more terraces present, while Zones 1, 2, 4, and 7 do not. Similarly, in Zone 3 only a single low terrace usually is present, while Zone 5 typically includes multiple high, wide terraces. Note that some zones have features that span a particularly wide range of values (e.g., Zones 5 and 6). This generally indicates that the zone was encountered in a wide range of valley sizes, and the smaller end of the range of reported values applies to the smallest valleys. The values in Table C1 are not intended to be used as strict restoration specifications. Rather, Table C1 and the general descriptions and illustrations of each zone provided in the section titled “Geomorphic Zones” should be used to estimate the physical and biological complexity that is appropriate to a particular riparian setting.

Level of effort

Based on the field evaluation of all riparian reaches, a scale was developed to estimate the level of effort that would be required to restore a riparian reach to the prescribed Restoration Template. Using aerial photography, baseline assessment data, and field verification, a level-of-effort category was assigned to each riparian reach. The level-of-effort measure was

Table C1. Range and average dimensions of alluvial features by geomorphic zone.

Feature	Dimensions	Geomorphic Zone						
		1	2	3	4	5	6	7[1]
Bank-full Width (ft)	Range	3-4	4-6	7.5-8	4-5	6-16	3-20	4-7
	Average	3.5	5	7.6	4.5	11.5	8.4	5.5
Bank-full Max Depth (in)	Range	6-10	8	5-11	3.5-5	6-24	3-12	3-4
	Average	8	8	8.3	4.25	13.2	5.8	3.5
Bank-full Mean Depth (in)	Range	4-8	6-8	4-7	2.5-4.5	3-20	2-11	1-3
	Average	6	7	6	3.5	10	4.6	2
Flooplain Width (ft)	Range	5-14	2-3	12-14.5	7.5-9	4-20	5-21	1-7
	Average	9.5	2.5	13	8.25	14.9	10.2	4
Terrace 1 Width (ft)	Range	NA[2]	NA	10-30	NA	7-120	5-20	NA
	Average	NA	NA	20	NA	70	10.5	NA
Terrace 1 Ht. Above Bank-full (ft)	Range	NA	NA	1.5-2	NA	1-8	1.5-4	NA
	Average	NA	NA	1.75	NA	3.2	2.5	NA
Terrace 2 Width (ft)	Range	NA	NA	NA	NA	35-500	10-150	NA
	Average	NA	NA	NA	NA	160	90	NA
Terrace 2 Ht. Above Bank-full (ft)	Range	NA	NA	NA	NA	3-8	4-15	NA
	Average	NA	NA	NA	NA	5.7	11	NA
Terrace 3 Width (ft)	Range	NA	NA	NA	NA	300-600	NA	NA
	Average	NA	NA	NA	NA	450	NA	NA
Terrace 3 Ht. Above Bank-full (ft)	Range	NA	NA	NA	NA	5-7	NA	NA
	Average	NA	NA	NA	NA	6	NA	NA

[1] No intact examples of Zone 7 were encountered in the Otay watershed, but parts of some Zone 6 reaches might be appropriate for restoration as Zone 7. Dimensions for Zone 7 features presented here are from the San Jacinto watershed. No dimensions are presented for Zone 8 features because no intact examples were encountered in any of the watersheds sampled in the region. Restoration of Zone 8 should be based on other published information on tidal creeks.

[2] Not Applicable (e.g., terraces not present).

intended to serve as a tool for planners based on the assumption that there would be limited resources available for restoration, or limited potential sites would be available to offset certain types of impacts, and it may be useful to consider cost as a factor in the event that a variety of potential scenarios must be assessed for feasibility and efficacy. To that end, the level-of-effort scale represents a crude, ordinal-scale estimate of restoration costs. This simply means it will cost more to restore areas assigned greater level-of-effort units, but exactly how much more can only be determined on a case-by-case basis. In addition, land purchase costs or similar issues are not considered in these estimates, and unforeseen issues could easily change the estimates dramatically.

Level of Effort - None

Since the reach is functional in its current condition, and requires only vigilance to prevent invasion of exotic plant species, no restoration is considered necessary. In the figures below, these reaches are assigned one Level of Effort unit (rather than a zero) to facilitate the calculations used in the assessment process as well as to reflect that surveillance and management activities are anticipated.

Level of Effort - Light Planting

No reconfiguration of the land surface is needed. Treatment consists of control of exotic species and spot planting of native plants. Typically, this would involve hand planting of willows at the base of an unstable bank, or adding species that may have been grazed from a community back into an otherwise intact riparian area or upland buffer. Three level-of-effort units are assigned to reaches in this category.

Level of Effort - Light Earthwork/Heavy Planting

This treatment is prescribed where, in addition to the activities mentioned under "Light Planting," a large number of plants must be introduced and/or substantial mechanical site preparation is needed (i.e., “Heavy Planting”). Under this designation, site contours are not reconfigured, but grubbing, tilling, and similar site preparation may be required prior to planting. Generally, activities in this category are limited to those that can be accomplished with a farm tractor or similar types of equipment. Five level-of-effort units are assigned to reaches in this category.

Level of Effort - Moderate Earthwork/Heavy Planting

This level of effort is assigned to stream segments and associated riparian areas that require reconfiguration in some areas, while other portions may be restored with the simpler methods described above. Moderate Earthwork is intended to indicate widening of floodplains and terraces in systems where channels are not deeply incised, but need more space to reestablish equilibrium and community diversity. Typically, this will involve excavation of less than 6 ft of soil depth, though there is no implication regarding the lateral extent of the excavation. Generally, this work could be accomplished with a backhoe or similar type of equipment. The Moderate Earthwork level of effort designation includes the assumption that heavy planting will be

required, including the site preparation activities described in that section above. Seven level-of-effort units are assigned to reaches in this category.

Level of Effort - Heavy Earthwork/Heavy Planting

This level-of-effort designation applies to a wide range of possible actions, all of which will end with the heavy planting site preparation and planting requirements described above. Sites designated as needing heavy earthwork may be deeply incised channel segments that require extensive soil removal to reestablish floodplains and terrace systems tens of feet below the current grade, and grading back of high vertical banks to establish stable angles of repose. The sites may also require cutting of new channel systems with adequate length to allow meander behavior where the original channels have been filled and replaced with engineered channels. Sites requiring the removal of concrete, rip-rap, or asphalt bank protection also are included in this category. Heavy equipment such as bulldozers, graders, and track-hoes will be required. Ten level-of-effort units are assigned to reaches in this category.

Level of Effort - Impractical

A restoration plan was selected on the assumption that reaches in the "impractical" category would not be likely candidates for restoration due to the extreme effort required. However, the impractical reaches are included in this analysis primarily to illustrate their distribution relative to the other, more feasible, restoration options. Reaches considered impractical to restore have been assigned 20 level-of-effort units. In reality, the cost of restoring “impractical” reaches could greatly exceed 20 times the cost of restoring a reach assigned a level-of-effort of 1 unit. As indicated above, the actual restoration costs can only be determined on a case-by-case basis.

Simulation of restoration scenarios

One of the primary applications of the information developed during this study is to identify the specific riparian reaches where restoration will maximize the increase in riparian ecosystem integrity in the watershed, given a specific set of criteria or objectives. To this end, three of many possible restoration scenarios were simulated. In the first scenario, the objective was to identify the riparian reaches where application of the restoration template would result in the maximum possible increase in riparian ecosystem integrity regardless of the level of effort required. This scenario assumed an infinite level of resources available for restoration, and that wherever restoration will increase integrity indices, it will be

accomplished. Scenarios 2 and 3 considered the effects of different levels of upland restoration on the riparian reach integrity scores within the watershed. Specifically, in Restoration Scenario 2, areas of active or former rangeland were restored to native vegetation, and in Restoration Scenario 3, areas of active or former rangeland (as well as agricultural areas) were restored to native vegetation.

In order to simulate the first restoration scenario, a GIS theme with attributes representing Geomorphic Zone, Restoration Template, and Level of Effort was developed for the study area in order to calculate post-restoration indices for each riparian reach. Specifically, the hydrology, water quality, and habitat integrity indices were recalculated using relevant indicator metrics/scores for each riparian reach after applying the prescribed Restoration Template to each reach. Seven of the original 27 indicators included in the hydrology, water quality, and habitat integrity baseline assessment were assigned new scores of 1 to 5, where 5 represented conditions of a fully functional riparian reach (Table C2). Most of the local drainage and drainage basin indicators are not affected by the application of a Restoration Template, since they are applied at the riparian reach scale. However, two drainage basin scale indicators—Altered Hydraulic Conveyance - Drainage Basin (AHC-DB) and Riparian Corridor Connectivity - Drainage Basin (RCC-DB) do acquire new indicator scores based on cumulative changes in indicators, i.e., Altered Hydraulic Conveyance - Riparian Reach (AHC-RR) and Riparian Corridor Connectivity - Riparian Reach (RCC-RR for all contributing upstream riparian reaches).

Table C2. New scores assigned to riparian reach scale indicators based on Restoration Template.

