San Diego Creek Watershed Riparian Ecosystem Restoration Plan: Site Selection and General Design Criteria

Prepared for:
U. S. Army Corps of Engineers, Los Angeles District, Regulatory Branch

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EXECUTIVE SUMMARY

The Los Angeles District Corps of Engineers - Regulatory Branch is developing a Special Area Management Plan (SAMP) for the San Diego Creek watershed of Orange County, California. The goal of the SAMP is to…"develop and implement a watershed-wide aquatic resource management plan and implementation program, which will include preservation, enhancement, and restoration of aquatic resources, while allowing reasonable and responsible economic development and activities within the watershed-wide study area" (Los Angeles District Corps of Engineers 1999). Several studies have been conducted in support of the SAMP including a watershed wide delineation of aquatic resources using a unique planning level delineation procedure (Lichvar 2000), and a baseline assessment of riparian ecosystem integrity (Smith 2000a). Information from the delineation and baseline assessment is currently being used in two additional studies to support the SAMP. The first is an alternatives analysis in which a variety of proposed alternatives are being analyzed to identify the level of impact each alternative will have on aquatic resources in the San Diego Creek watershed. The second is the topic of this report, the development of a watershed restoration plan for riparian ecosystems in the San Diego Creek watershed.

The objective of the Watershed Restoration Plan is to facilitate development of an aquatic resources reserve program in the San Diego Creek watershed through an evaluation of both the potential for restoring a riparian ecosystem, given the current condition within the riparian ecosystem as well as the adjacent landscape and drainage basin, and the "level of effort" required to restore individual riparian reach segments to their appropriate restoration template. The general approach to achieving this objective is to classify each riparian area in terms of their geomorphic characteristics, characterize the current condition of each riparian area, assign an appropriate restoration template given the geomorphic characteristics and current condition of each riparian area, and then estimate the level of effort necessary to restore each riparian area using an appropriate restoration template. The approach allows consideration of restoration effectiveness at both the riparian ecosystem and drainage basin spatial scales, and 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 implemented in the context of a geographic information system. Thus, the information presented here constitutes a flexible planning tool that is adaptable to changes in field conditions, data quality, project priorities, and similar eventualities.

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1.0 Introduction

The Los Angeles District Corps of Engineers, Regulatory Branch is developing a Special Area Management Plan (SAMP) for the San Diego Creek watershed of Orange County, California. The SAMP is being conducted in coordination with the existing and proposed amendment to the Central - Coastal Natural Community Conservation Plan (NCCP). The goal of the SAMP is to…"develop and implement a watershed-wide aquatic resource management plan and implementation program, which will include preservation, enhancement, and restoration of aquatic resources, while allowing reasonable and responsible economic development and activities within the watershed-wide study area" (Los Angeles District Corps of Engineers 1999).

In support of the SAMP a number of studies have been conducted. These include a watershed wide delineation of aquatic resources using a unique planning level delineation procedure (Lichvar 2000), and a baseline assessment of riparian ecosystem integrity (Smith 2000a). For the baseline assessment riparian ecosystems were defined as linear corridors of variable width that occur along perennial, intermittent, and ephemeral streams that exhibit distinctive geomorphic features and vegetation communities in response to periodic exchange of surface and ground water between the stream channel and adjacent areas. Due to the large size of the watershed, inherent variability of riparian ecosystems, and differential nature of historical impacts to riparian ecosystems, the initial task in the baseline assessment was to delineate the riparian ecosystems into relatively homogenous assessment units called "riparian reaches". Riparian reaches were defined as discrete segments of the mainstem, bankfull stream channel, and the adjacent riparian ecosystem that were relatively homogenous with respect to geology, geomorphology, channel morphology, substrate type, vegetation communities, and cultural alteration. Each riparian reach unit was assessed using a suite of indicators that represent physical, chemical, and biological factors influencing riparian ecosystem integrity at the three spatial scales: the riparian reach, the local drainage (area contributing to tributary, groundwater, and overland flow that directly enters the riparian reach), and the drainage basin (area contributing to mainstem inflow from upstream of a riparian reach). Indicators were scaled to a reference condition and then combined into indices for hydrologic, water quality, and habitat integrity. The methods used to conduct the baseline assessment are more fully described in Appendix 2.

Information from the delineation and baseline assessment is currently being used in two additional studies to support the SAMP. The first is an alternatives analysis in which a variety of proposed alternatives are being analyzed to identify the level of impact each alternative will have on aquatic resources in the San Diego Creek watershed. The second is the topic of this report, the development of a watershed restoration plan for riparian ecosystems in the San Diego Creek watershed.

2.0 Objectives, Definitions, and Assumptions

The objective of the Watershed Restoration Plan outlined in this report is to develop an aquatic resources reserve program in the San Diego Creek watershed that will lead to an overall increase in riparian ecosystem integrity in the San Diego Creek watershed. This will be accomplished through the evaluation of factors such as the "restoration potential" of specific riparian reaches, and the "level of effort" necessary to restore a specific riparian.

Restoration potential refers to the type and extent 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 physical and biological processes that determine the extent to which natural patterns of vegetation composition, structure, and diversity can be re-established and sustained. We assume that it is possible to restore any riparian reach to a fully functioning riparian ecosystem given unlimited time, resources, and authority. However, for practical reasons, we have adopted general restoration guidelines that preclude fundamental changes to major roads or developed areas, or the use of massive excavation or fill. For example, stream segments that pass through culverts under highways, have been converted to underground/surface engineered drainage systems, are laterally constrained by infrastructure, or are deeply incised are considered impractical to restore fully. The restoration potential of riparian reaches under these circumstances is less than riparian reaches without these constraints.

Level of effort is a simple estimate of the resources that will be required to restore a riparian ecosystem to the level of ecosystem integrity dictated by practical constraints. One of five levels of effort is assigned to each riparian reach segment to provide a relative estimate of the resources required to complete restoration. The level of effort estimates provides a tool for planners to incorporate the level of resources required when a variety of potential scenarios must be compared in terms of feasibility and efficacy. This need to consider the level of resources required is based on the assumption that there will be either a limited amount of resources available for restoration, or a limited number of restoration sites available to offset certain types of impacts. It should be noted that the level of effort estimates do not include the cost of land purchases or similar issues, and the unforeseen issues could significantly alter the accuracy of the estimates.

It should be recognized that using the two components of this approach (i.e., restoration potential and level of effort) allows consideration of restoration effectiveness at the riparian reach, local drainage, and drainage basin spatial scales. 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 of effort. All of these mechanisms for testing and analyzing restoration options and scenarios are designed to be implemented in the context of a geographic information system or spreadsheet environment. Thus, the information presented here constitutes a flexible planning tool that is adaptable to changes in field conditions, data quality, project priorities, and similar eventualities.

3.0 Study Area

The San Diego Creek watershed occupies approximately 450 km^2 in south-central Orange County, California (Figure 1). Headwaters originate in the Santa Ana Mountains in the eastern portion of the watershed, and the San Joaquin Hills in the southern portion of the watershed. Streams in the watershed generally drain in a western direction towards Newport Bay located in the southwestern portion of the watershed.

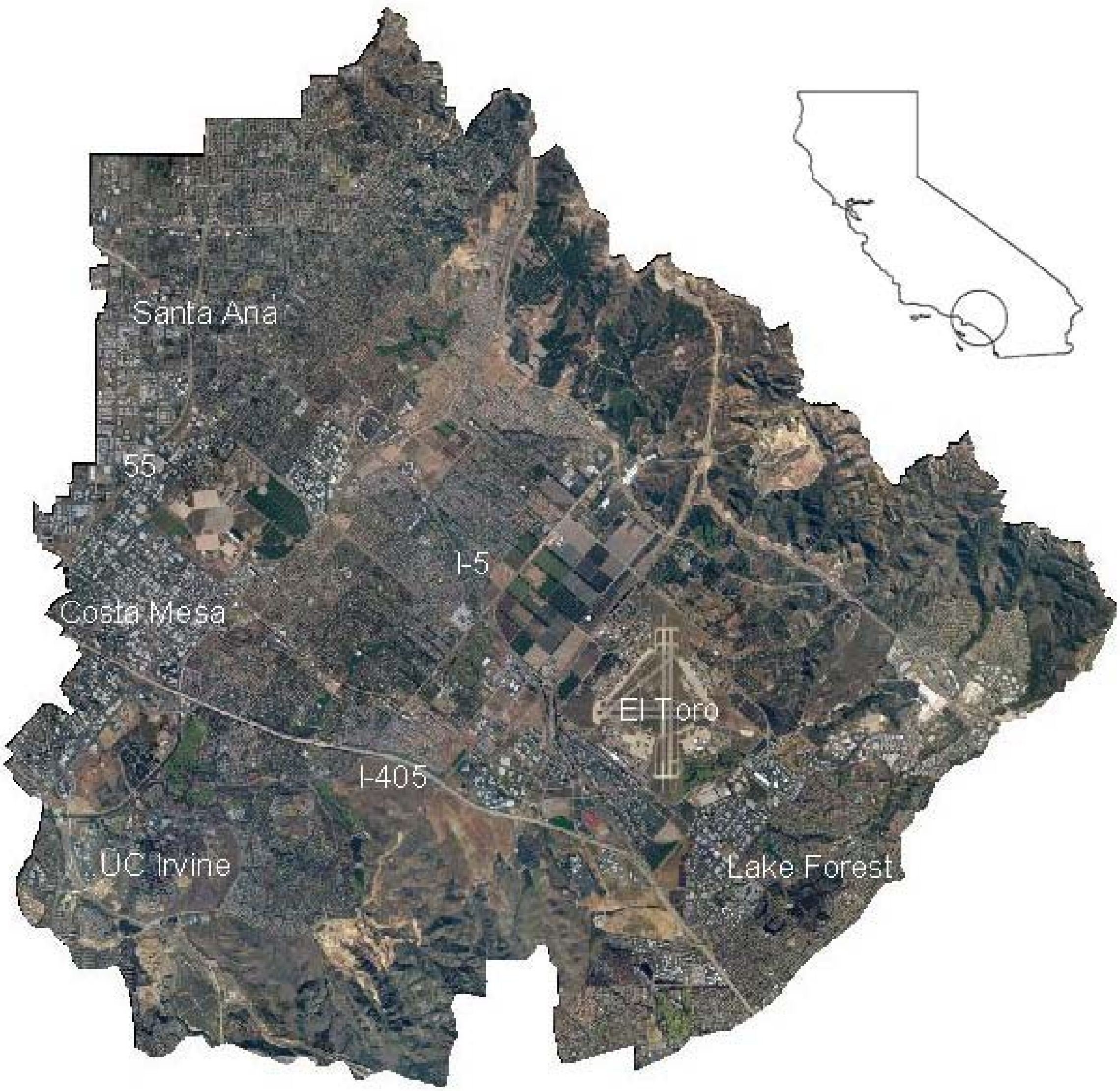


Figure 1. San Diego Creek watershed, Orange County, California

The geology of the San Diego Creek watershed is complex reflecting crustal compression and faulting, uplift and subsidence, volcanism, and multiple periods of erosion and deposition in both marine and alluvial environments (Morton et al. 1976). For the purposes of this report, the geology of the basin can be described in terms of three major geologic settings: the Mountains and Coastal Foothills Unit, the Alluvial Deposition Unit, and the Marine Terraces Unit (Figure 2). The following discussion of these geologic settings provides a framework for defining and recognizing the riparian systems and restoration approaches discussed in this report.

The Santa Ana Mountains and San Joaquin Hills are collectively mapped as the Mountain and Coastal Foothill Unit (Figure 2). Elevations in the Santa Ana Mountains reach more than 1500 m, while elevations in the San Joaquin Hill are generally less than 350 m. Surface rocks in both areas are primarily sedimentary reflecting the multiple sequence of depositional environments that have dominated the region in recent geologic time. They include massive sandstones, mudstones, siltstones and other units, with chemistries reflecting their depositional environments. Headwater stream channels typically originate in steep V-shaped valleys eroded deeply into the sedimentary rocks. As valley widths increase and channel gradients flatten, valley bottoms gradually become filled with alluvial material transported from upstream areas as well as slope wash and colluvial deposits originating on adjacent valley slopes.

The Alluvial Depositional Unit (Figure 2) is made up of three major sections. The Canyon and Valley Bottom Section interfingers with the Mountain and Coastal Foothills Unit, where valleys widen considerably and are filled largely by alluvial deposits carried and deposited by the stream channel. Where streams exit these valleys, they form broad alluvial fans, which coalesce into the Alluvial Fan Section that flanks the margins of the mountains and foothills. These distinctly sloping areas consist of very deep sediments, usually sandy loam, but they are subject to local variability. As the gradient of the Alluvial Fan Section flattens, it transitions into the Coastal Plain Section, which is nearly flat, or slopes very slightly toward the sea. Sediments in this area are up to 60 m thick, reflecting periods of basin floor lowering due to subsidence, or erosion during low sea level stands, followed by periods of sediment refilling as sea levels rose.

The third major geological setting in the watershed is the Marine Terrace Unit (Figure 2). Unlike the alluvial deposits in the basin, the marine terraces were deposited in ocean environments during periods when sea levels were higher than present. Some of the terraces experienced uplift subsequent to deposition. Generally, marine terraces are flat to rolling, wave-

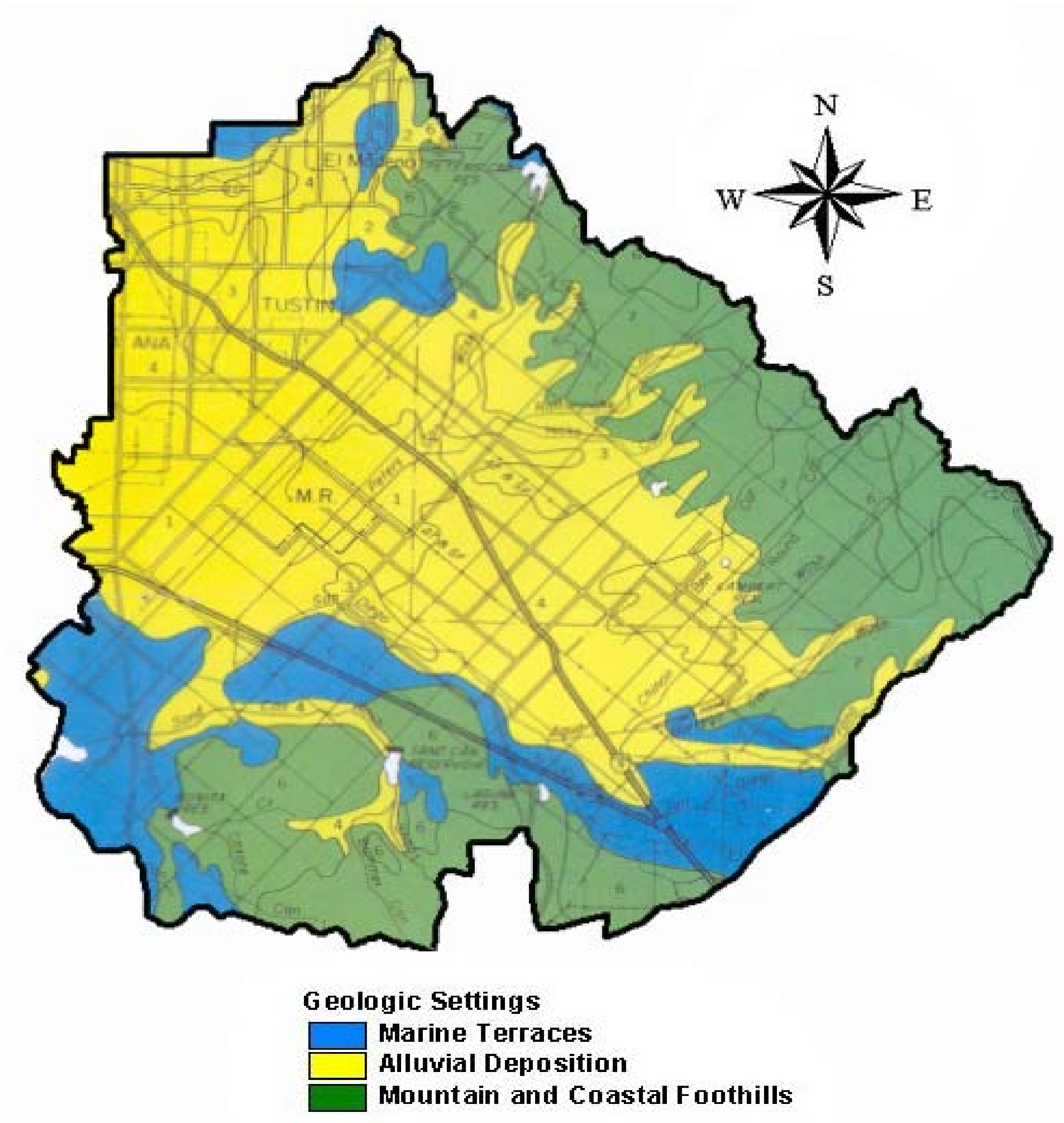


Figure 2. Major geologic settings of the San Diego Creek watershed (adapted from the soil associations map of Wachtell, 1978)

cut platforms with sandy loam surface soils, much like many local alluvial deposits, but with very different subsoils, which are generally limey clays. The cohesive subsoils are less erodible than many of the alluvial soils in the area, thus stream courses through the marine terrace units tend to be somewhat narrow and have steep sideslopes, similar to streams in the mountain and foothill valleys.