Restoration Template	Indicators								
	AHC_{RR}[1]	AHC_{DB}	FI_{RR}	SR_{RR}	EXO_{RR}	RCC_{RR}	RCC_{DB}	VC_{FLOOD}	$VC_{TERRACE}$
Natural (1)	5	Cumulative	5	5	5	5	Cumulative	5	5
Incised (2)	5	Cumulative	5	4	5	5	Cumulative	4	4
Constrained (3)	NC**	Cumulative	NC	2	5	5	Cumulative	3	3
Aggraded (4)	NC	Cumulative	NC	NC	5	5	Cumulative	5	5
Engineered (5)	NC	Cumulative	NC	1	5	5	Cumulative	1	1
Impractical (6)	NC	Cumulative	NC	NC	NC	NC	Cumulative	NC	NC

[1] AHC_{RR} = Altered Hydraulic Conveyance – Riparian Reach Scale, AHC_{DB} = Altered Hydraulic Conveyance – Drainage Basin Scale, FI_{RR} = Floodplain Interaction – Riparian Reach Scale, SR_{RR} = Sediment Regime Index – Riparian Reach Scale, EXO_{RR} = Exotic Plant Species Index - Riparian Reach Scale, RCC_{RR} = Riparian Corridor Continuity – Riparian Reach Scale, RCC_{DB} = Riparian Corridor Continuity – Drainage Basin Scale, VC_{FLOOD} = Vegetation Condition Index – Floodplain, $VC_{TERRACE}$ = Vegetation Condition Index – Terrace

[2] NC = No change.

Results and discussion

Reach reclassification and simulation of restoration scenarios

Figure C18 shows Geomorphic Zones, Figure C19 shows the Restoration Templates, and Figure C20 shows the Level of Effort category assigned to riparian reaches within the study area.

To provide a point of reference for the results of the restoration scenarios simulations, Figures C21, C22, and C23 show the baseline, normalized hydrologic, water quality, and habitat integrity indices for riparian reaches. The integrity indices, or change in integrity indices, shown in Figures C21-C32, are represented at the local drainage area scale to facilitate a comparison between riparian reaches. However, it should be realized that integrity indices apply only to the riparian reach and not the full extent of the local drainage.

In the first scenario, the objective was to identify the riparian reaches where application of the restoration template would result in the maximum possible increase in riparian ecosystem integrity regardless of the level of effort required. Results from Restoration Scenario 1 are shown as the change in the normalized hydrologic (Figure C24), water quality (Figure C25), and habitat (Figure C26) integrity indices after applying the recommended restoration template. These results show which riparian reaches exhibit the greatest increase in integrity indices without regard to level of effort required to implement the restoration template.

Unlike Restoration Scenario 1, which focused solely on restoration within the riparian ecosystem proper (i.e., stream channel geomorphic features, riparian vegetation, etc.), Restoration Scenarios 2 and 3 simulated the effect on riparian reach integrity by restoring upland areas to native vegetation. Under Restoration Scenario 2, the areas currently in rangeland were simulated as native vegetation communities. Results from Restoration Scenario 2 are shown as the change in normalized hydrologic (Figure C27), water quality (Figure C28), and habitat (Figure C29) integrity indices. Under Restoration Scenario 3, the areas currently in rangeland and agriculture were simulated as native vegetation communities. Results from Restoration Scenario 3 are shown as the change in the normalized hydrologic (Figure C30), water quality (Figure C31), and habitat (Figure C32) integrity indices. These results indicate which riparian reaches exhibit the greatest increase in integrity indices based on restoring upland areas to native vegetation.

Figure C18. Geomorphic Zone assignments for riparian reaches.

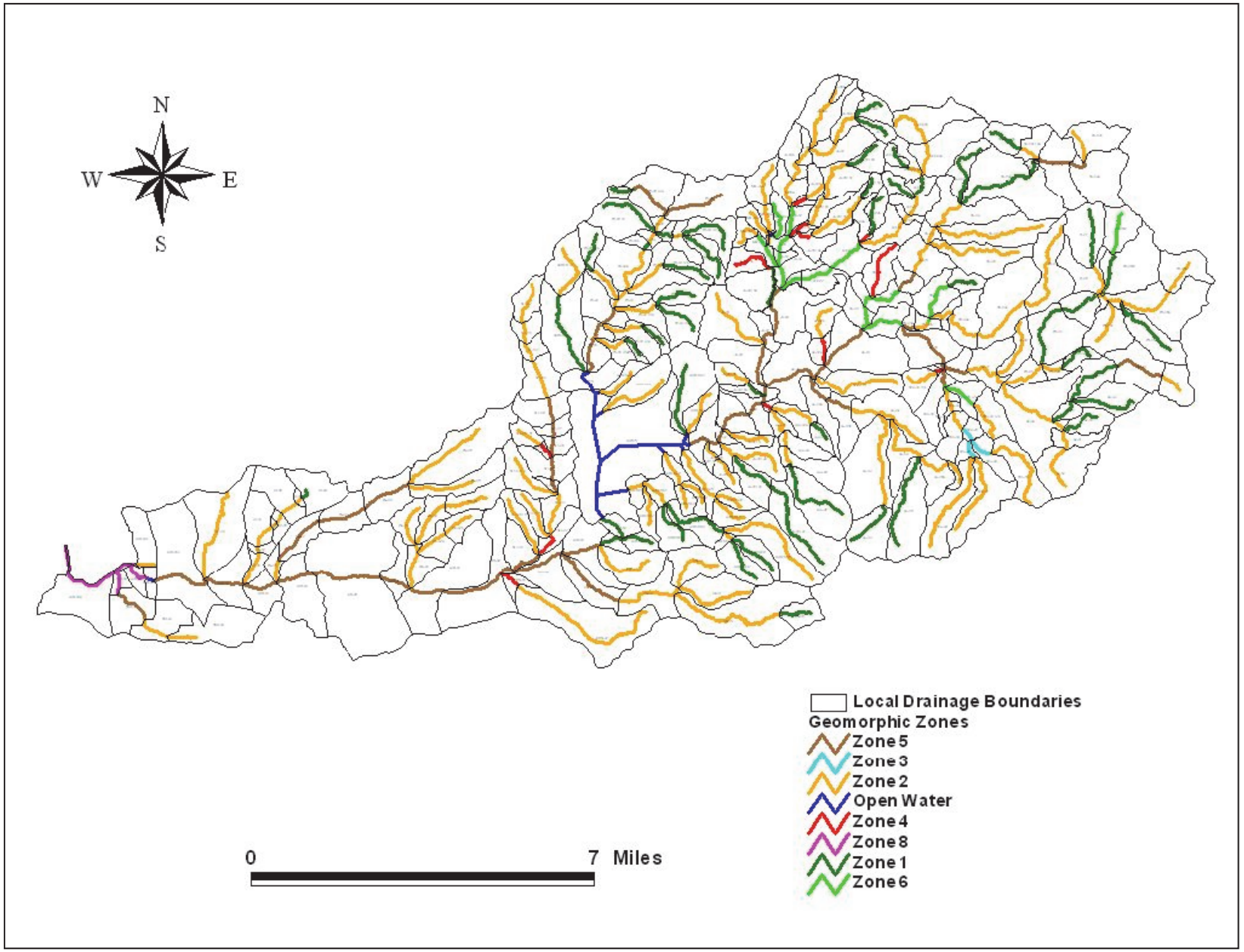


Figure C19. Restoration Template assignments for riparian reaches.