4.0 Methods

4.1 Geomorphic Zones

The baseline assessment of riparian ecosystems (Smith 2000a) designated riparian reaches within the San Diego Creek watershed. Riparian reaches were defined as discrete, relatively homogenous, segments of the mainstem, bankfull stream channel and the adjacent riparian ecosystem in terms of geology, geomorphology, channel morphology, substrate type, vegetation communities, and cultural alteration. Associated with each riparian reach were local drainages (the area contributing to tributary, groundwater, and surface flow directly to the riparian reach), and a drainage basin (the area contributing to mainstem flow into the riparian reach).

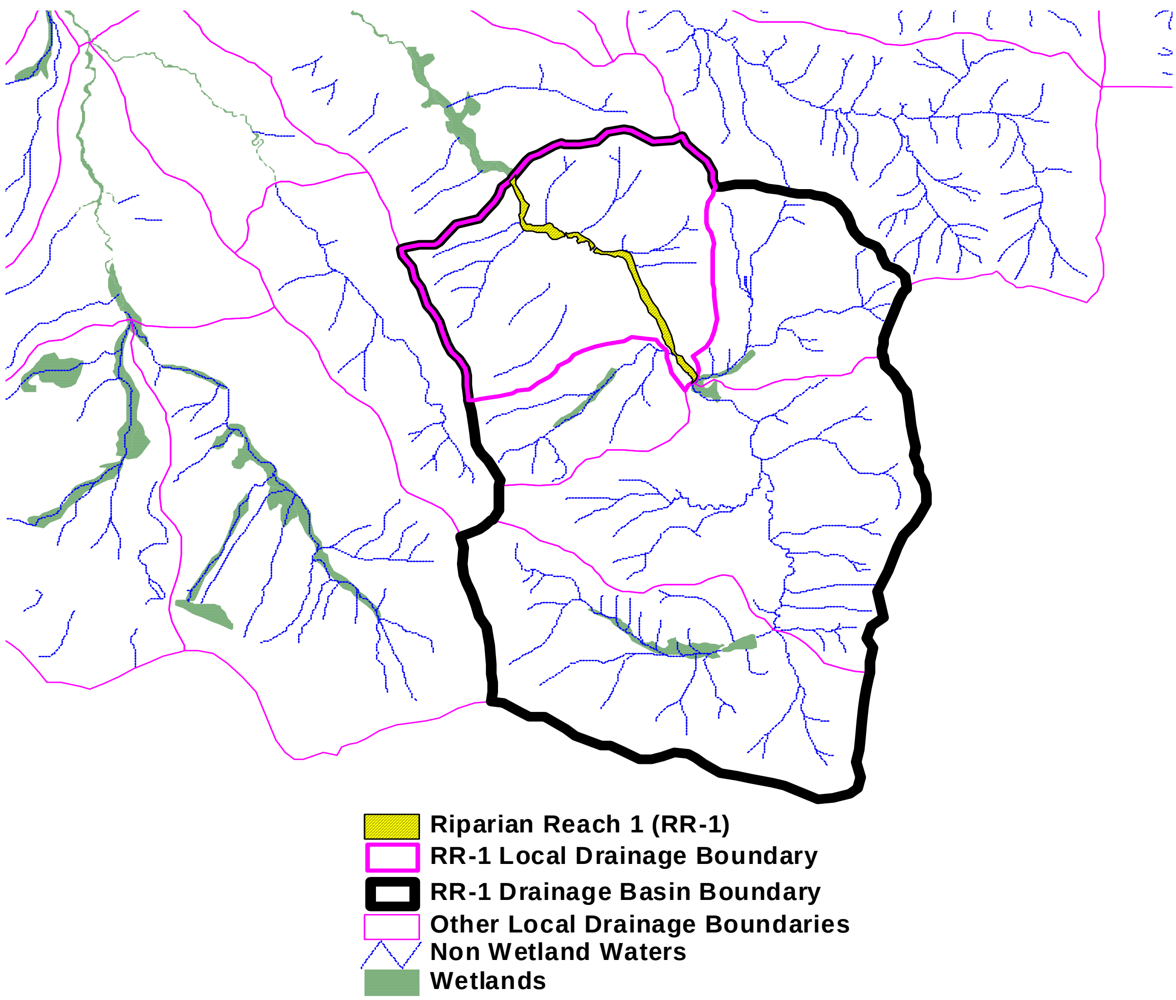


Figure 3. Illustration of riparian reach and its associated local drainage and drainage basin

Five geomorphic zones were identified based on topographic maps, the maps and descriptions provided in the county soil survey (Wachtell 1978), and geologic maps and reports on Orange County and the region (Morton et al. 1976, Morton and Miller 1981). Figure 4 illustrates a generalized representation each geomorphic zone in terms of landscape position. We assigned a geomorphic zone to each riparian reach using aerial photography, baseline assessment data, and our knowledge of each riparian reach acquired during baseline assessment field sampling. The following sections describe the typical, "natural" condition of each of the five geomorphic zones in terms of geomorphology, vegetation structure, and the typical current condition.

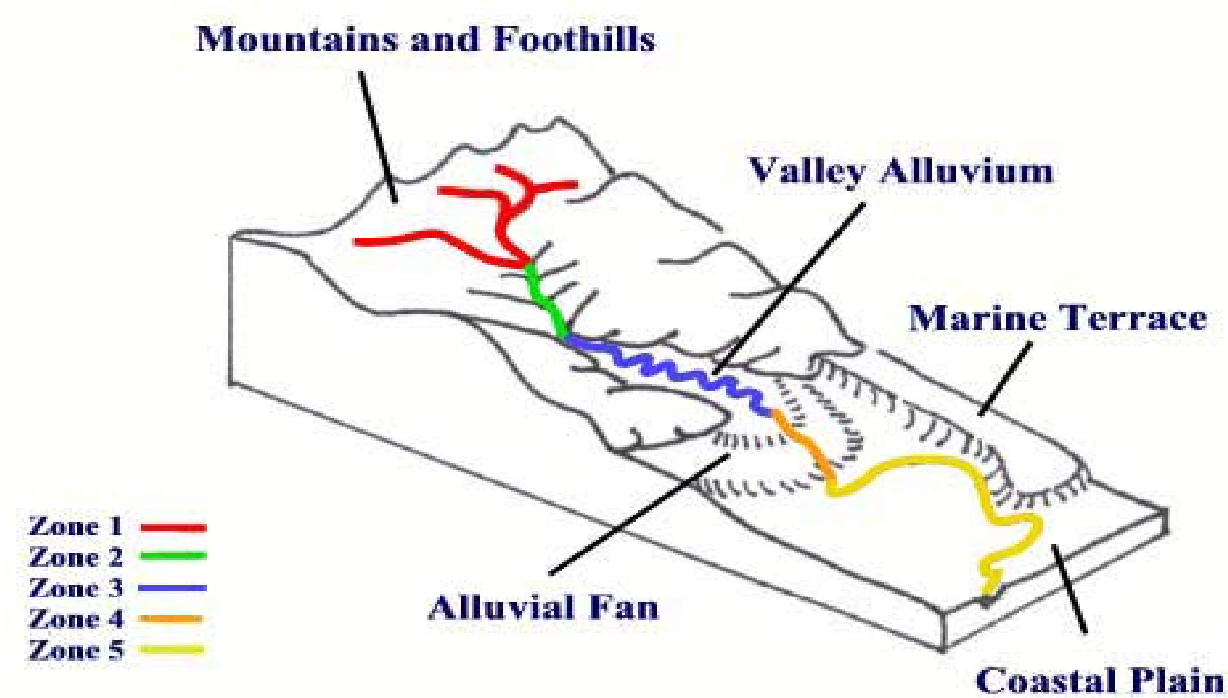


Figure 4. Generalized representation of landscape settings associated with geomorphic zone assignments.

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

These are primarily high-gradient systems within the mountains and foothills. Geologic mapping (Morton and Miller 1981) usually indicates 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. Hillslope vegetation, usually coastal sage scrub or oak woodland, extends to the top of the bank. Some moderate-gradient narrow valleys within the erosion-resistant marine terraces also are assigned to Zone 1, because they lack significant alluvial deposits, and riparian species are restricted to the immediate vicinity of the channel.

Many Zone 1 streams are in relatively good condition, because the adverse impacts of past land uses (primarily grazing) have been moderated by the influence of bedrock control on channel incision. Nevertheless, many channels have been deepened, as evidenced by terrace remnants at various levels, and some appear to be unstable in places.

4.1.2 Geomorphic Zone 2: Small floodplains and terrace fragments in mountain and foothill valleys, where meander belt formation is restricted by lateral impingement of alluvial fans and colluvium

These systems have the sinuous appearance of meandering streams on topographic maps and aerial photos, but in fact are winding between alternating fan or colluvial deposits that extend from the valley walls to the center of the valley. On the geologic map, these areas may be mapped as alluvium in some areas, but they are very different from the broad alluvial valley bottoms that characterize Zone 3 (described below). Streams within Zone 2 are fairly tightly confined by the material moving into the valley from the sideslopes, but generally are not bedrock-controlled. They have narrow floodplain and channel systems, and narrow, discontinuous terraces. Riparian vegetation is restricted to these settings, forming a narrow strip. Upland vegetation predominates immediately above the bank. Coastal sage scrub is the predominant native upland vegetation in most settings, but oak woodlands may dominate lower slopes in the more protected, upstream segments of the Zone 2 type.

Most channels in this zone appear to have incised significantly, and often lack a defined floodplain. Sediments shoal in places, and bank caving is common.

4.1.3 Geomorphic Zone 3: Meander belts in alluvium within broad mountain and foothill valleys, and through marine terraces

These sites are mapped as Quaternary Alluvium (Morton and Miller 1981), fingering into the mountains and hills from the coastal plain below. Sinuous channel systems meander widely across the valley floor, have well-developed floodplains with alternating bars, and one or more broad terraces 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 such as *Rhus ovata* and coastal sage scrub. Overall, the effect is a broad and complex riparian system with upland elements fingering into the valley bottom, further increasing community diversity.

Most examples of this type exhibit historic down cutting of channels, resulting in creation of multiple terrace levels, often with a predominance of non-native plant species outside the immediate vicinity of the active channel. Often, the highest terraces support scattered mature sycamore, but regeneration is not occurring and the terraces are being colonized by more upland plant species.

4.1.4 Geomorphic Zone 4: Broad alluvial fan deposits where mountain and foothill valleys open to the coastal plain, and marine terraces

Alluvial fans form an almost continuous sloping apron (*bajada*) of deep sediments along the base of the Santa Ana Mountains, and they also occur at the base of large valleys within the San Joaquin Hills. Individual fan splays have a convex shape, and the typical patterns of stream flow under natural conditions differ greatly from other geomorphic settings either upslope or down. In undisturbed conditions on a typical, active alluvial fan, the stream that emerges from the relatively confined valley remains in a defined, somewhat incised channel as it crosses the head of the fan. Down slope, the channel gradually shallows and at some point intersects with the fan surface, where flows become braided or move across the lower fan as sheet flow. Depending on site-specific factors, the surface flow may collect in channels at the base of the fan, or it may infiltrate and disappear completely under normal flow (non-flooding) conditions. Fans go through cycles of growth and erosion that are influenced by various factors, and the general pattern described above may not predominate at some stages of development. During periods of high runoff, flows across alluvial fans can be particularly unpredictable (National Research Council 1996).

Within the study area the historic flow patterns across alluvial fans were no doubt highly variable, depending on drainage basin and fan characteristics and various climatic and geologic events that influenced fan development. In the modern landscape, most of these sites have been developed or cleared for agriculture, and the stream flow has been directed into linear ditch systems. There is little evidence of what constituted the natural riparian vegetation on these surfaces. However, the ephemeral, shallow, and relatively undefined state of the natural channel system indicate that it would likely have been dominated by pioneer communities typical of the active floodplains upstream (e.g., willows and mulefat).

It is unlikely that the highly dynamic pre-settlement patterns can be re-established in the modern, developed environment. The somewhat entrenched channel systems are more appropriate for Zone 4 riparian areas and adjacent uplands, similar to those that traverse the marine terraces within relatively narrow, confined valleys. Therefore, channels within both the alluvial fans and the marine terraces are mostly classified as Zone 4.

4.1.5 Geomorphic Zone 5: Riparian areas along larger streams of the coastal plain area

The area referred to here as the coastal plain is the alluvium-filled basin below the fan apron flanking the mountains and hills. It is nearly flat, predominantly consists of sandy silts and sandy clays, and formerly included depressional wetlands, but the historical extent and location of large channel systems is uncertain. Soil maps (Wachtell 1978) show linear alluvial deposits on the surface of the larger alluvial fill that may indicate the presence of channels at various times in the past, but currently there are only a few large channel systems on the surface, and these have been highly modified. However, using other basins in the region as reference systems indicates that whatever surface channels existed in Zone 5 prior to widespread historic modifications to the basin probably meandered widely creating broad floodplains and terraces similar to the systems found in Zone 3, but on a larger scale. As in Zone 3, there would have been a highly dynamic, structurally complex community of willows and mulefat in the active floodplain with species such as sycamore, elderberry, mulefat, and ash on the terraces, and upland coastal sage-scrub communities or native grasslands interfingering on higher terraces and lower side slopes. Where the Zone 5 streams abut or traverse marine terraces, they become less sinuous than elsewhere on the coastal plain (Figure 4), evidently due to the less erodible nature of the marine sediments. However, the presence of higher clay content in the marine terrace soils, as well as other unusual conditions elsewhere within the coastal plain (such as local occurrences of caliche hard pans and highly organic deposits) suggest that plant community composition may have been, and hast the potential to be, more diverse in this part of the basin than the modern disturbed landscape indicates.

4.2 Restoration Templates

Next, we developed a classification of potential Restoration Templates for riparian ecosystems in various states of cultural alteration. We analyzed 50 riparian reach segments to establish specific restoration criteria in terms of channel cross section and form, the scale of terraces present, and characteristic vegetation types for each of the Restoration Templates. Using aerial photography, baseline assessment data, our knowledge of each riparian reach acquired during baseline assessment field sampling, and field verification we assigned one of five restoration templates to each riparian reach based 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. In some cases we divided riparian reaches into segments, and assigned a different Restoration Template to each riparian reach segment. 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.

4.2.1 Terminology

This section defines the terminology used to describe restoration templates. Table 1 lists and defines the common riparian plant communities depicted in Figure 5 and referenced elsewhere in this report. Note that plant communities are defined only in terms of dominant or characteristic species. Numerous other species occur and may be appropriate for inclusion in site-specific restoration plans.

Table 1. Plant community codes used in Figures 12-16 (Note: community types named using characteristic, but not necessarily dominant, species encountered in reference reaches)

Plant Community Codes	
B / S	*Baccharis salicifolia* / *Salix* spp.
P	*Platanus racemosa*
Q / H / R	*Quercus agrifolia / Heteromeles arbutifolia / Rhus* spp.
P / B / Sm	*Platanus racemosa / Baccharis salicifolia / Sambucus mexicana*
P / B / S	*Platanus racemosa / Baccharis salicifolia / Salix* spp.
P / F / B	*Platanus racemose / Fraxinus velutina / Baccharis salicifolia*
P / F	*Platanus racemose / Fraxinus velutina*
CSS	Coastal Sage Scrub

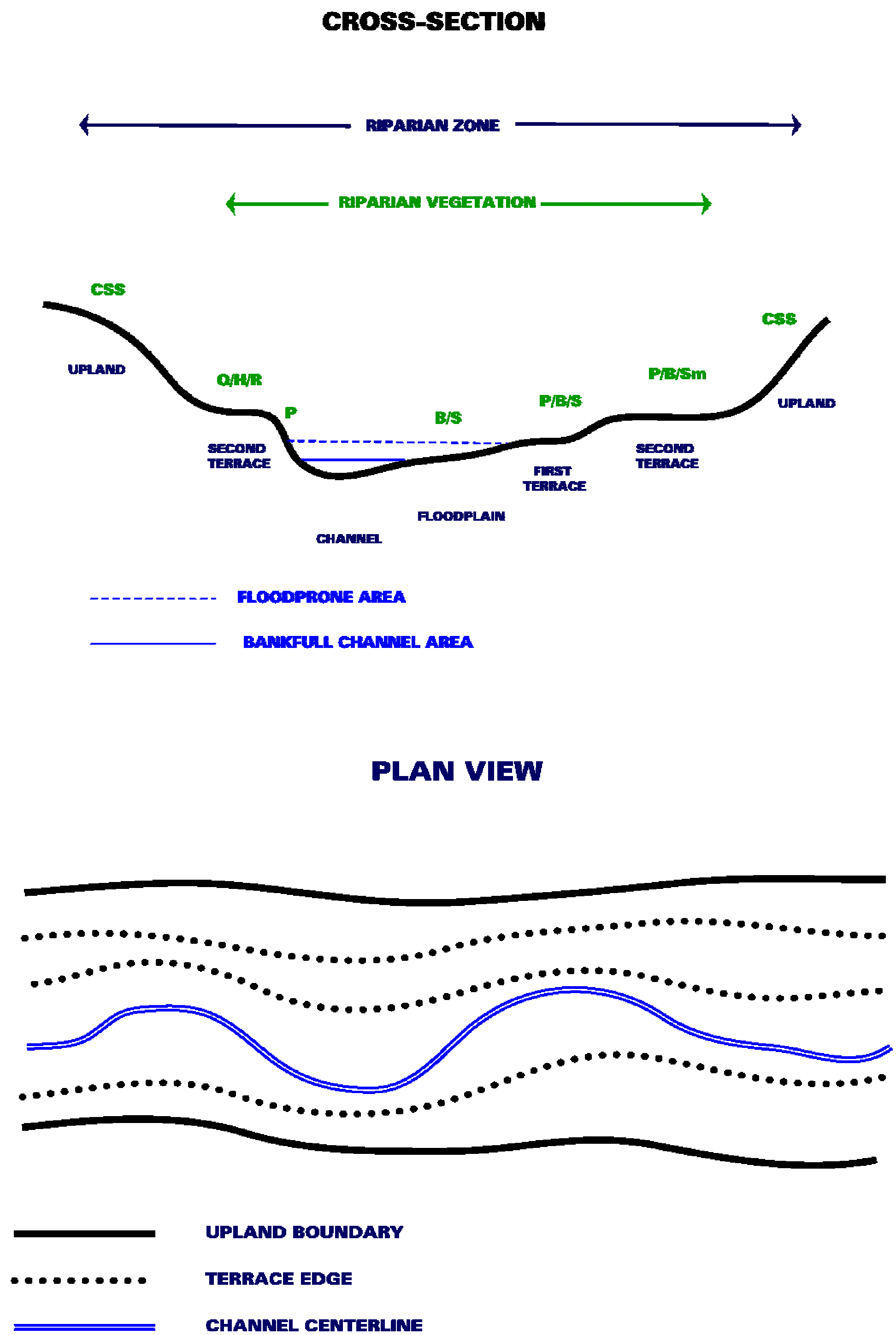


Figure 5. Generalized representations of geomorphic surfaces, hydrologic zones, and vegetation distribution used in this report. See Table 1 for interpretation of plant community codes.

The terms used in Figure 5 and subsequent figures have been defined in various ways by different authors. The definitions below largely reflect the usage of Dunne and Leopold (1978), Rosgen (1996), and/or Ritter (1986). However, some definitions have been framed in terms specific to the San Diego Creek watershed and the objectives of this study.

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

Floodplain: Technically, the floodplain is the valley floor level corresponding to the bankfull stage, but in fact there are various "floodplains" (e.g. 5-year, 10-year, etc.) that 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 "flood prone area" as defined by Rosgen (1996). This is the area flooded to twice the depth of the maximum channel depth at bankfull stage, which is usually assumed to correspond approximately to the 50-year floodplain. In coastal streams of southern California, the flood prone 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 the marine terraces. For the purposes of this study, terraces (excluding marine deposits) are alluvial features originally deposited as floodplains, but which now are situated outside the 50-year flood zone (i.e., the flood prone area). There may be multiple terraces 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 bankfull stage.

Riparian: The riparian zone usually is defined as the area that lies along a stream channel. The term “riparian zone” implies some interaction with the channel (e.g., inputs of organic material), but our definition is based primarily on proximity and may include upland vegetation growing on a high terrace or overhanging a channel from the top of a cut bank as well as species that occur only in association with watercourses. In this report, the term "riparian vegetation" is reserved for the latter group of plants, such as sycamores, willows, and mulefat.

Flood Channel: As noted above, the term "floodplain" has been reserved for the area subject to inundation at the 50-year recurrence interval. However, one or more terraces may also be inundated by larger magnitude floods. In a developed environment, protection of life and property requires that containment of floodwaters be a part of the design criteria for stream systems. Therefore, the design templates presented here generally specify the number and height of terraces appropriate to sustain a riparian community characteristic of a particular geomorphic zone, based on reference data from streams in the basin and region. However, the range of terrace widths encountered in reference systems varied widely. Although the reference data provide general target ranges, actual minimum terrace widths for restored systems must be determined by hydrologists calculating the overall "flood channel" size, including channel, floodplain, and terraces needed to contain a major flood event. In most cases this is likely to be the 100-year flood, but local flood control criteria will be the final determinants of overall "flood channel" size.

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 et al. 2000). In order to re-establish such natural conditions, floodplains, terraces, and adjacent uplands must be available for restoration. Furthermore, surfaces must be restored to appropriate height relative to bankfull stage to establish self-sustaining plant communities. The ranges of appropriate values for the widths and heights of these surfaces were estimated based on using reference data from the most intact reaches within southern California watersheds including the San Diego Creek watershed, as well as the criteria for channel geometry determinations defined by Rosgen (1996).

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 report, 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 Fischenich 2000). As noted, this is a minimum figure. Final restoration designs will 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 general templates structured specifically to determine the feasibility of restoring individual reaches, and to prioritize restoration actions based on the increases in riparian ecosystem function that are likely to be realized. Although the final restoration designs will resemble these templates, site-specific restoration designs will have to be developed. These designs must include hydrologic/sediment analysis to insure that the predicted discharges and sediment loads are compatible with maintenance of the prescribed design template, and vegetation specifications relating to planting stock, planting densities, and irrigation required to establish plantings..

The five restoration templates are described below.

4.2.2 Natural Channel Template

Channel, floodplain, and terrace morphology and vegetation, as well as a minimal upland buffer of native vegetation, can be restored to a condition approximating the estimated undisturbed condition for the particular Zone and site-specific conditions. Some stream incision is acceptable in this category, provided any shift in vegetation distribution is reversible. Generally, the Natural Template is assigned only if sufficient room for a floodplain exists and appropriate terraces are present and the hydrologic conditions required to sustain them are present. For example, many channels in Zone 3 have a high terrace that supports mature sycamores, but there is no evidence of sycamore reproduction, and coastal sage-scrub species are establishing on the terrace. In such cases, the conditions necessary to establish sycamore no longer prevail, due to channel incision, and the Natural Template would not apply. In fact, the Natural Template was typically assigned only to Zone 1 channels, where bedrock control prevented severe incision, and restoration is largely a matter of localized re-establishment of native vegetation.

4.2.3 Incised Channel Template

The most commonly assigned restoration target was the Incised Template. This template was applied to channels that had incised sufficiently to change the configuration of their floodplains and the heights of terraces, but where a relatively stable (equilibrium) facsimile of the original relationship could be re-established with a reasonable expectation of success. Usually, this template was applied to channels with incised beds in which the normal range of the bankfull width/depth ratio was exceeded, channel sinuosity could not be maintained at expected levels, and floodplains were insufficient (i.e., less than the required flood prone width). Standards for adequate terrace widths were less rigid, but were generally based on reference data from the region. The Incised Template was assigned to systems where the existing condition fell outside the normal range for all of these values, but where those ranges could be re-established through excavation of a wider floodplain with terraces of adequate width and height. Restoration of an "adequate floodplain" implies creation of room for meander activity as appropriate within the incised channel. A few sites have been straightened to the point that restoration of adequate sinuosity could be more efficiently achieved by excavation of additional channel length (i.e., a longer flood channel) rather than widening of the floodplain of the existing channel.

4.2.4 Constrained Channel Template

The Constrained Template 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., flood prone width, sinuosity, terrace configuration) to normal ranges. This template was rarely applied, but was necessary in some instances where surrounding infrastructure (e.g., roads and buildings) irreversibly crowds the incised channel. In these cases, field evaluation indicated that sufficient room is present to establish functional, and presumably stable (equilibrium) channels and floodplains, but that room to establish terraces and upland buffers is inadequate to approximate conditions found in reference systems. Thus, stream segments restored to the Constrained Template have all vegetation communities present, but one or more of those communities is significantly reduced in extent from the normal reference condition. The restored but constrained system is less functional in various ways than more complete systems, and must be regarded as being at some risk for failure due to a lack of room to adjust to extreme events.

4.3.5 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. This template allows for only minimal restoration of native vegetation, and is regarded as being unable to significantly improve ecosystem function beyond 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. Some concrete-walled channels are soft-bottomed and are designed to accommodate some native vegetation within the channel. Others may be modified to replace one of the engineered banks with a natural bank and native vegetation. However, some 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.

4.3.6 Restoration Impractical

For stream segments with no practical way to address the existing deficiencies without making fundamental changes to major roads and developed areas, or massive excavations, the Restoration Impractical Template is applied. Thus, stream segments that pass under highway corridors within culverts, and lengthy stream segments that have been converted to the underground drainage/storm drain system are assigned the Restoration Impractical Template, and no further action is recommended. Should planners determine that restoration of a stream segment in this category is feasible, the segment can be assigned to the appropriate template and appropriate action re-assessed under the selected template.

4.3 Level of Effort

Based on the analysis of 50 riparian reaches we also developed a scale estimating the level of effort that would be required to restore a riparian reach segment to the prescribed Restoration Template. Using aerial photography, baseline assessment data, knowledge of each riparian reach acquired during baseline assessment field sampling, and field verification, we assigned a level of effort value to each riparian reach segment. Level of effort was intended to serve as tool for planners based on the assumption that limited resources or potential sites would be available for restoration, or limited potential sites available to offset certain types of impacts. Furthermore, and it may be useful to consider the amount of resources required 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 surrogate for the amount of resources required. There is no consideration of land purchase costs or similar issues in these estimates, and unforeseen issues could easily change the estimates dramatically.

The process of determining the most effective combination of restoration actions is often independent of level of effort considerations for any template. However, such considerations may be included a broader planning context, where upland land use changes might be implemented as part of a watershed restoration plan. Reaches were ranked based on overall gain in function, assuming application of the recommended restoration template.

4.3.1 Level of Effort - None

No restoration is necessary because the reach is functional in its current condition. One level of effort unit was assigned to reaches in this category.

4.3.2 Level of Effort - Light Planting

No re-configuration 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 reintroducing species that may have been grazed from a community into an otherwise intact riparian area or upland buffer. Two level of effort units were assigned to reaches in this category.

4.3.3 Level of Effort - Heavy Planting

This treatment is prescribed where, in addition to the activities mentioned under "Light Planting," large numbers of plants must be introduced and/or significant mechanical site preparation is needed. 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. Three level of effort units were assigned to reaches in this category.

4.3.4 Level of Effort - Light Earthwork

This level of effort is assigned to stream segments and associated riparian areas that require reconfiguration in some areas, although other portions may be restored with the simpler methods described above. Light Earthwork is intended to indicate widening of floodplains and terraces in systems where channels are not deeply incised, but need more space to re-establish equilibrium and community diversity. Typically, this will involve excavation of less than six feet 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 Light Earthwork level of effort designation includes the assumption that heavy planting would be required, including the site preparation activities described in Section 4.3.3. Four level of effort units were assigned to reaches in this category.

4.3.5 Level of Effort - Heavy Earthwork

This level of effort category encompasses a wide range of possible actions, all of which will end with the Heavy Planting site preparation and planting requirements described in Section 4.3.3. Sites designated as needing Heavy Earthwork may be deeply incised channel segments that require extensive soil removal to re-establish floodplains and terrace systems tens of feet below the current grade, and grading back of high vertical banks to create stable angles of repose. These efforts may also require cutting of new channel systems with adequate length to allow meander behavior where the original channels have been obliterated and replaced with straight engineered channels. Additionally, relocation of roadbeds, removal of concrete channel segments, and other major site reconfiguration activities may be warranted. Necessary equipment would include bulldozers, graders, track-hoes and similar heavy machinery. Five level of effort units were assigned to reaches in this category.

Although we have proceeded on the assumption that reaches in the "impractical" category will not be candidates for restoration due to the extreme effort required, we have included them in this analysis primarily to illustrate their distribution relative to the other, more feasible, restoration options. These "impractical to restore" reaches have been assigned 10 level-of-effort units, but this by no means implies that the level of resources required to restore them are similar among the reaches, or that they are in proportion (i.e. 10x) to the effort required on other reaches.

4.4 Restoration Simulations

We developed an ArcView theme with attributes representing Geomorphic Zone, Restoration Template, and level of effort for each riparian reach segment in the San Diego Creek watershed. We then re-calculated the assessment scores (scale of 1 to 5, where 5 is fully functional) determined by Smith (2001) using new indicator scores assigned to each riparian reach segment based on the conditions that could be expected to exist after applying the prescribed Restoration Template. The methods used to determine the original assessment scores are described in Appendix 2. Table 2 lists the indicators for each of the Restoration Templates. Not all of the original 19 indicators were assigned new indicator scores because some indicators represent local drainage or drainage basin scale factors that influence the hydrologic, water quality, or habitat integrity of riparian ecosystems. These indicators are not affected by applying a Restoration Template to a riparian reach, and therefore are not assigned new indicator scores. Two indicators, Altered Hydraulic Conveyance - Drainage Basin Scale and Riparian Corridor Connectivity - Drainage Basin Scale were not assigned new indicator scores directly, but acquired new indicator scores that reflect changes in Altered Hydraulic Conveyance and Riparian Corridor Connectivity indicators in upstream riparian reach segments.

Table 2. Example of new scores assigned to riparian reach scale indicators based on Restoration Template

Restoration Template	**Riparian Reach Indicators**						
	AHC-RR*	**AHC-DB**	**FI**	**SR**	**NVR**	**RCC-RR**	**RCC-DB**
Natural	5	Cumulative	5	5	5	5	Cumulative
Incised	5	Cumulative	5	4	5	5	Cumulative
Constrained	No Change	Cumulative	No Change	2	5	5	Cumulative
Engineered	No Change	Cumulative	No Change	1	5	5	Cumulative
Impractical	No Change	Cumulative	No Change	No Change	No Change	No Change	Cumulative
* see Appendix 2 for indicator code descriptions							

Indices for hydrologic, water quality, and habitat integrity were then recalculated for each riparian reach segment based on the new indicator scores. The estimates for Level of Effort were then used to calculate a ratio of (Functional Improvement to Level of Effort) for each riparian reach segment that integrates the overall functional improvement with level of effort required to achieve the prescribed Restoration Template. This measure of functional improvement per unit effort was then used to illustrate how implementation of different restoration scenarios might affect overall riparian ecosystem integrity in a watershed context at the local drainage and drainage basin scales. Modifying riparian reach characteristics affects certain variable scores for downstream and upstream reaches and their associated drainage areas. The restoration simulation in Section 5.3 contrast the landscape-level effects of implementing restoration based on the highest-functional gain criteria and highest return-on-effort criteria versus a restoration strategy that focused on correcting deficiencies throughout a single drainage basin.

5.0 Results and Discussion

5.1 Riparian Reach Segment Classification

Figure 6 shows Geomorphic Zones assigned to riparian reach segments for the entire San Diego Creek watershed. Figure 7 shows Restoration Templates assigned to riparian reach segments for the entire San Diego Creek watershed. Figure 8 shows the level of effort assigned to riparian reach segments for the entire San Diego Creek watershed. These figures were exported from the ArcView themes Geomorphic Zone, Restoration Template, and level of effort described in Appendix 2: ArcView Theme Metadata.