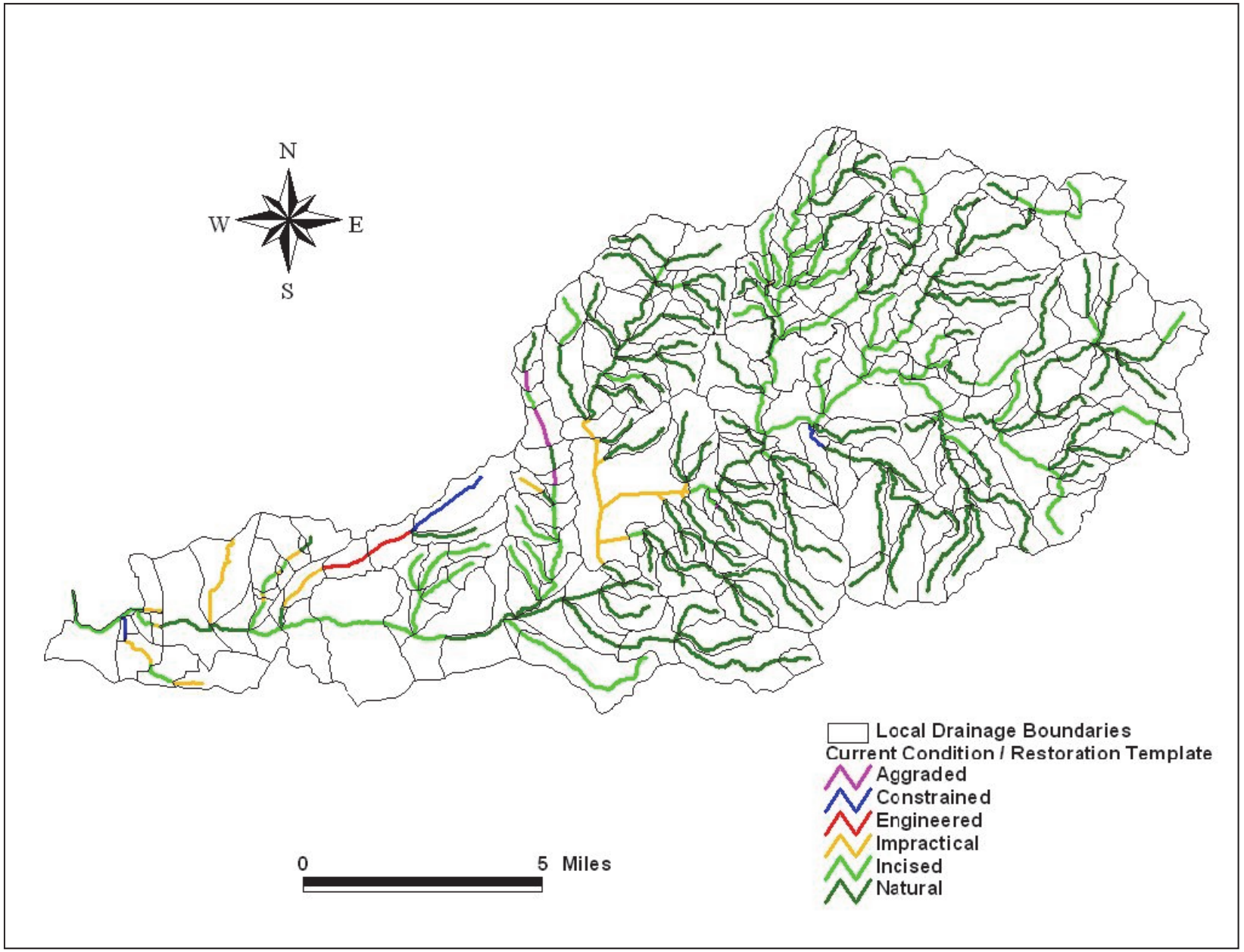


Figure C20. Level-of-Effort assignments for riparian reaches.

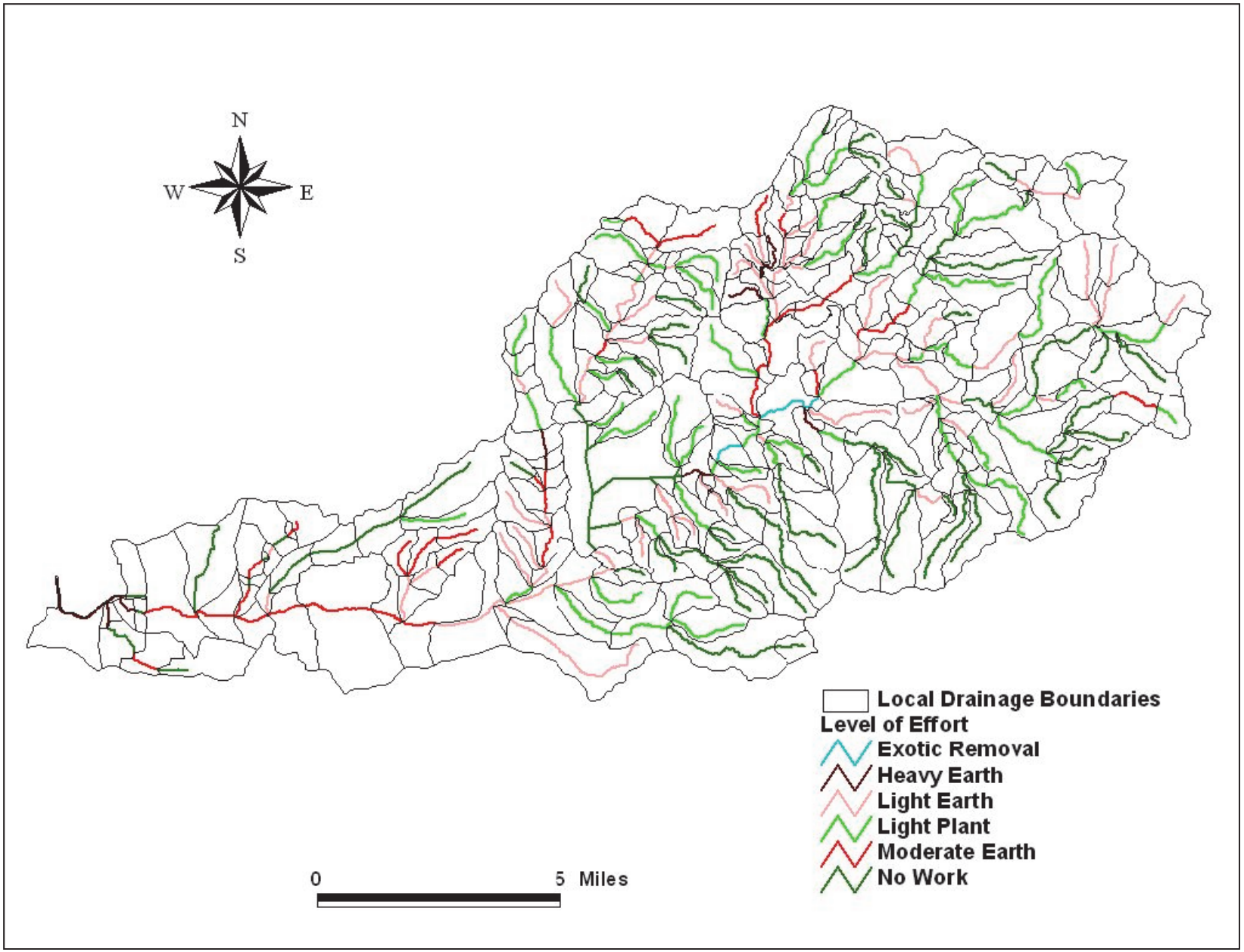


Figure C21. Normalized baseline hydrology integrity indices for riparian reaches.

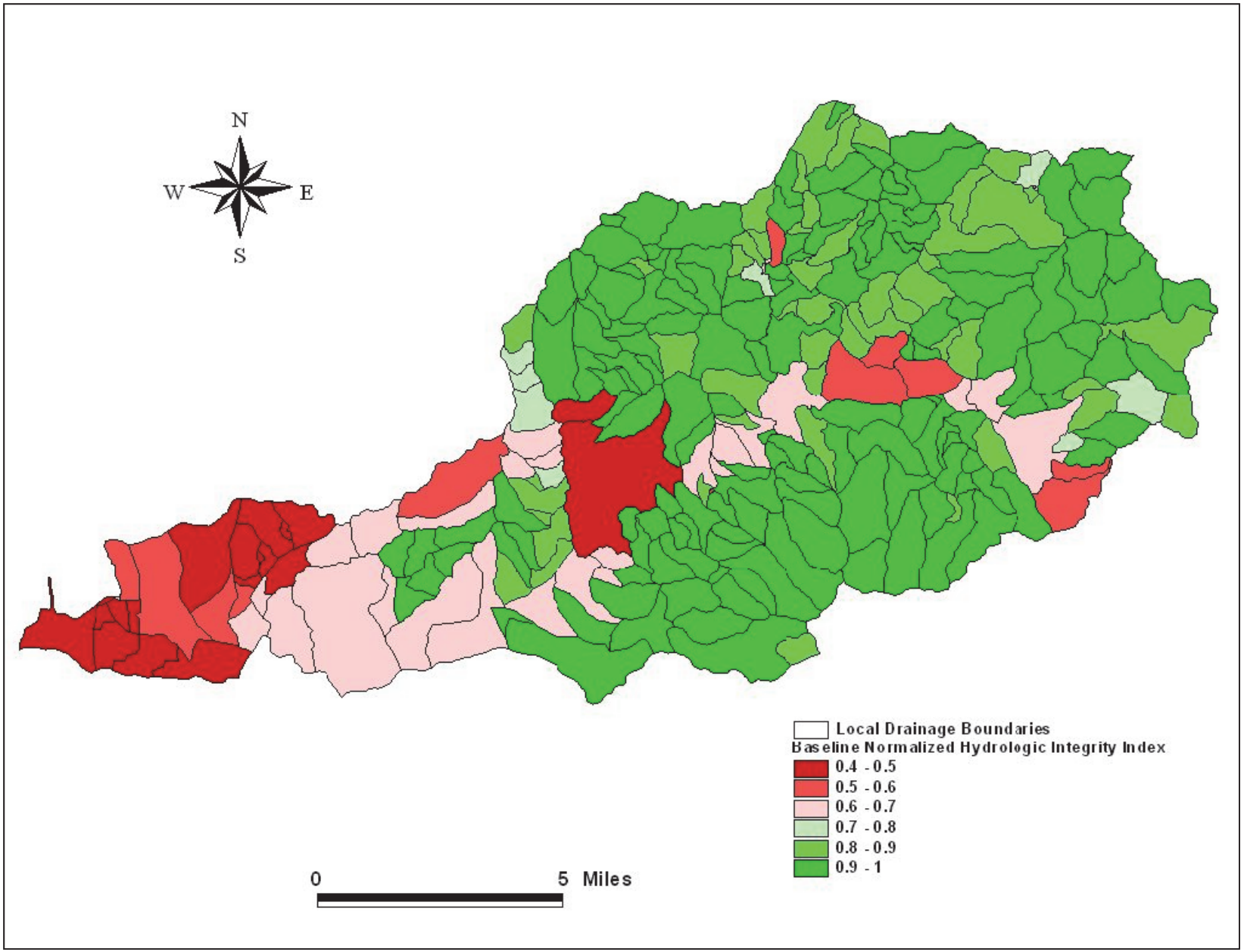


Figure C22. Normalized baseline water quality integrity indices for riparian reaches.