5.2 Conceptual Restoration Designs

Figures 9-13 illustrate common features of riparian systems and adjacent uplands for each geomorphic zone in the study area. The figures show geomorphic surfaces, water levels for the bankfull channel and flood prone area, and the distribution of dominant or characteristic vegetation. For each zone, these features are illustrated for a generalized "natural" condition, for the typical existing "incised" condition, and for a conceptual "restored" condition for that incised channel (the "incised restoration template"). Photos show examples of typical natural and existing conditions. Accompanying the conceptual "restored" condition are dimensions of geomorphic surfaces, expressed as means and ranges based on measurements in the most intact (highest function) reaches sampled in the San Diego Creek watershed (Smith 2000a) and elsewhere in the region (Smith 2002b). Note that where terraces occur on both sides of the channel the terrace width dimensions represent the sum of terraces on both sides of the channel . Conceptual design templates are not illustrated for the constrained and engineered templates. These restoration templates are limited in distribution and will require site-by-site adaptation of the general design principles described in the Approach Section, depending on opportunities and limitations associated with each site.

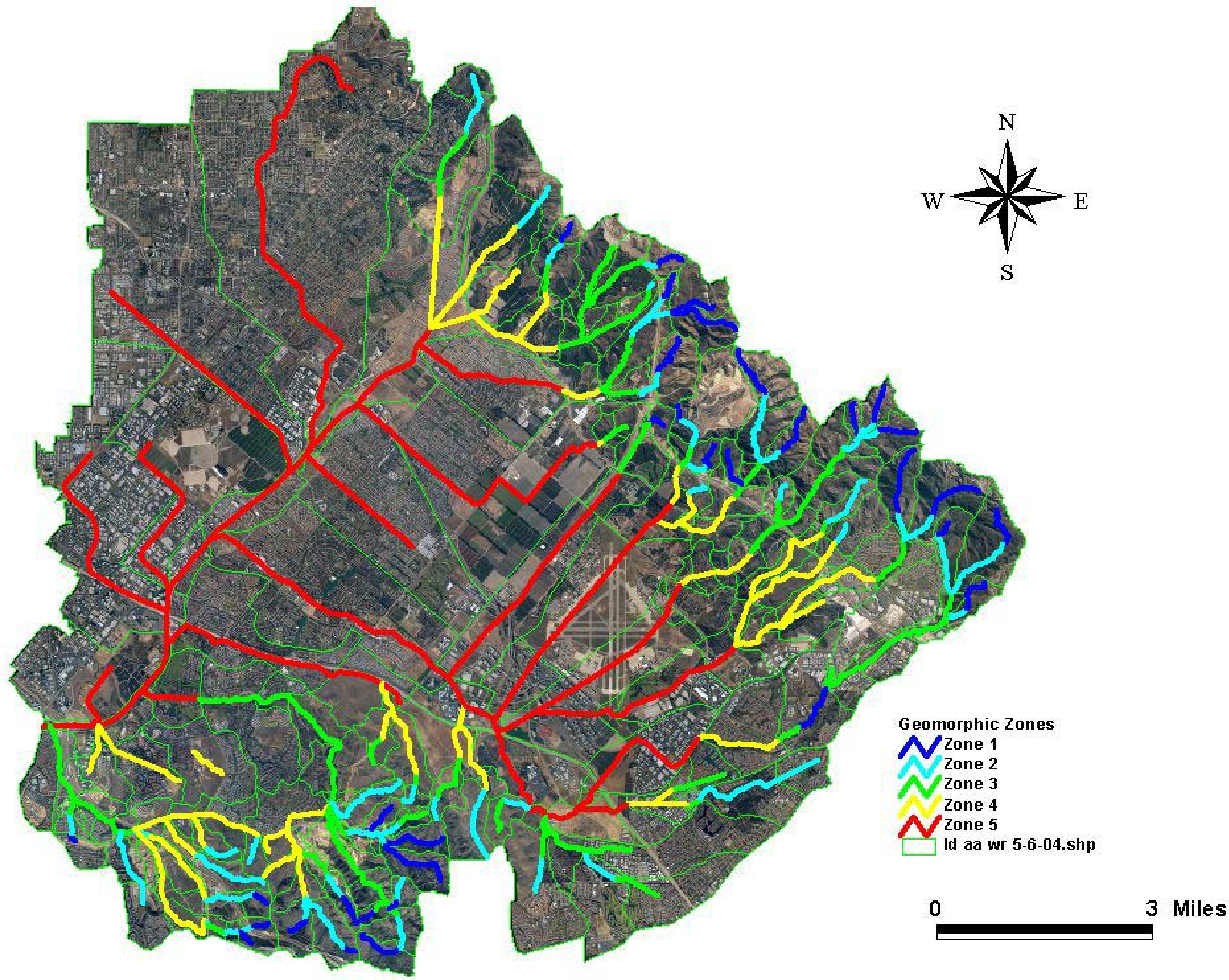


Figure 6. Geomorphic Zone assignments for riparian reach segments in San Diego Creek watershed

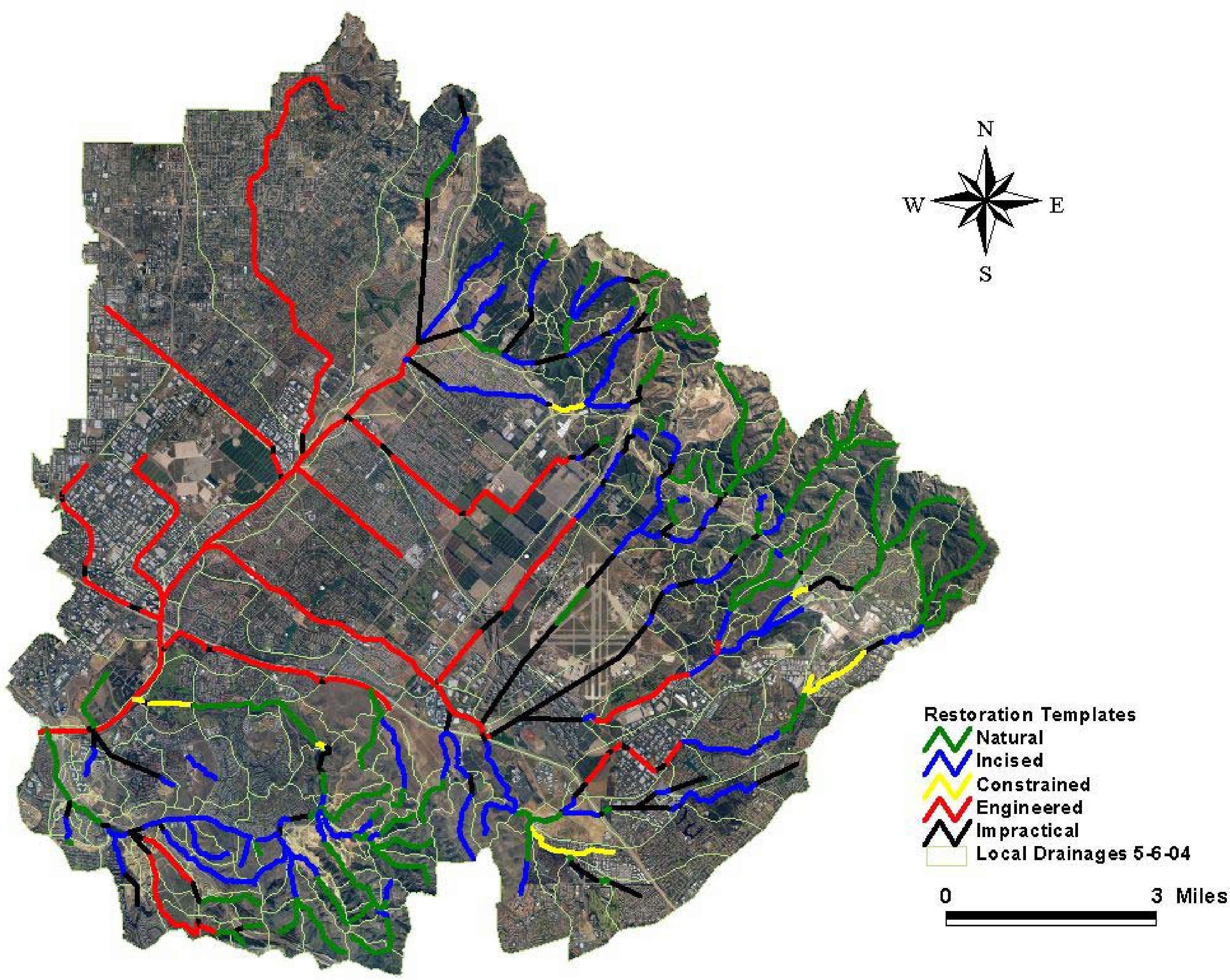


Figure 7. Restoration Template assignments for riparian reach segments in San Diego Creek watershed

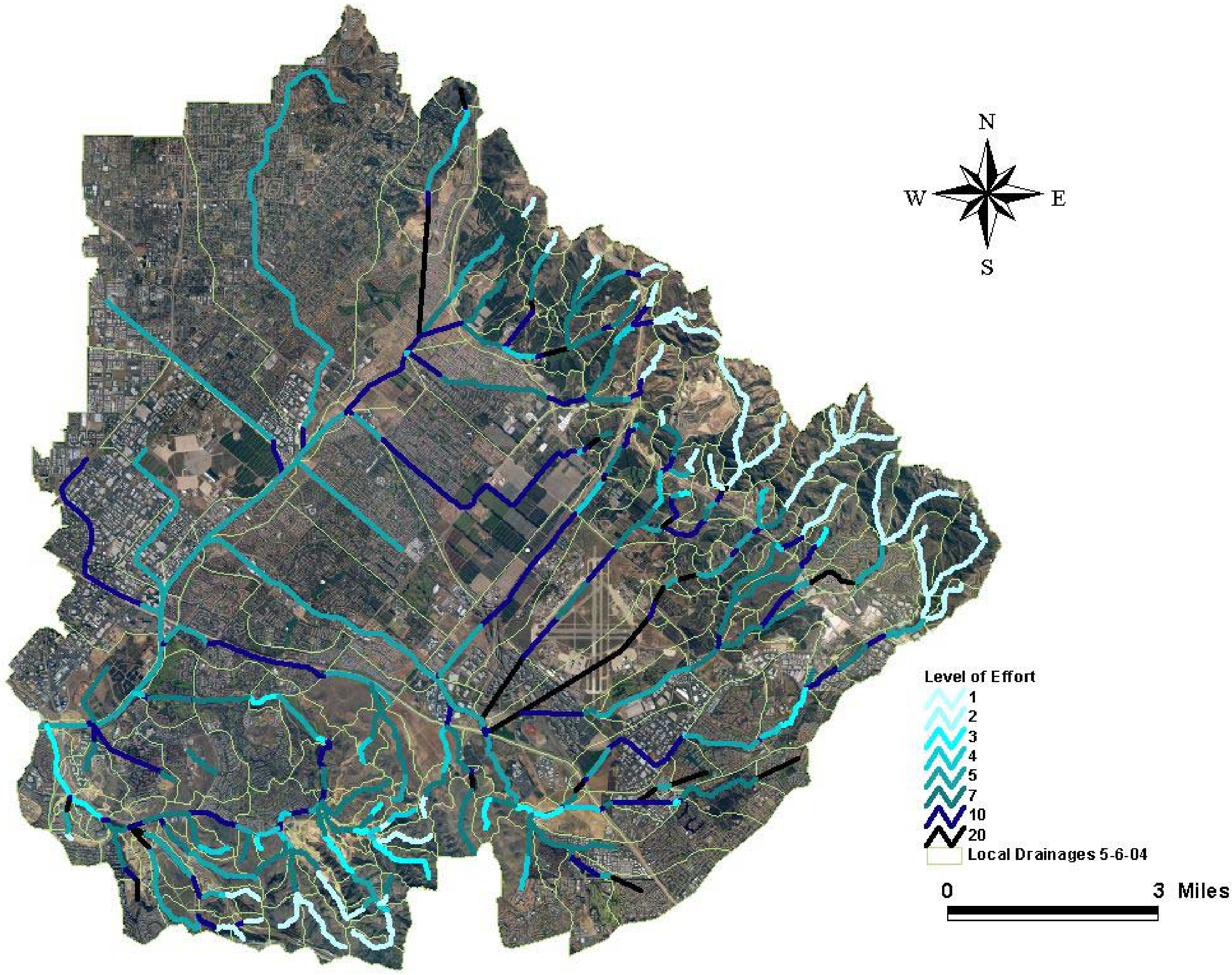
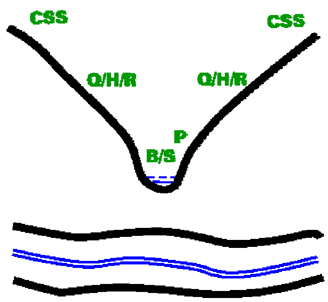


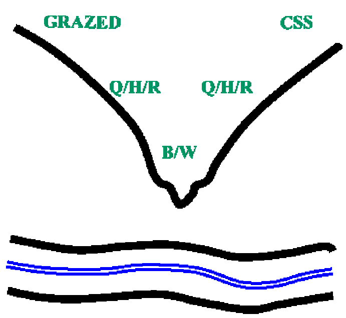
Figure 8. Level of effort assignments for riparian reach segments in San Diego Creek watershed

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

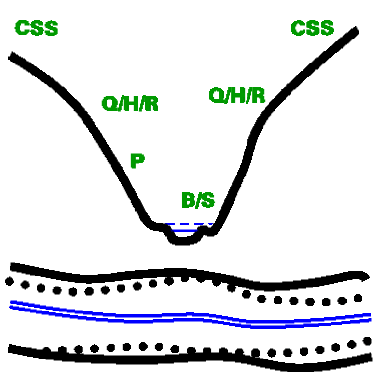
NATURAL CONDITION



TYPICAL INCISED CONDITION



GENERAL RESTORATION OBJECTIVE



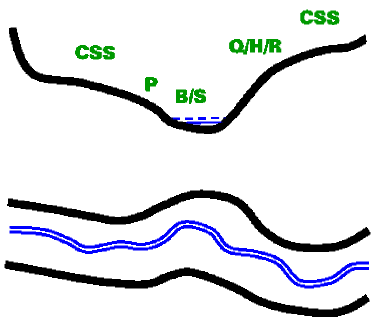
Approximate Dimensions of Surfaces

Bankfull Width	**1.5m (0.6-2.7)**
Bankfull Depth	**0.15m (0.10-0.23)**
Flood Prone Width	**2.4m (1.1-2.7)**
First Terrace	
Width	**1.8m (0.9-3.7)**
Height above Bankfull	**0.46m (0.15-0.9)**
Second Terrace	
Width	**NA**
Height Above Bankfull	

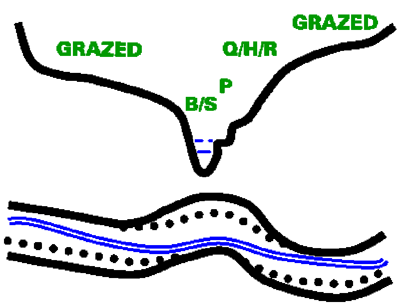
Figure 9. Natural conditions, typical existing conditions, and general restoration objectives for Zone 1 riparian areas (see Figure 5 for features legend and Table 1 for vegetation types)

ZONE 2: Small floodplains and terrace fragments in mountain and foothill valleys, with lateral restriction due to alluvial fans and colluvium

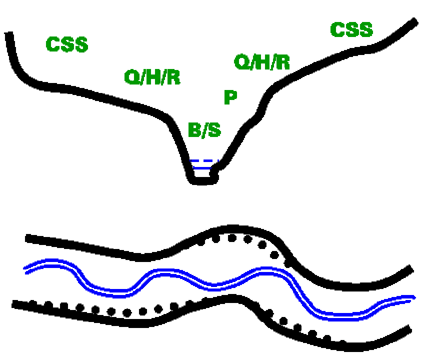
NATURAL CONDITION



TYPICAL INCISED CONDITION



GENERAL RESTORATION OBJECTIVE



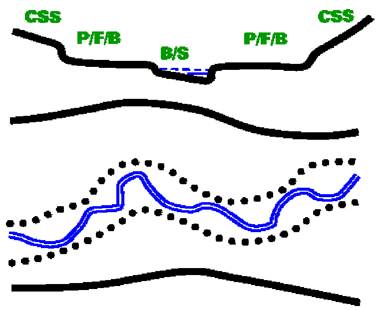
Approximate Dimensions of Surfaces

Bankfull Width	**1.9m (1.2-3.0)**
Bankfull Depth	**0.17m (0.10-0.25)**
Flood Prone Width	**3.1m (1.2-5.5)**
First Terrace	
Width	**2.4m (0.9-6.0)**
Height above Bankfull	**0.6m (0.3-0.9)**
Second Terrace	
Width	**NA**
Height Above Bankfull	