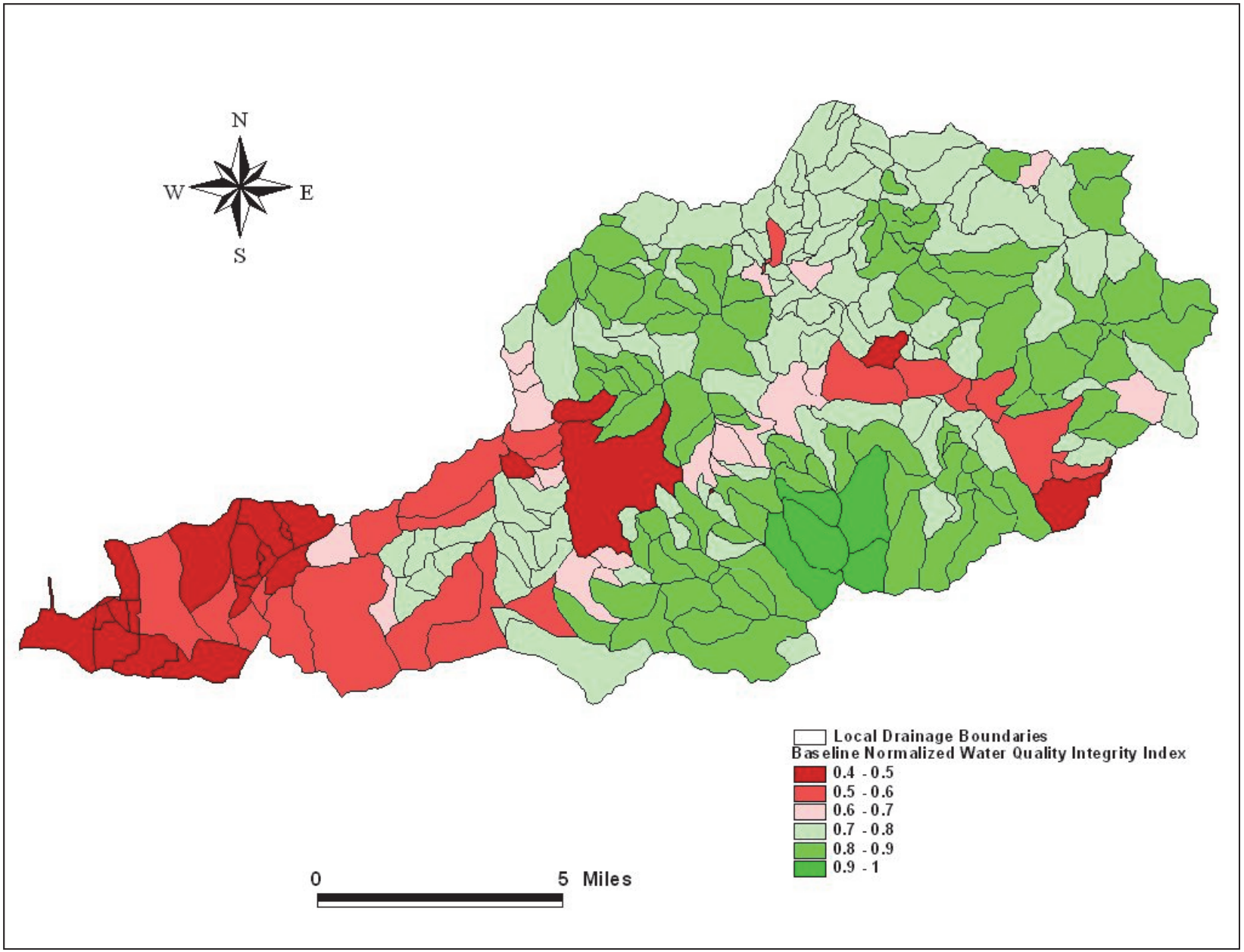


Figure C23. Normalized baseline habitat integrity indices for riparian reaches.

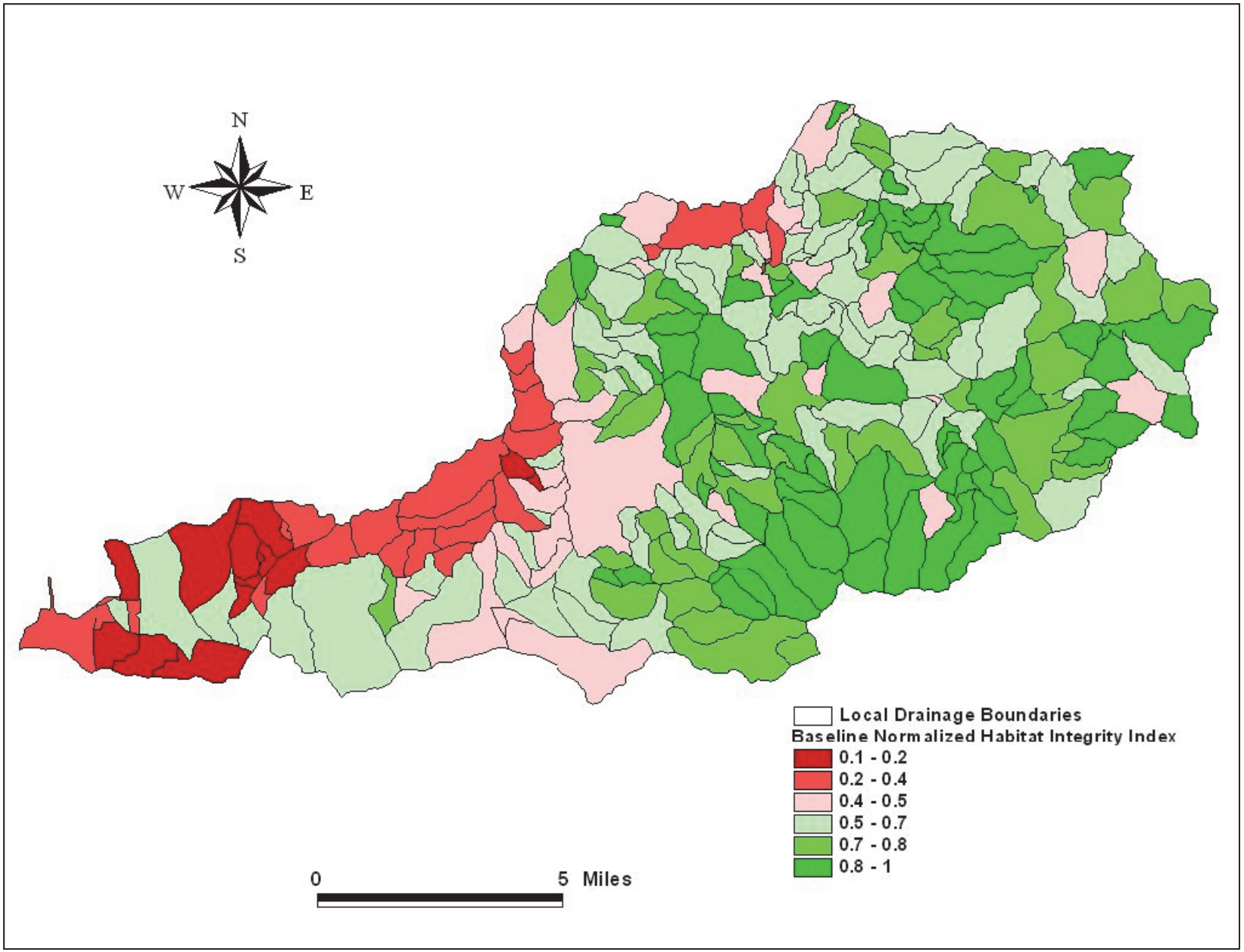


Figure C24. Increase in normalized hydrologic integrity index under Restoration Scenario 1.

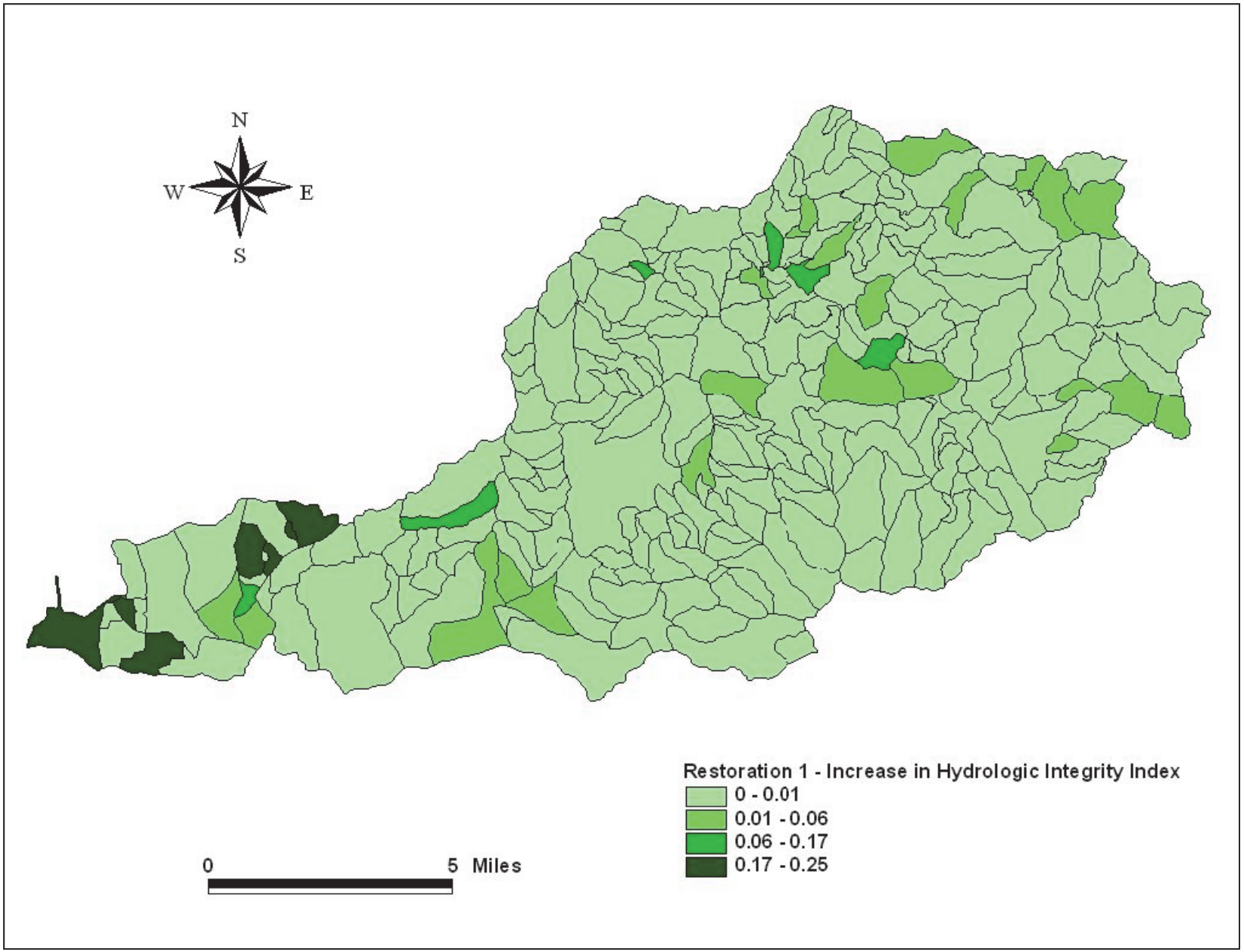


Figure C25. Increase in normalized water quality integrity index under Restoration Scenario 1.

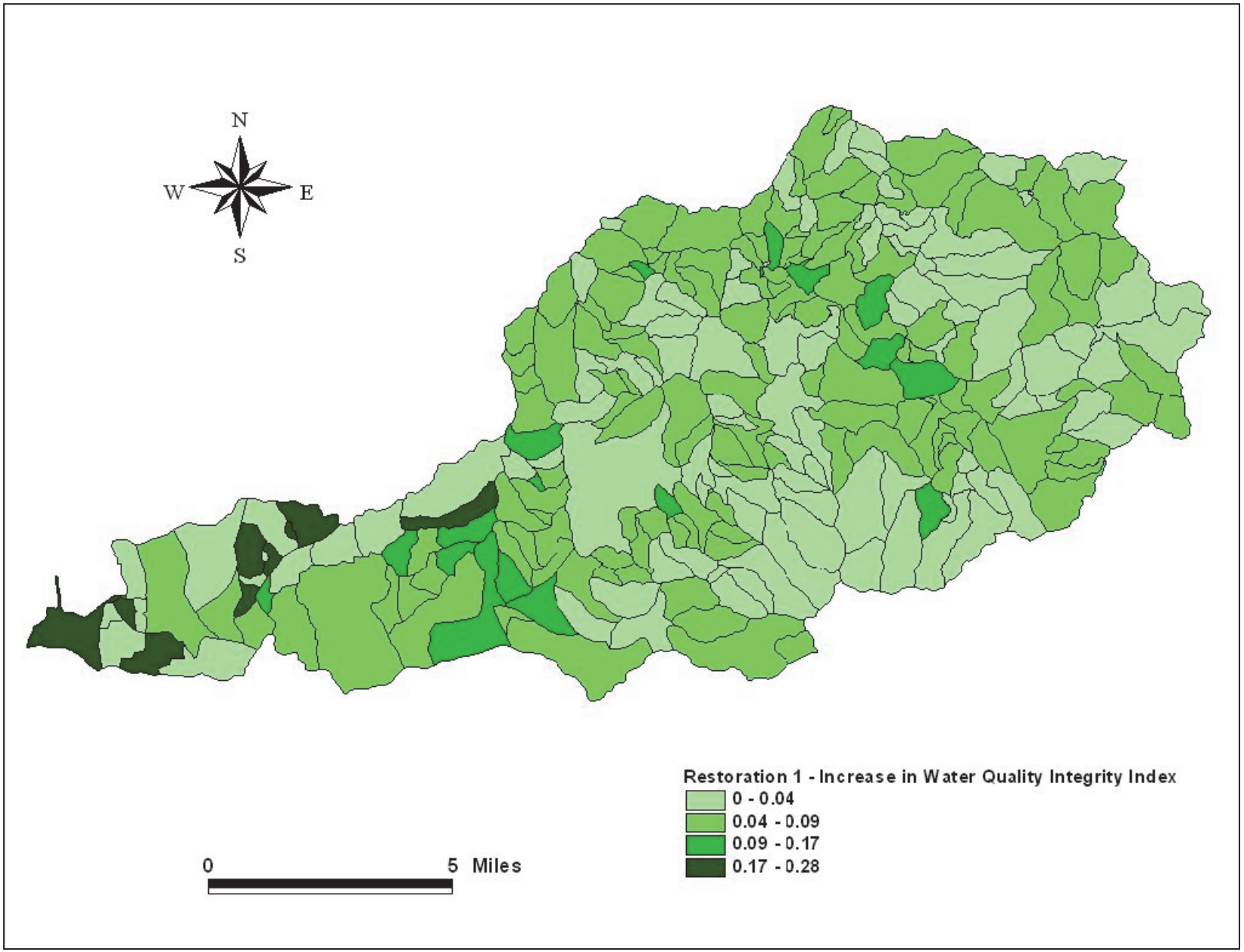
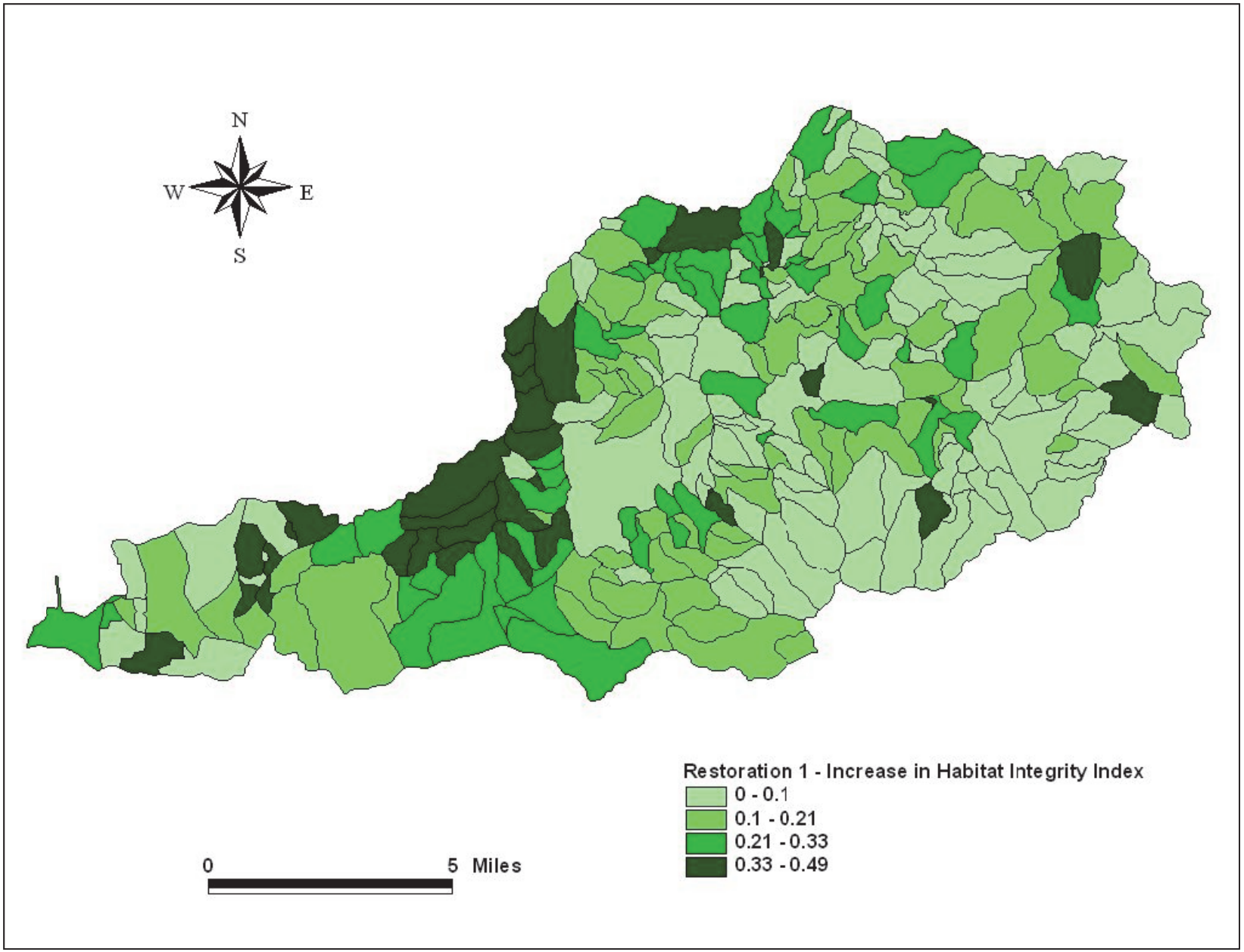