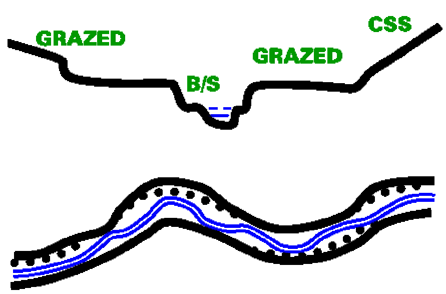
Figure 10. Natural conditions, typical existing conditions, and general restoration objectives for Zone 2 riparian areas (see Figure 5 for features legend and Table 1 for vegetation types)

ZONE 3: Meander belts in alluvium within broad mountain and foothill valleys and trough marine terraces

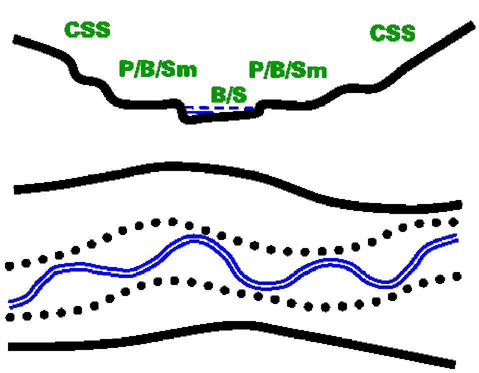
NATURAL CONDITION



TYPICAL INCISED CONDITION



GENERAL RESTORATION OBJECTIVE



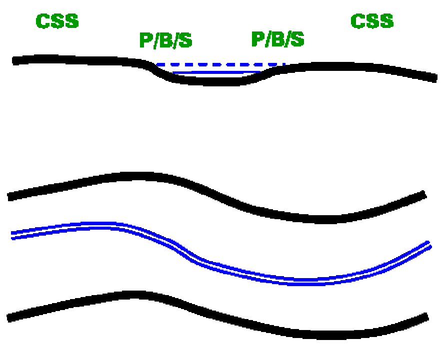
Approximate Dimensions of Surfaces

Bankfull Width	**3.9m (2.1-7.6)**
Bankfull Depth	**0.23m (0.15-0.31)**
Flood Prone Width	**7.8m (4.0-13.7)**
First Terrace	
Width	**4.6m (3.0-12.2)**
Height above Bankfull	**0.5m (0.3-0.9)**
Second Terrace	
Width	**NA**
Height Above Bankfull	

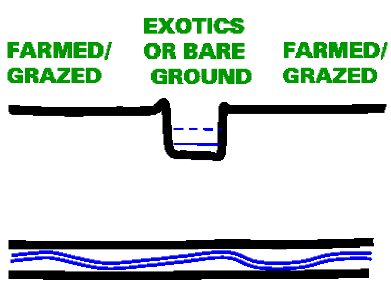
Figure 11. Natural conditions, typical existing conditions, and general restoration objectives for Zone 3 riparian areas (see Figure 5 for features legend and Table 1 for vegetation types)

ZONE 4: Broad alluvial fan deposits where mountain and foothill valleys open to the coastal plain

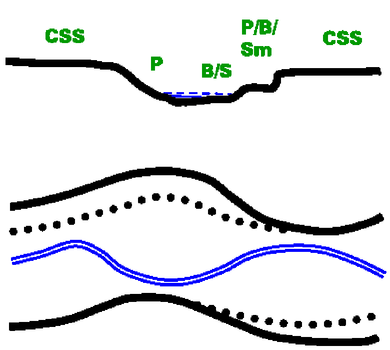
NATURAL CONDITION



TYPICAL INCISED CONDITION



GENERAL RESTORATION OBJECTIVE



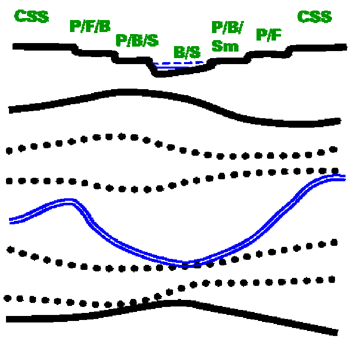
Approximate Dimensions of Surfaces

Bankfull Width	**4.7m (0.9-8.5)**
Bankfull Depth	**0.24m (0.13-0.36)**
Flood Prone Width	**8.6m (1.8-18.5)**
First Terrace	
Width	**5.5m (3.0-12.0**
Height above Bankfull	**0.6m (0.3-1.2)**
Second Terrace	
Width	**NA**
Height Above Bankfull	

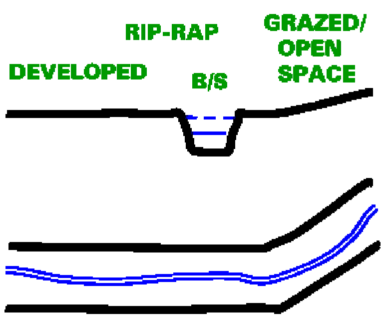
Figure 12. Natural conditions, typical existing conditions, and general restoration objectives for Zone 4 riparian areas (see Figure 5 for features legend and Table 1 for vegetation types)

ZONE 5: Riparian areas along larger streams of the coastal plain.

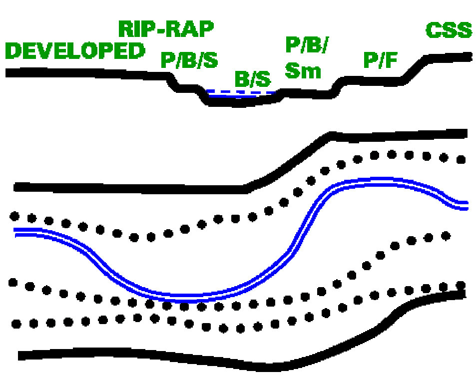
NATURAL CONDITION



TYPICAL INCISED CONDITION



GENERAL RESTORATION OBJECTIVE



Approximate Dimensions of Surfaces

Bankfull Width	**5.3m (3.7-7.3)**
Bankfull Depth	**0.28m (0.20-0.36)**
Flood Prone Width	**8.6m (4.6-13.7)**
First Terrace Width	**7.6m (4.6-15.2)**
Height above Bankfull	**0.6m (0.3-1.2)**
Second Terrace Width	**15.2m (9.1-24.4)**
Height Above Bankfull	**1.8m (1.5-3.0)**

Figure 13. Natural conditions, typical existing conditions, and general restoration objectives for Zone 5 riparian areas (see Figure 5 for features legend and Table 1 for vegetation types)

5.3 Restoration Simulations

The primary application of the information developed during this study is to identify the specific riparian reach segments in the San Diego Creek watershed where restoration efforts would be most effective in terms of maximizing the increased riparian ecosystem integrity in the San Diego Creek watershed, and in terms of level of resources required per unit of effort. To this end we conducted two restoration simulations. In the first scenario, the object was to identify the riparian reach segments where restoration would result in the greatest increase in riparian ecosystem integrity in the San Diego Creek watershed regardless of the level of effort required. Thus this simulation provides a ranking of riparian reach segments in terms of the greatest increase of riparian ecosystem integrity regardless of effort. Figure 14 shows the change in the hydrologic integrity index that resulted after assigning new indicator scores to each riparian reach segment in the entire San Diego Creek watershed. Figure 15 shows the change in the water quality integrity index. Figure 16 shows the change in the habitat integrity. In all of these figures darker colors represent a greater increase in riparian ecosystem integrity. Selecting riparian reach segments with the greatest increase in integrity indices after restoration will result in the maximum increase in riparian ecosystem integrity in the San Diego Creek watershed.

In the second simulation the objective was to identify the riparian reach segments where restoration efforts are similar to the first, but after incorporating Level of Effort into the simulation. Thus this simulation provides a ranking of riparian reach segments in terms of the greatest increase of riparian ecosystem integrity per unit of effort. Figure 17 shows the functional improvement per level of effort in terms of the hydrologic integrity index for each riparian reach segment in the entire San Diego Creek watershed. Figure 18 shows the functional improvement per level of effort in terms of the hydrologic integrity index for riparian reach segments. Figure 19 shows the functional improvement per level of effort in terms of the habitat integrity index for riparian reach segments. Again, in all of these figures darker colors represent a greater increase in riparian ecosystem integrity per unit of effort. Selective restoration of the riparian reach segments will insure the maximum increase in riparian ecosystem integrity per unit of effort in the San Diego Creek watershed.

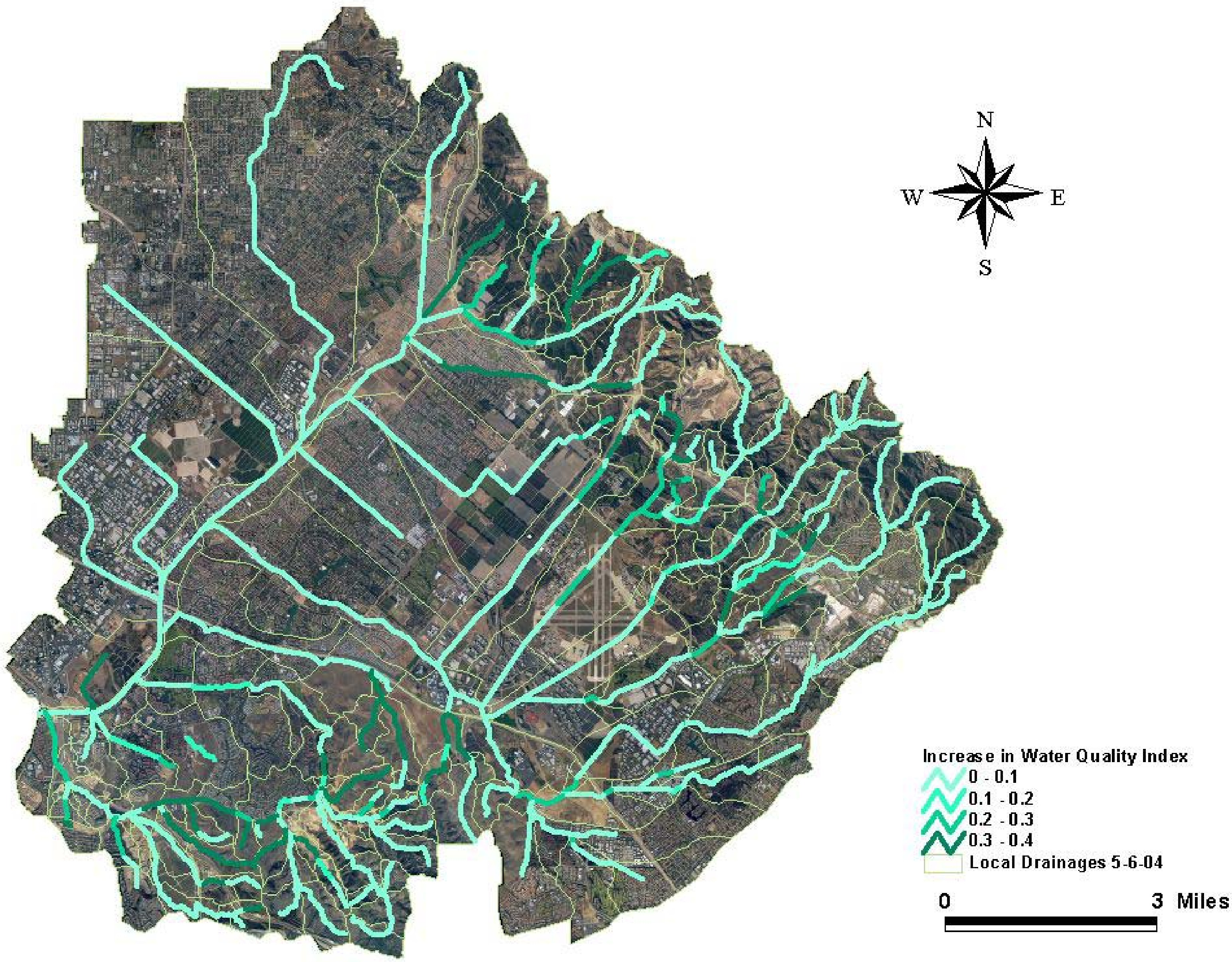


Figure 14. Increase in hydrology index increase following restoration for riparian reach segments

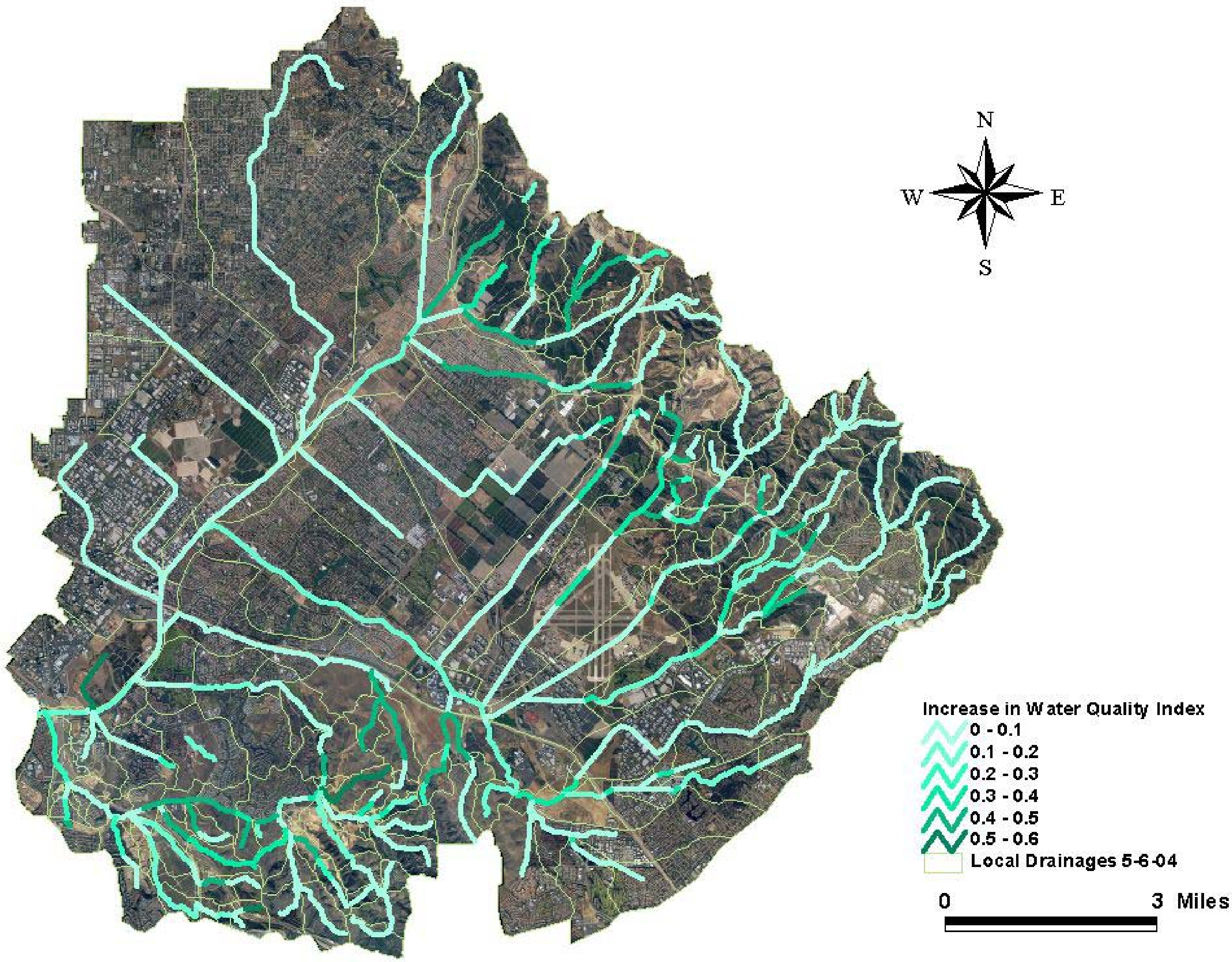


Figure 15. Water quality index increase for riparian reach segments in San Diego Creek watershed

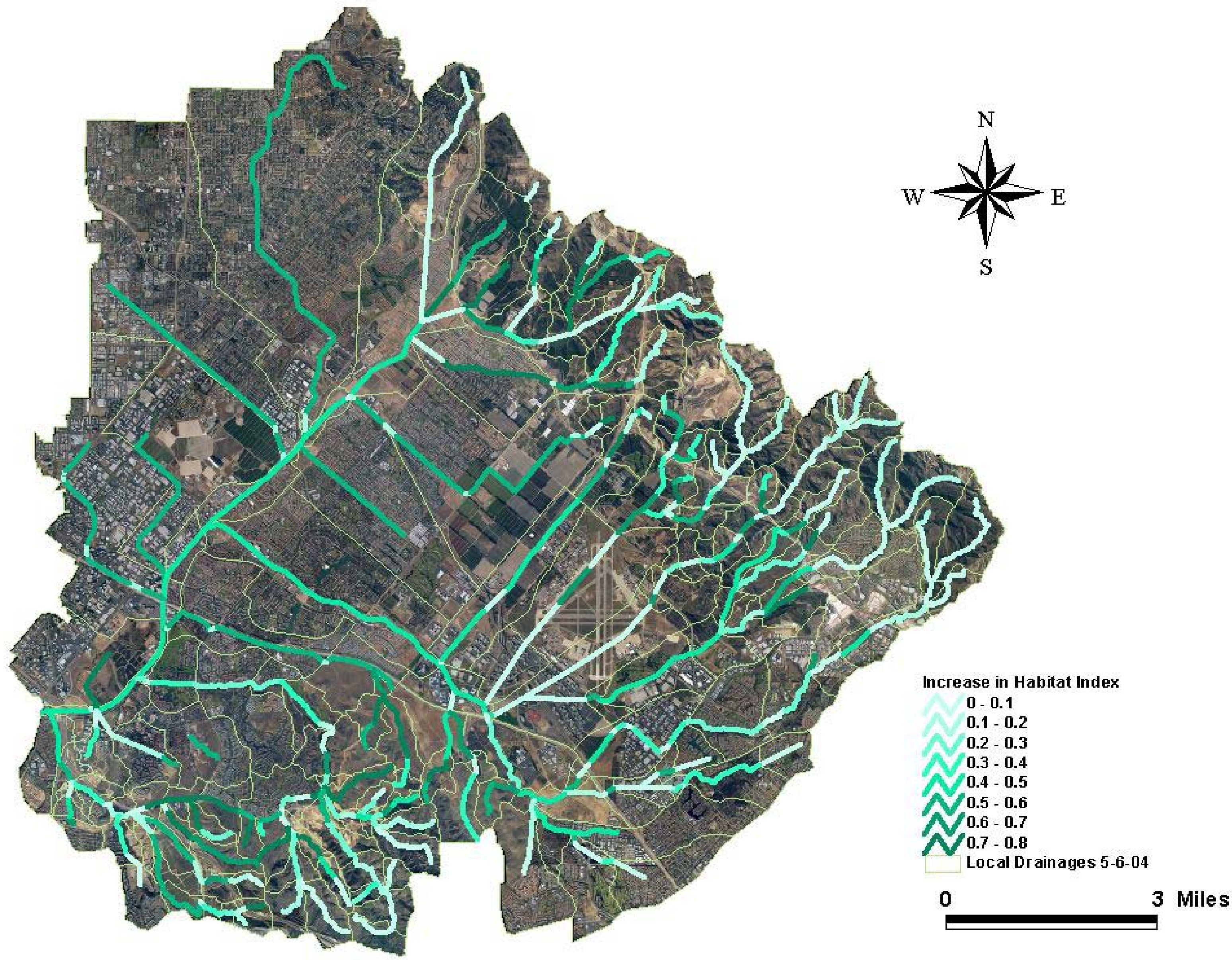


Figure 16. Habitat index increase for riparian reach segments in San Diego Creek watershed

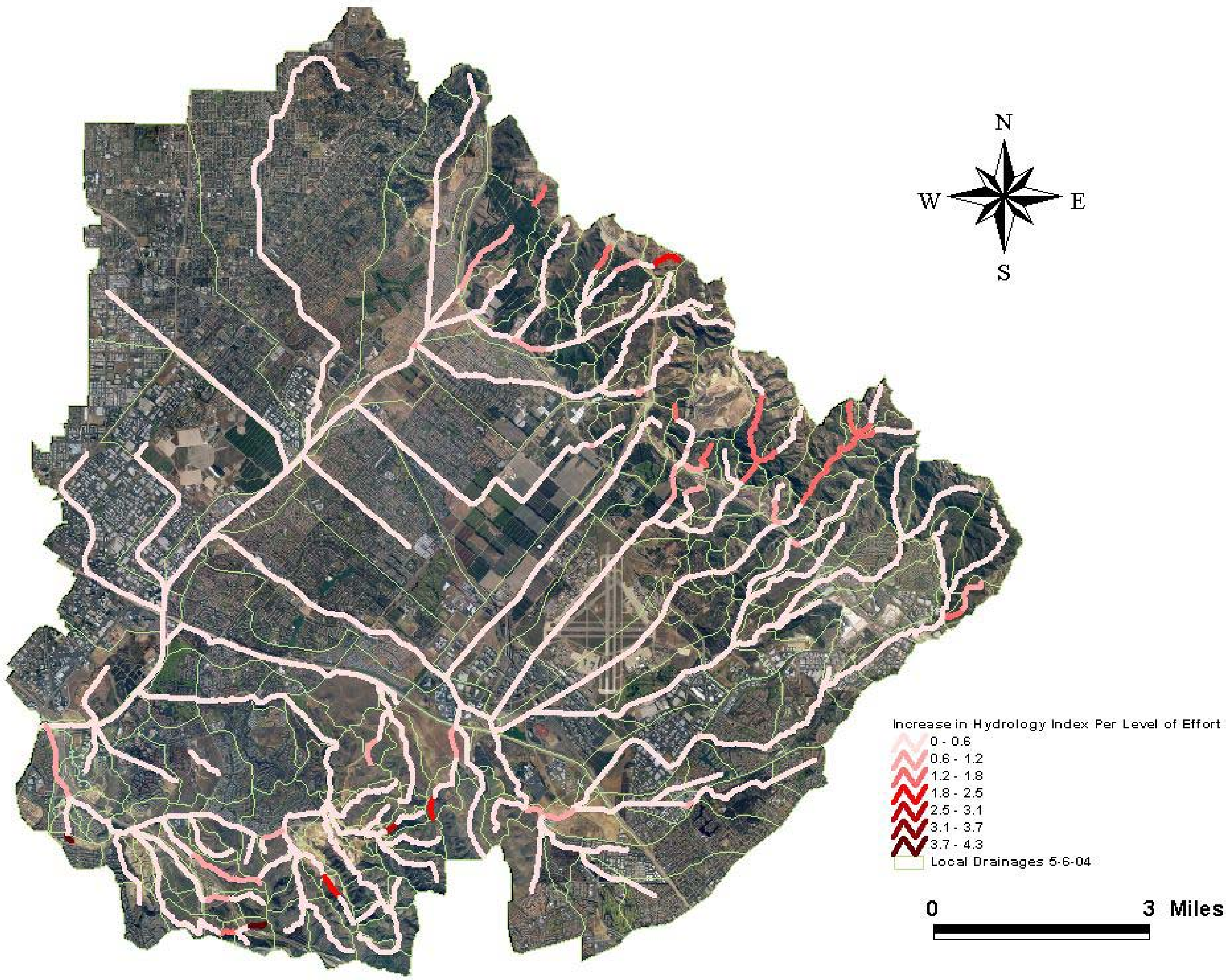


Figure 17. Hydrology index increase per level of effort for riparian reach segments in San Diego Creek watershed

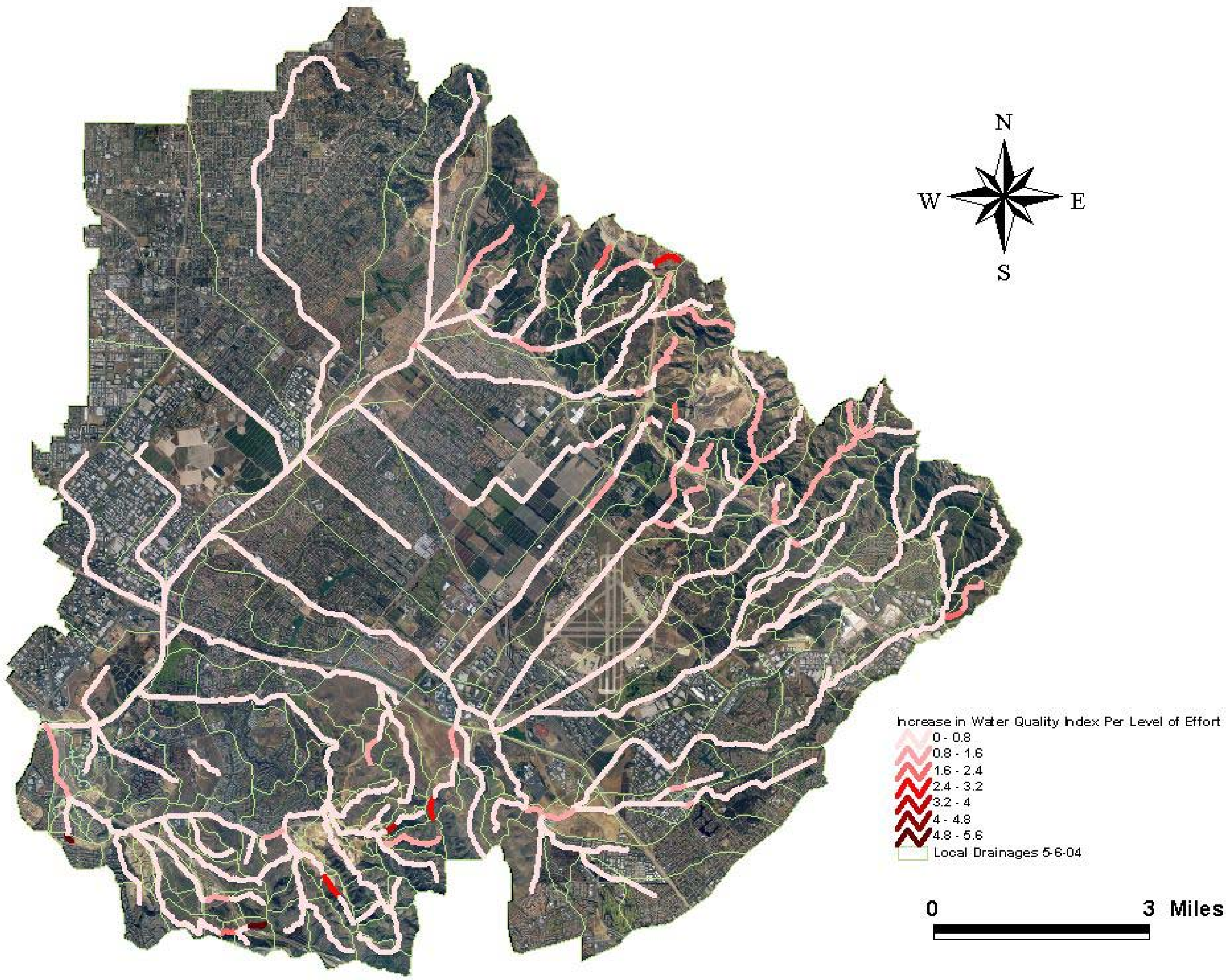


Figure 18. Water quality index increase per level of effort for riparian reach segments in San Diego Creek watershed

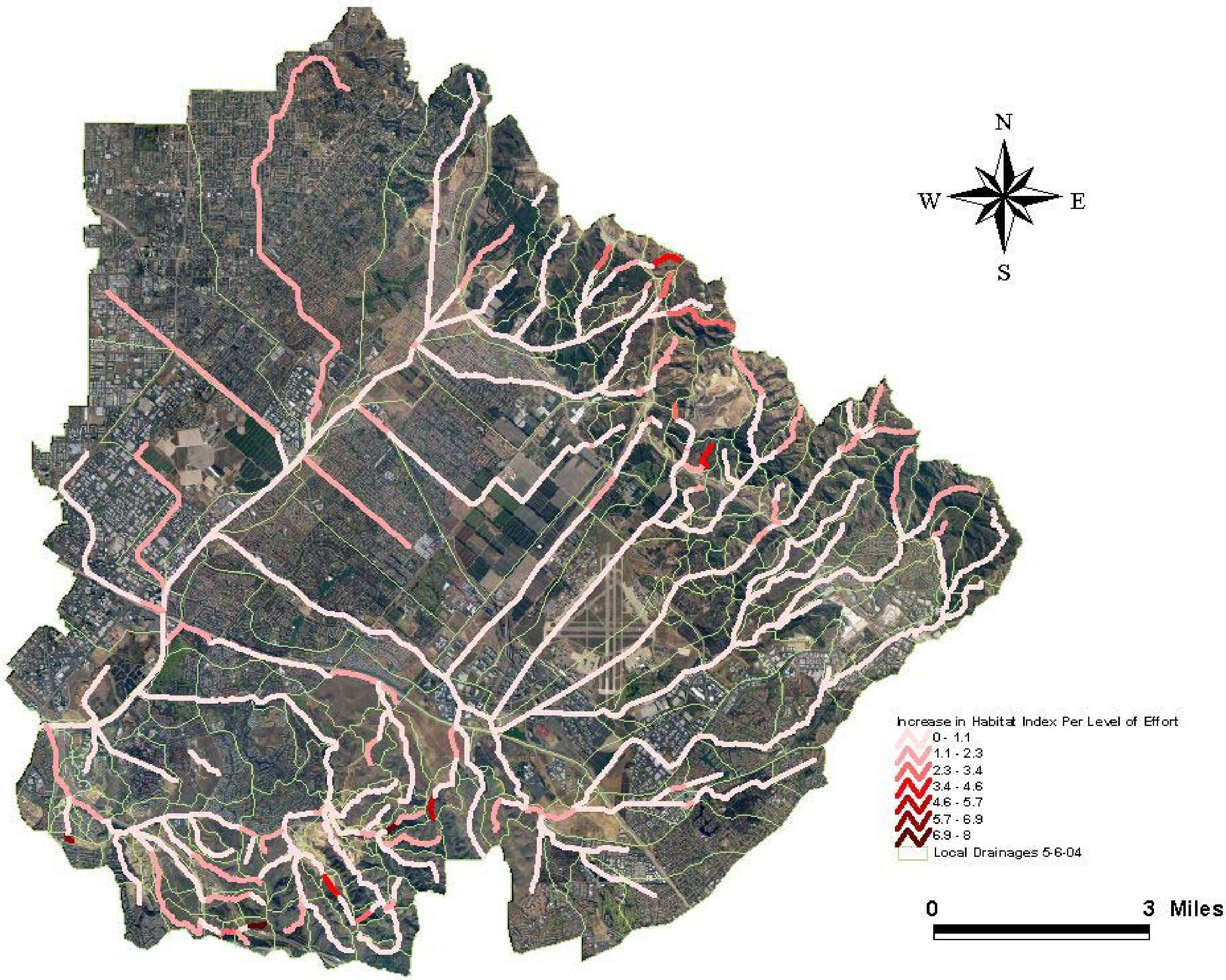


Figure 19. Habitat index increase per level of effort for riparian reach segments in San Diego Creek watershed

Figures 14 and 17 illustrate the important difference between the objectives of the two simulations. Figure 14 shows the result of selecting riparian reach segments based on where restoration would result in the greatest increase in riparian ecosystem integrity in the San Diego Creek watershed regardless of the level of effort required. Note in Figure 14 that many riparian reach segments in the coastal plain have a high increase in the habitat integrity index (i.e., darker colors) because these reaches are engineered sections that respond significantly to application of the prescribed Restoration Template. However, as illustrated in Figure 17 when level of effort is considered, the ranking of these riparian reach segments decreases (i.e., lighter colors) because the level of effort required to restore these riparian reach segments is great.

5.4 Future Work

The two simulations presented above were designed to meet two objectives. First, a ranking of which riparian reach segments will result in the greatest amount of “functional lift” to riparian ecosystems in the San Diego Creek watershed regardless of the resources required to accomplish the task. Second, a revised ranking of which riparian reach segments will result in the greatest amount of “functional lift” to riparian ecosystems in the San Diego Creek watershed with a added consideration of consideration of the level of effort required.

It is important to recognize that these two simulations represent the tip of the iceberg in terms the types of simulations that are possible depending on the objectives. For example, if the objective is to restore large patches (i.e., subbasins) to facilitate habitat restoration for certain species, it is possible to identify which subbasins will require the greatest, or least, level of effort to restore to the designated restoration templates. Another objective might be to restore riparian corridors to connect existing large patches, it will be possible to identify which of several candidate corridors would require the greatest level of effort to restore. Possible simulation scenarios are limited only by the ability to identify specific objectives.

It is also important to recognize that all the foregoing discussions have been limited to the situation in which riparian reach segments are the focus of restoration efforts. Shifting attention to restoration of upland habitats in the local drainage and drainage basin of riparian reaches would open a vast array of other opportunities for increasing the hydrologic, water quality, and habitat integrity indices of riparian reaches. This would involve changing the scores for indicators reflecting local drainage and drainage basin factors that affect the integrity of riparian ecosystem.