Figure C26. Increase in normalized habitat integrity index under Restoration Scenario 1.



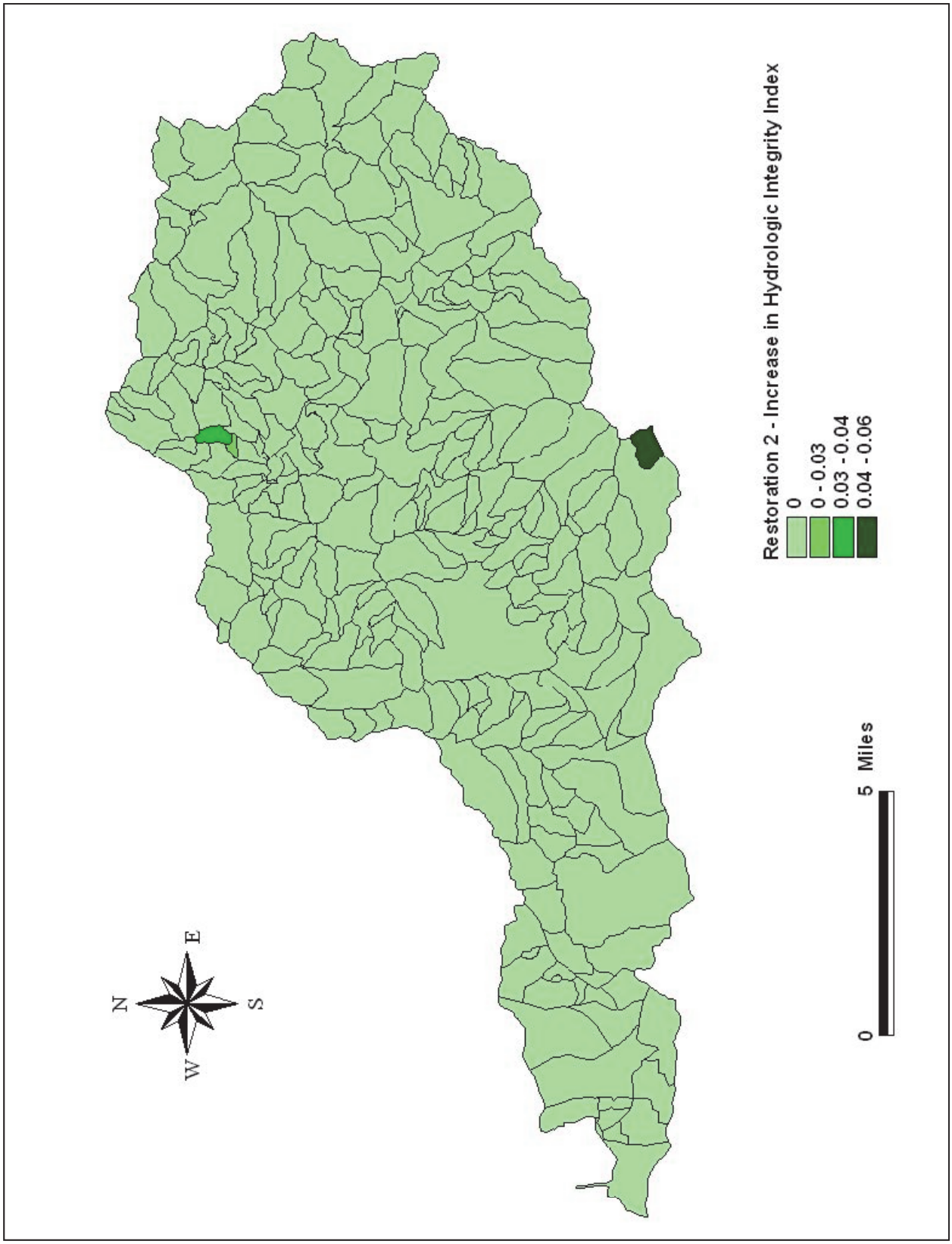


Figure C27. Increase in normalized hydrology integrity index under Restoration Scenario 2.

Figure C28. Increase in normalized water quality integrity index under Restoration Scenario 2.