Finally, it must be realized that the results of a simulation scenario is just one of a variety of factors the must be considered when selecting where riparian restoration should occur in the San Diego Creek watershed. For example, one of the proposed uses for the decommissioned El Toro Air Station has been the creation of a regional park. This has implications for restoration of riparian ecosystems in the San Diego Creek watershed. Based strictly on second simulation scenario above, the riparian reach segments (mostly engineered or underground presently) rank low in terms of restoration priority. However, based on the potential for these riparian reaches to connect large patches of high quality habitat in the regional parks and national forest in the eastern portion of the watershed with large patches remaining in the San Joaquin Hills, their role and importance in terms of endangered species as well as riparian ecosystem integrity in the San Diego Creek watershed should be considered.

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7.0 Appendix 1: ArcView Theme Metadata

Spatial information collected and utilized during this project are briefly described below. More detailed descriptions of each theme can be found in the metadata files on the data CD accompanying this report. All themes and images in the project file are in a UTM83, Zone 11, meters. The U. S. Army Corps of Engineers – Los Angeles District Regulatory Branch is responsible for distribution of this information.

7.1 Riparian Reach Segment Theme

This theme represents the riparian reach segments that are the basic unit of analysis in this study. The shape files are named “reach segs aa wr 8-18-04.xxx”.

7.2 Local Drainage Theme

This theme represents the local drainages of riparian reaches. The local drainage is the area contributing to tributary, groundwater, and surface flow directly to a riparian reach. The shape files are named “ld aa wr 5-6-04.xxx”.

7.3 Geomorphic Zone Theme

This theme represents the Geomorphic Zone class assigned to each riparian reach segment. The shape files are named “zones 8-18-04.xxx”.

7.4 Restoration Template Theme

This theme represents the Restoration Template class assigned to each riparian reach segment. The shape files are named “templates 8-18-04.xxx”.

7.5 Level of Effort Theme

This theme represents the level of effort class assigned to each riparian reach segment. The shape files are named “loe 8-18-04.xxx”.

7.6 San Diego Creek Watershed Image

This image is an aerial photograph of the San Diego Creek watershed. The image files are named “sdc mosaic.xxx”.

8.0 Appendix 2: Methods for Conducting Baseline Assessment of Riparian Ecosystem Integrity

8.1 Riparian Reach and Associated Areas

Due to the large geographic area covered by the project watershed, inherent variability of riparian ecosystems, and differential nature of historical impacts to riparian ecosystems in the watershed, the selection of an appropriate spatial unit for assessing riparian ecosystem integrity was critical. The assessment unit selected for this project was called the riparian reach (RR), defined as a segment of a mainstem bankfull stream channel and adjacent riparian ecosystem that was relatively homogenous in terms of its geological, geomorphological, edaphic, hydrological, channel morphological, vegetation, and cultural alteration characteristics (Olson and Harris 1997).

In association with each riparian reach several other entities were identified. These included the "local drainage", "mainstem channel", "mainstem tributary channels", and "drainage basin". The local drainage of a riparian reach includes the area from which surface water drains directly to the mainstem channel, or tributaries that enter the mainstem channel, of the riparian reach. The mainstem channel is the primary channel in the local drainage, and mainstem tributaries are stream channels that originate in the local drainage of the riparian reach and flow directly to the mainstem channel.

Figure 20 provides and illustration of the riparian reach, local drainage, mainstem channel, and mainstem tributary channels for riparian reach "BM-05". In Figure 20, the local drainage boundary of BM-05 is shown as a thick brown line, and the local drainage boundary of adjacent riparian reaches is shown as a thin brown line. The mainstem is the thick blue line running through the riparian ecosystem, within the local drainage boundary, and mainstem tributaries are the dotted blue lines within the local drainage boundary. The riparian reach (i.e., the actual unit of assessment) is the green shaded area labeled riparian ecosystem adjacent to the mainstem channel, and within the confines of the local drainage boundary. The drainage basin of a riparian reach includes the local drainage of the riparian reach as well as the local drainage of all upstream riparian reaches. Figure 21 illustrates the local drainage of riparian reach BM-05. This is the dark green stippled area which includes the local

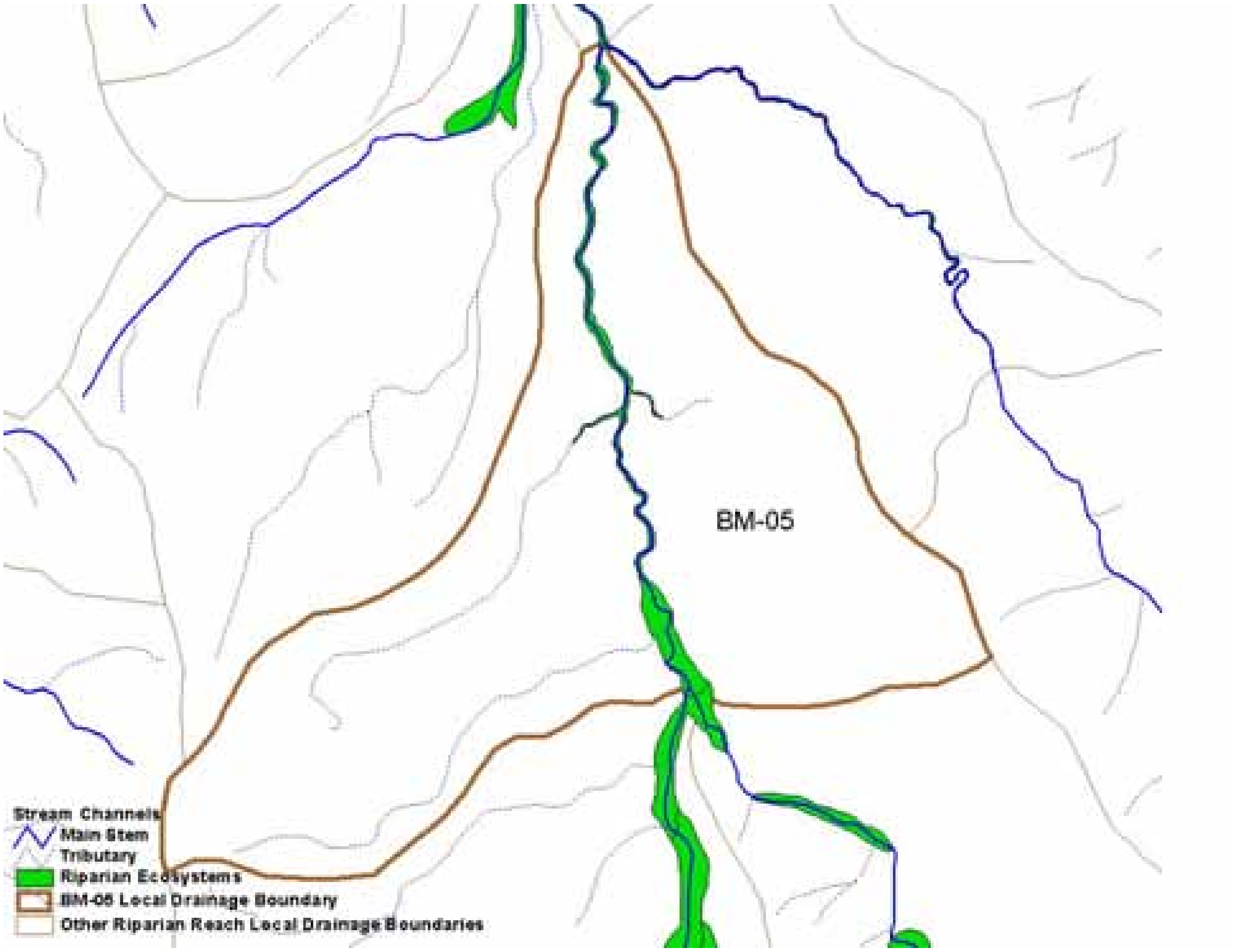

Figure 20. Example riparian reach and its associated local drainage

drainage of BM-05, as well as the local drainage of upstream riparian reaches BM-06 and BM-07. Figure 21 also illustrates the distinction between “headwater” and “non-headwater” riparian reaches. Headwater riparian reaches are those that do not have other riparian reaches upstream, while non-headwater reaches do have other riparian reaches upstream. In Figure 21, BM-06 and BM-07 are headwater riparian reaches, and BM-05 is a non-headwater riparian reach.

Preliminary maps of riparian reach, local drainage, and drainage basin boundaries (see Section 8.1) and mainstem streams in each riparian reach were developed as ArcView themes on basis of initial field reconnaissance, aerial photos, topographic maps (i.e., a digital raster graphic), and the WoUS maps developed by Lichvar (2000).

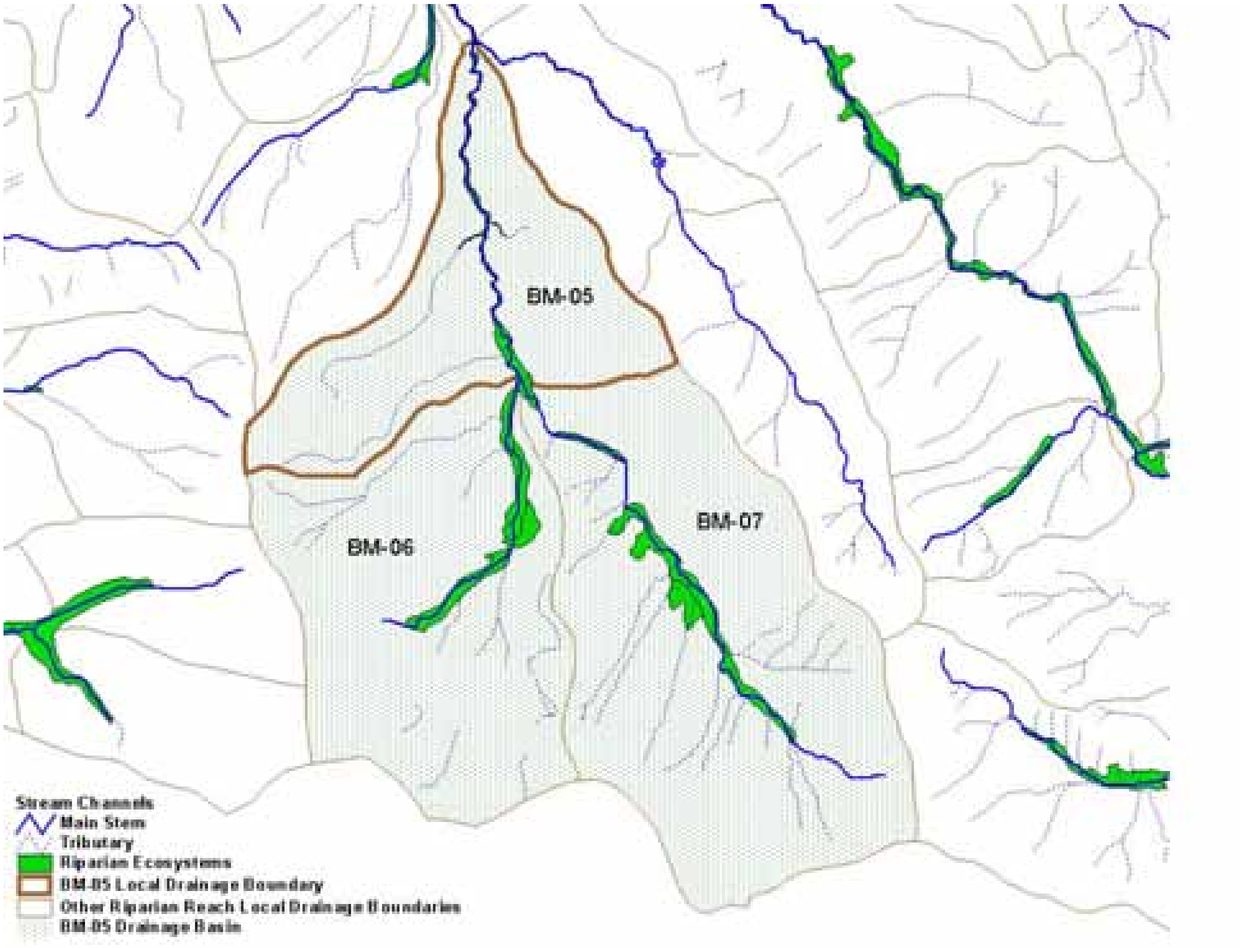

Figure 21. Example riparian reach and its associated local drainage and drainage basin the

Each riparian reach was assigned pneumonic identifier for display and digital manipulation purposes. The local drainage of a riparian reach was combined with the local drainages of all upstream riparian reaches to define the drainage basin boundary of each riparian reach. On non-headwater riparian reaches (i.e., riparian reaches with other riparian reaches upstream) the longitudinal (i.e., upstream / downstream) boundaries of a riparian reach corresponded to changes in stream gradient or channel morphology resulting from geological control (e.g. knick points), tributaries / distributaries, artificial grade control structures, or other features related to cultural alteration. On headwater reaches, the upstream end of mainstem channel of headwater riparian reach always included third order streams (Strahler 1952, 1957) as mapped by Lichvar (2000), and in many cases the upstream end included second order streams. Strahler stream order refers to a stream numbering method in which the smallest, terminal stream segments receive a designation of first order or “1” (Figure 22). A stream segment downstream from the confluence of two first order stream segments receives a designation of second order or “2”. A stream segment downstream from the confluence of two second order stream segments receives a designation of third order or “3”, and so on. In all cases, stream order increases only when two stream segments of equal order join.

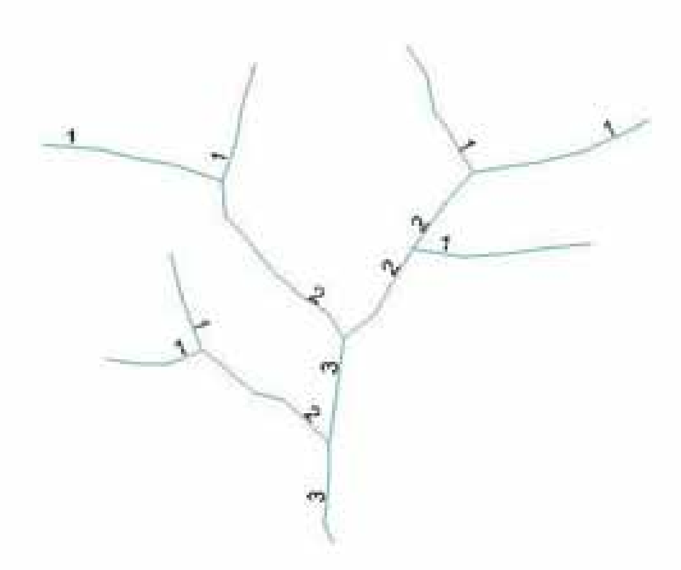

Figure 22. Example of Strahler stream orders

The factors that determined the upstream extent of the riparian reach were stream density, accessibility, and the extent of a riparian vegetation component. Lateral boundaries of riparian reaches corresponded to either an estimate of the 100-year flood elevation contour, the extent of identifiable historic alluvial terraces, or the base of valley wall or artificial structure

8.2 Assessment Indicators

The objective in selecting assessment indicators was to capture, to the greatest degree possible, the full range of characteristics and processes that influence hydrologic, water quality, and habitat integrity of riparian ecosystems at the riparian reach, adjacent upland, and drainage basin scale. Potential indicators were gleaned from a review of existing assessment methods (Dinius 1987; Lee et al. 1997; Ladson et al. 1999). Further investigation of the literature on riparian ecosystems, field observations, and the collective experience of individuals participating in the project provided additional potential indicators.

Several factors influenced the final selection of assessment indicators. First, was the need to match the project objectives of establishing baseline conditions and the ability to make comparisons between riparian ecosystems with available data, time and resources. Other factors included the large project area (>450 km^2), a short time frame and limited budget, the lack of quantitative data at the riparian reach assessment unit scale, and the lack of existing confirmed indicators. Another 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 agencies charged with the protection of sensitive, threatened, and endangered species. Ultimately, a balancing of all these factors led to the selection of the indicators described below.

Each of the indicators selected are defined in the following sections and discussed in terms of the relationship between the indicator and relevant assessment endpoints. In addition, the method used to measure the indicator and assign an indicator value is described, along with the reference condition and range of indicator values used to assign indicator scores. Throughout this section the subscripts following the indicator acronym designates the spatial scale at which the indicator is applied with “RR” indicating the riparian reach, “LD” indicating the local drainage of the riparian reach, and “DB” indicating the drainage basin of the riparian reach.