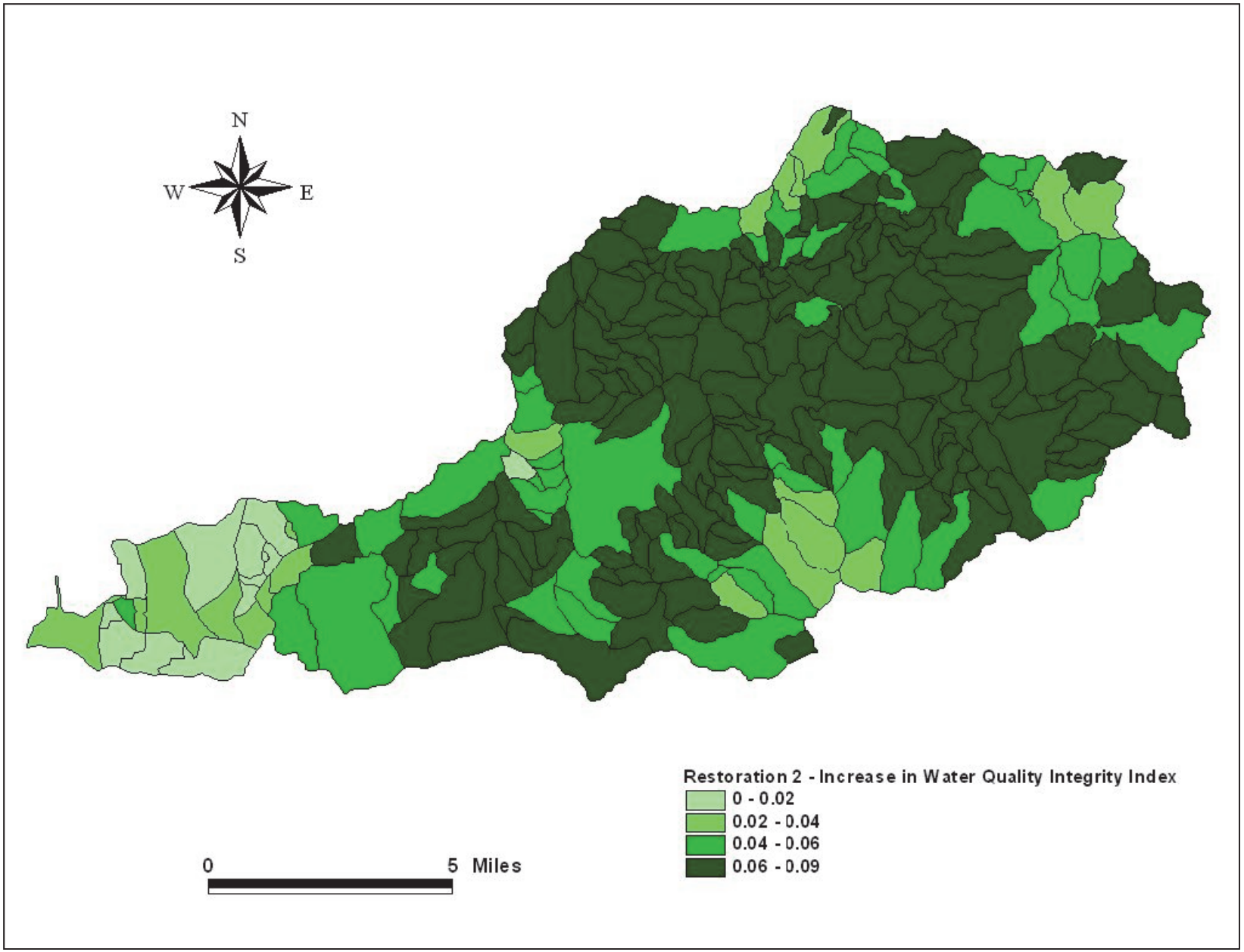
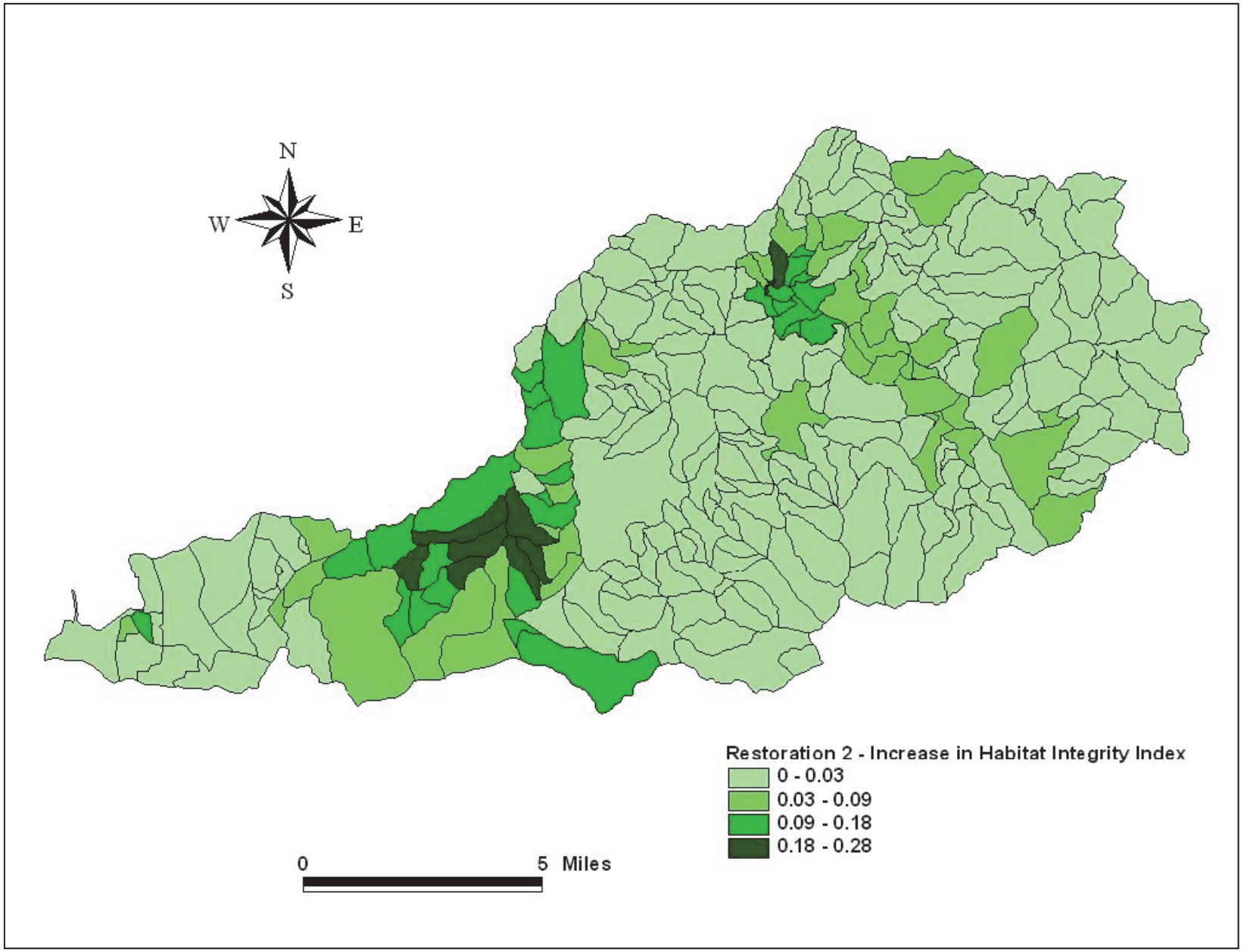


Figure C29. Increase in normalized habitat integrity index under Restoration Scenario 2.



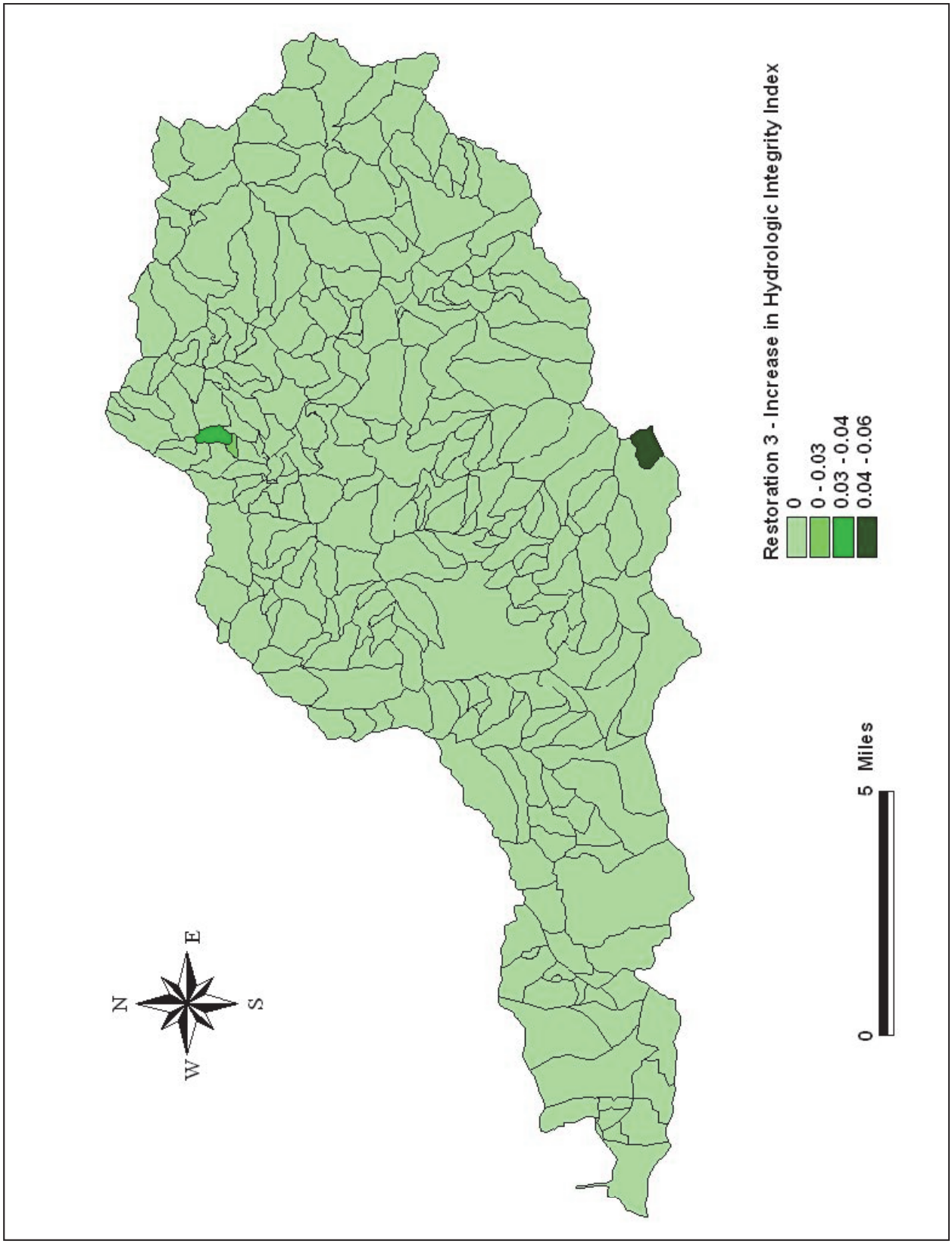


Figure C30. Increase in normalized hydrologic integrity index under Restoration Scenario 3.

Figure C31. Increase in normalized water quality integrity index under Restoration Scenario 3 simulation.

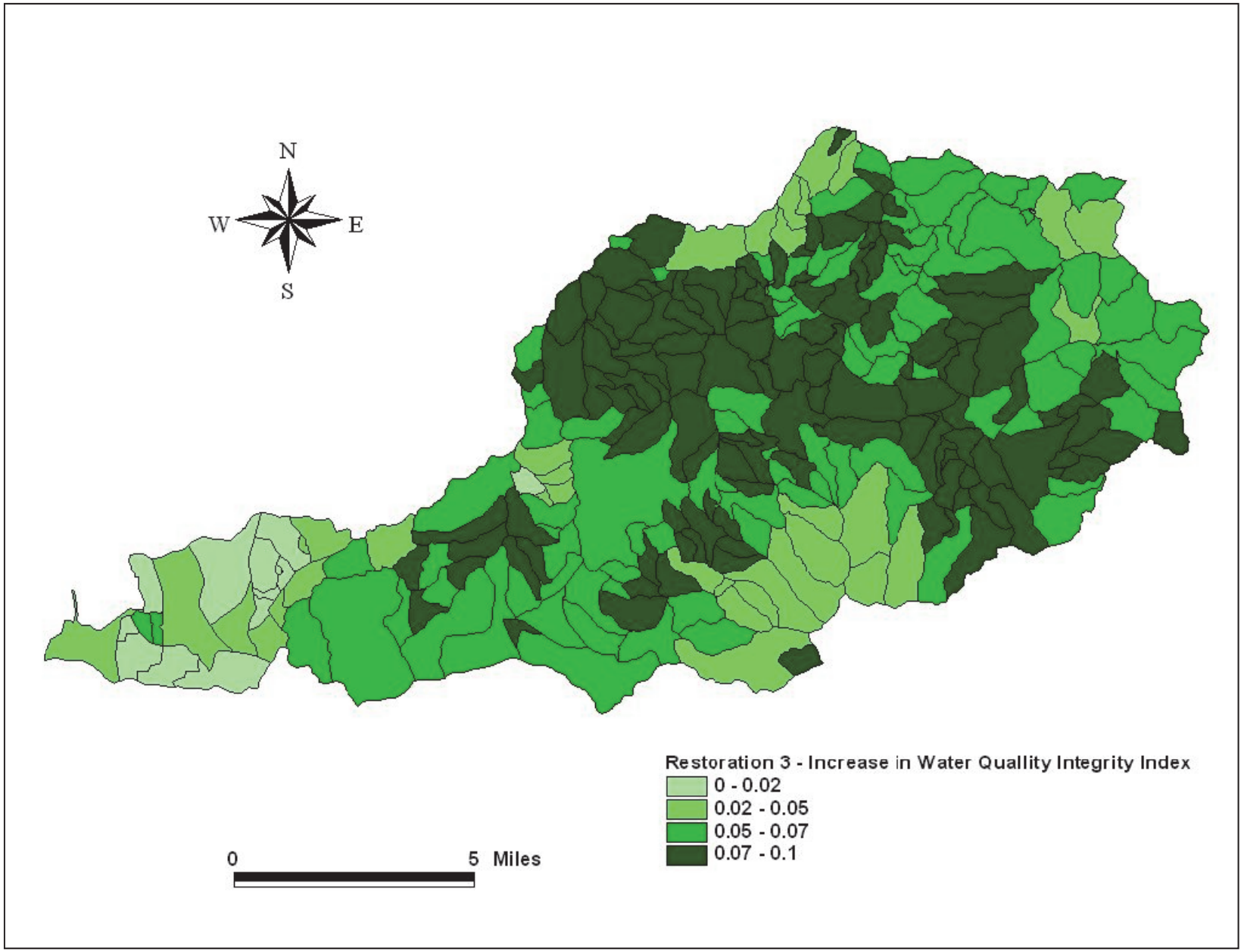
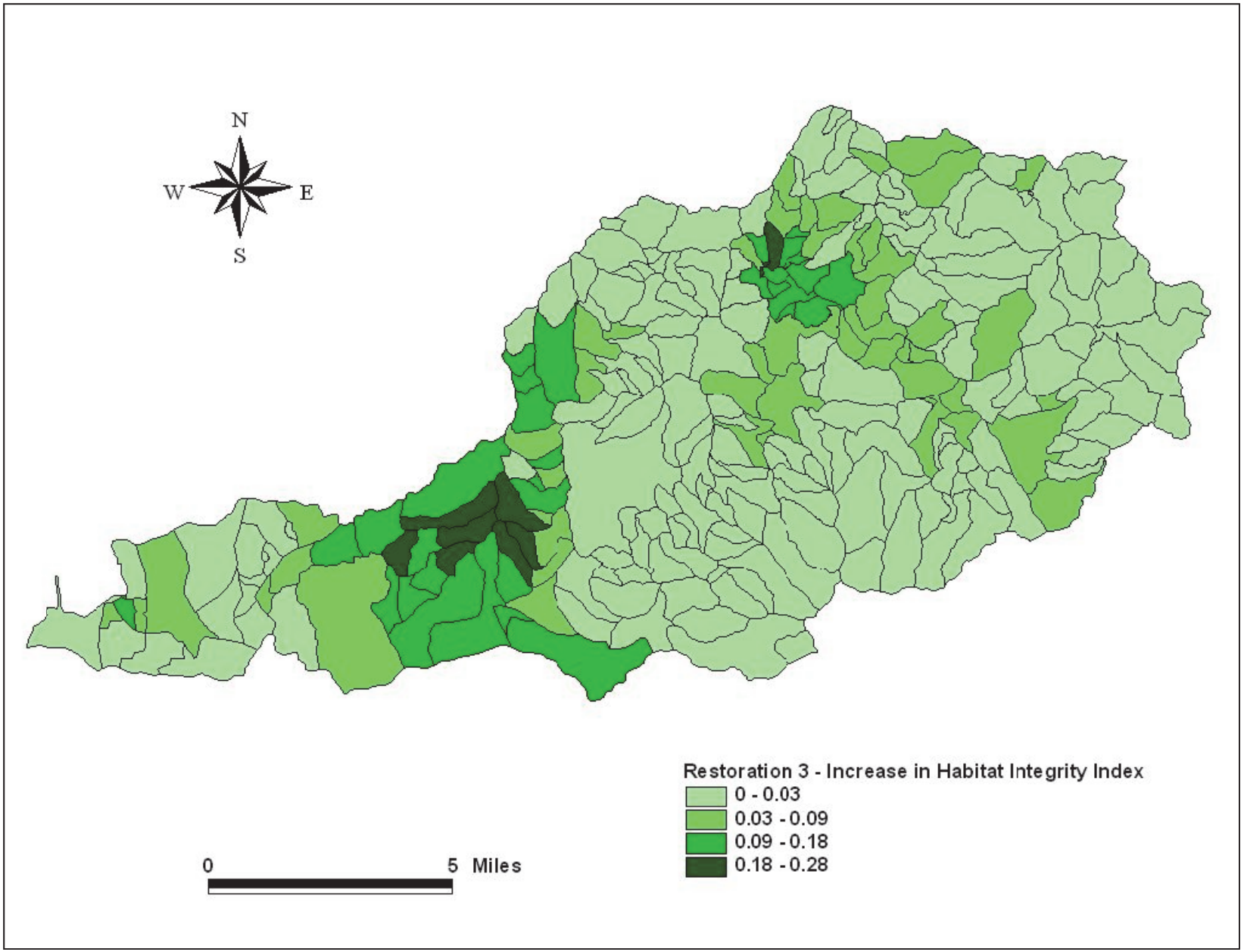


Figure C32. Increase in normalized habitat integrity index under Restoration Scenario 3 simulation.



The three restoration scenarios presented represent only a small sample of the variety of scenarios that are possible. Depending on restoration objectives, numerous variations for prioritizing reaches may be identified. For example, if the objective is to restore large patches (i.e., subbasins) to restore habitat for area-sensitive wildlife species, or to restore riparian corridors for the purpose of connecting existing large patches, it would be possible to identify which of various candidate subbasins or riparian reaches would require the least effort (cost) to restore, and which could be most fully restored, or combinations of both considerations could be developed. This assessment approach also provides the option of considering upland restoration as a component of the overall hydrologic, water quality, and habitat integrity indices of riparian areas.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

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

4. TITLE AND SUBTITLE

A Multi-Scale Approach to Assess and Restore Ecosystems in a Watershed Context

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Ronald D. Smith and Charles V. Klimas

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-13-18

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

This report describes a multi-scale watershed assessment procedure that can be used to evaluate existing ecological conditions as well as proposed changes. The approach employs indicators of ecosystem integrity that are assessed at the stream reach scale using existing spatial data as well as field observations. Ecological integrity scores can be calculated using those indicators at multiple scales, ranging from the reach to the entire watershed. Reach-level integrity scores are dependant in part on upstream and downstream conditions; therefore, the method accounts for offsite effects of proposed impacts or restoration actions by recognizing degradation or improvement to areas not directly within the project footprint. Case studies are presented illustrating typical applications of the approach, including baseline and alternative impact assessments, as well as restoration scenarios.

15. SUBJECT TERMS

Ecological integrity scores
Ecosystems
Natural resource management
Restoration
Watershed
Watershed assessment

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		169	