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

Altered Hydraulic Conveyance indicates the degree to which engineering techniques have been used to “improve” the capacity of channels to convey surface water downstream. The engineering 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. Specific techniques include dredging, straightening, hardening/lining of the stream channel, and the removal of vegetation (Galay 1983, Brookes 1988).

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 headcutting 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.

This indicator was measure as the percent of the mainstem channel through the riparian reach with altered hydraulic conveyance. At the riparian reach and riparian reach tributary scale, aerial photography and field observations were used to estimate the value of the metric. At the drainage basin scale, the indicator was 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:

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

Where: AHC_{RR} = % of mainstem in a riparian reach with altered hydraulic conveyance
ML_{RR} = Length of mainstem channel in a riparian reach
ML_{DB} = Length of mainstem channel of all riparian reaches in drainage basin

The reference condition was defined as <5% of the mainstem channel in riparian reach, or major tributaries to the riparian reach, with altered hydraulic conveyance. Indicator scores were assigned based on range of indicator values in Table 3.

Table 3. Range of indicator values for scaling the altered hydraulic conveyance indicator

Indicator Value Range	Score
<5% of riparian reach mainstem/drainage basin with AHC	5
>5 and <15% of riparian reach mainstem/drainage basin with AHC	4
>15 and <30% of riparian reach mainstem/drainage basin with AHC	3
>30 and <50% of riparian reach mainstem/drainage basin with AHC	2
>50% of riparian reach mainstem/drainage basin with AHC	1

8.2.2 Surface Water Retention (SWR_{DB})

Surface Water Retention indicates 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, and similar surface water storage facilities. Streams in 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 ecosystems have adapted to these episodic cycles of disturbance, and developed a variety of mechanisms that make it possible to survive and indeed flourish where other organisms cannot. Short and long-term retention 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 importantly, 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, change the pattern of seed distribution, germination, and survival, and change a variety of other physical and biological processes necessary to perpetuate the riparian ecosystem (Hynes 1975; Warren 1979; Lotspeich and Platts 1982; Frissell et al.1986; Kondolf et al.1987; Debano and Schmidt 1989; Stromberg and Patton 1991; Johnson 1994; Power et al. 1996; Kershner 1997; Kondolf 1997; Richter et al. 1997).

This indicator was measured as the percent of the drainage basin of a riparian reach upstream of lakes, reservoirs, dry dams, sediment basins, retention ponds, or similar facilities capable of storing surface water from several days to months. The total area within each drainage basin upstream of the downstream extent of all storage facilities was determined using the ArcView GIS themes of riparian reaches, surface water retention facilities, and USGS 7.5 minute topographic map. Using the theme of surface water retention structures and a topographic map as background, the reach theme was split along topographic boundaries at the downstream extent of the retention structures. Upstream areas above these reach segments were calculated and summed across the drainage basin to determine the metric value.

The reference condition was defined as <5% of the drainage basin of a riparian reach upstream of a lake, reservoir, dry dam, sediment basin, retention pond, or similar facility capable of storing surface water from several days to months. Indicator scores were assigned based on the range of indicator values in Table 4.

Table 4. Ranges of indicator values for scaling the surface water retention indicator

Indicator Value Range	Score
<5% of drainage basin drains to surface water storage facilities	5
>5 and <15% of drainage basin drains to surface water storage facilities	4
>15 and <30% of drainage basin drains to surface water storage facilities	3
>30 and <50% of drainage basin drains to surface water storage facilities	2
>50% of drainage basin drains to surface water storage facilities	1

8.2.3 Perennialized Stream Flow (PSF_{RR})

Perennialized Stream Flow indicates the degree to which the hydrologic regime of a riparian reach has been altered by a supplementary supply of surface water resulting from cultural activities such as irrigation. Perennialization refers to the conversion of intermittent or ephemeral stream channels to a perennial stream through the addition of surface water flow (usually at low levels) in a stream channel from artificial supplies of surface water. The supply of water usually occurs in the form of irrigation or treated return water. In arid regions, perennialization facilitates a shift in plant and animal community composition away from what normally occurs in a riparian reach that is not perennialized. Perennialization also has the potential to affect physical and chemical processes in riparian ecosystems.

This indicator was measured as the percent of the mainstem channel through a riparian reach that exhibited perennialized stream flow due to supplementary sources of water at the time of the field visits, or showed evidence of perennialized stream flow (i.e., occurrence of *Typha* sp., *Carex* sp. and/or other emergent aquatic species). Field observations and aerial photographs were used to assign a value to the indicator. The evidence used to identify a stream as perennialized was the presence of low flow during dry periods. Other types of evidence included nutrient enrichment based on the presence of blue-green algae and vascular species such as *Typha* sp., outfall pipes and other inlet structures entering a reach, residential developments and golf courses in the drainage basin, interbasin transfer import points, and the lack of evidence of a natural source of low flow.

The reference condition was defined as <5% of the mainstem channel of a riparian reach with perennialized stream flow. Indicator scores were assigned based on the range of indicator values in Table 5.

Table 5. Range of indicator values for scaling the perennialized stream flow indicator

Indicator Value Range	Score
<5% of stream channel exhibiting perennialized flow	5
>5 and <15% of stream channel exhibiting perennialized flow	4
>15 and <30% of stream channel exhibiting perennialized flow	3
>30 and <50% of stream channel exhibiting perennialized flow	2
>50% of stream channel exhibiting perennialized flow	1

8.2.4 Import, Export, or Diversion of Surface Water (IED_{DB})

Import, Export, or Diversion of Surface Water indicates 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 ground water recharge is common in the arid western United States. The import, export, or diversion of water within and between watersheds has been shown to affect a wide variety 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, Thoms, and Meador 1992)

This indicator was measured as the percent of a riparian reach drainage basin from which surface water was imported, exported, or diverted on a continuous or periodic basis. In the case of imported water, the area of the watershed from which water was being imported was added to the area of the riparian reach drainage basin receiving water prior to calculating the percentage of the drainage basin that contributed to import. Using the ArcView GIS theme of riparian reaches and USGS 7.5 minute topographic map images the area below import, export, or diversion points were calculated and summed across the drainage basin to determine the metric value.

The reference condition was defined as <5% of the drainage basin of a riparian with surface water continuously or occasionally imported, exported, or diverted. Indicator scores were assigned based on the range of indicator values in Table 6.

Table 6. Range of indicator values for scaling the import, export, or diversion of water indicator

Indicator Value Range	Score
<5% of drainage basin with import, export, or diversion of water	5
>5 and <15% of drainage basin with import, export, or diversion of water	4
>15 and <30% of drainage basin with import, export, or diversion of water	3
>30 and <50% of drainage basin with import, export, or diversion of water	2
>50% of drainage basin with import, export, or diversion of water	1

8.2.5 Floodplain Interaction (FI_{RR})

Floodplain Interaction indicates of the degree to which the overbank hydrologic connection between the bankfull channel and the active floodplain and terraces of the riparian ecosystem has been lost in a riparian reach. The lost connection could be a result of levees, channelization, or channel incision. Many of the characteristics and processes of riparian ecosystems are dependent on periodic hydrologic interaction between the stream channel and the floodplain. When the hydrologic connection is lost, the physical and biological characteristics of the riparian ecosystem change, regardless of the reason.

This indicator was measured as the percent of the mainstem channel through a riparian reach that was physically disconnected from the floodplain as a result of culturally accelerated channel erosion/incision, channel improvements, or levees. An incised mainstem channel in which the active floodplain has been reestablished within the incised channel through normal fluvial processes was not considered disconnected (Keller 1972). When one side of the channel was disconnected from the floodplain, 50% of the stream channel was considered disconnected from the floodplain and terraces. When both sides of the channel were disconnected from the floodplain, 100% of the stream channel was considered disconnected. Aerial photography and field observations were used to estimate the value of the metric.

The reference condition was defined as <5% of the mainstem stream channel disconnected from the floodplain. Indicator scores were assigned based on the range of indicator values in Table 7.

Table 7. Range of indicator values for scaling the floodplain interaction indicator

Indicator Value Range	Score
<5% of mainstem stream channel disconnected from the floodplain	5
>5 and <15% of mainstem stream channel disconnected from the floodplain	4
>15 and <30% of mainstem stream channel disconnected from the floodplain	3
>30 and <50% of mainstem stream channel disconnected from the floodplain	2
>50% of mainstem stream channel disconnected from the floodplain	1

8.2.6 Impervious Surface (IMP_{DB})

Impervious surfaces (i.e., roads, rooftops, parking lots) have been shown to be related to increases in surface water runoff and the reduction of the quality of surface water runoff (Klein 1979). Urbanization is the primary cause of increases in the amount of impervious surfaces. Activities that compact or alter the soil surface, porosity, or vegetation cover, reduce the infiltration capacity of the soil and increase the amount of surface water that runs off. Vehicular traffic, grazing, and intensive recreational are the primary causes of reduced soil infiltration. Exposure of the soil to direct raindrop impact by removal of vegetation diminishes the openness of the soil surface and reduces infiltration. 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; Bush and Smith 1995; Rothrock et al. 1998). Heavily grazed areas can reduce infiltration rates by more than half (Berglund et al. 1981).

The effects of impervious and compacted surfaces 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 the altered tract of land (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 LULC and the quantity and quality of surface water has been documented for a variety of wetland and aquatic systems in the United States (Brugham 1978; Ehrenfield 1983; Kuenzler 1986; Howarth et al. 1991; Richards and Host 1994; Cooper 1995; Blair 1996; Wilber et al. 1996; Caruso and Ward 1998).

An index of imperviousness and reduced infiltration capacity was developed to capture the degree to which changes in LULC affect hydrologic and water quality integrity in downstream riparian ecosystems. This indicator was assigned a score by matching existing land use in the local drainage of a riparian reach to the descriptions in Table 8. The reference condition was defined as a LULC of primarily native vegetation.

Table 8. Description of conditions for assigning the Impervious Surface indicator score

Description of Conditions	Score
Land Use Primarily (> 75%) Native Vegetation	5
Land Use Primarily (>75%) Grazing Land / Native Vegetation Mix	4
Land Use Primarily (> 75%) Grazing Lands or Agriculture	3
Land Use Primarily (> 75%) Residential OR Residential / Grazing Land / Agricultural Mix	2
Land Use Primarily (>75%) Industrial OR Commercial OR Industrial / Commercial / Residential Mix	1

8.2.7 Sediment Regime (SR_{RR})

Sediment Regime indicates the degree to which the sediment dynamics in the mainstem channel of a riparian reach are in equilibrium with respect to the supply of sediments from upstream sources and erosion and deposition processes within the channel. A variety of cultural activities can alter sediment dynamics and/or channel geometry. These types of changes include channel erosion due to physical disturbance, channel incision and head-cutting due to the alteration of slope, channel aggregation due structures that impede flow (i.e., weirs, drop structures, culverts), and irrigation diversions (Kondolf et al. 1987).

This indicator was assigned a score by matching field observations to the descriptions in Table 9. The reference condition was defined as exhibiting a sediment regime in equilibrium with respect to supply, erosion, and deposition processes, and not affected by cultural alteration.

8.2.8 Land Use / Land Cover in Drainage Basin ($LULC_{DB}$)

Land use / land cover (LULC) indicates the way in which a tract of land is utilized, has been developed, or the physiognomic class of vegetation. For example, a tract of land that is used to produce row crops is assigned an agricultural LULC, golf courses and parks are assigned to a recreational or open space LULC, urban areas are typically assigned to a residential, industrial, or commercial LULC. Lands supporting natural vegetation communities (i.e., chaparral versus pasture) are assigned to a shrub, forest, or grassland LULC. A variety of LULC classifications have been developed over the years. Today however, the reference to LULC usually implies the USGS classification of LULC (Anderson et al. 1976) or a similar, but more detailed regional variations of this classification. This type of LULC classification is typically developed through the interpretation of aerial photographs or the analysis of other remote sources of thematic information (USGS 1990).

Over the centuries, humans have modified the LULC of the natural landscape through intensive land management practices such as agriculture, forestry, and grazing, as well as through industrialization and urbanization. The net effect of these activities has been a dramatic shift in the type and extent of LULC that occur around the world today, particularly in developed countries (Meyer and Turner 1992; Hannah et al. 1994).

A number of studies have related LULC to water quality. While they have consistently shown that the water quality decreases as natural LULC are culturally altered, they 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 (1988) found that changes in LULC in the surrounding landscape had the greatest effect. The

Table 9. Description of Conditions for assigning sediment regime indicator score

Description of Conditions	Score
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.	5
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 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.	4
Sediment disequilibrium 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.	3
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.	2
Sediment dynamics within most of the reach are seriously disrupted. This includes reaches where there is no significant storage or recruitment of sediment (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, change in slope, channel straightening, or other changes that are likely to cause channel downcutting during future high-flow events.	1

relationship between LULC and quantity and quality of surface water has been documented for a variety of wetland and aquatic systems (Brugham 1978; Ehrenfield 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; Bush and Smith 1995; Rothrock et al. 1998).

Four sub-indicators were used to measure the LULC indicator. Each of the sub-indices were measured as the percent of the drainage basin of a riparian reach with LULC types with the potential to increase the nutrient, pesticide, hydrocarbon, or sediment loading in downstream surface waters. Land use / land cover categories with the potential to increase these categories of pollutants are shown in Table 10. Using the ArcView GIS themes of riparian reach and LULC themes, the area of a drainage basin occupied by each LULC was determined for each sub-indicator. The area of LULC types with the potential to increase pollutants, hydrocarbons, nutrients, and sediment were then summed across the drainage basin and divided by the total drainage basin area to determine the sub-indicator value. The four sub-indicator values were averaged to determine the LULC indicator value.

The reference standard condition was defined as <5% of the watershed and surrounding landscape area with LULC types with the potential to increase nutrient, pesticide, hydrocarbon, or sediment loading in surface waters downstream. Indicator scores were assigned based on the range of indicator values in Table 11.

Table 11. Range of indicator values for scaling the land use / land cover indicator

Indicator Value Range	Score
<5% of watershed / landscape with LULC types that increase N/P/H/S	5
>5 and <15% of watershed / landscape with LULC types that increase N/P/H/S	4
>15 and <30% of watershed / landscape with LULC types that increase N/P/H/S	3
>30 and <50% of watershed / landscape with LULC types that N/P/H/S	2
>50% of watershed / landscape with LULC types that increase N/P/H/S	1

8.2.9 Area of Native Riparian Vegetation (NRV_{RR})

Area of Native Riparian Vegetation indicates the degree to which native riparian vegetation communities occupy the floodprone area of the mainstem channel through a riparian reach. Much has been written about the importance of native riparian vegetation communities in the support of specific faunal groups such as amphibians (Brode and Bury 1984), birds (Hendricks

Table 10. Land Use / Land Cover (LULC) types

LULC Code	LULC Description	Increase in LULC Type Increases Runoff	Increase in LULC Type Increases Nutrient Load	Increase in LULC Type Increases Pesticide Load	Increase in LULC Type Increases Hydrocarbon Load	Increase in LULC Type Increases Sediment Load	Increase in LULC Type Inhibits Animal Use / Movement
11	Residential	Yes	Yes	Yes	Yes	No	Yes
12	Commercial and Services	Yes	Yes	Yes	Yes	No	Yes
13	Industrial	Yes	Yes	Yes	Yes	No	Yes
14	Transportation/Commercial/Utilities	Yes	Yes	Yes	Yes	No	Yes
15	Industrial and Commercial	Yes	Yes	Yes	Yes	No	Yes
16	Mixed Urban and Built-Up	Yes	Yes	Yes	Yes	No	Yes
17	Other Urban or Built-Up	Yes	Yes	Yes	Yes	No	Yes
21	Cropland and Pastureland	Yes	Yes	Yes	No	Yes	Yes
22	Orchards/Vinyards/Nurseries	Yes	Yes	Yes	No	Yes	Yes
23	Confined Feeding Operations	Yes	Yes	No	No	Yes	Yes
24	Other Agricultural Land	Yes	Yes	Yes	No	Yes	Yes
31	Herbaceous Rangeland	Yes	Yes	Yes	No	Yes	Yes
32	Shrub and Brush Rangeland	Yes	Yes	Yes	No	Yes	No
33	Mixed Rangeland	Yes	Yes	Yes	No	Yes	Yes
41	Deciduous Forest Land	No	No	No	No	No	No
42	Evergreen Forest Land	No	No	No	No	No	No
43	Mixed Forest Land	No	No	No	No	No	No
52	Lakes	No	No	No	No	No	No
53	Reservoirs	No	No	No	No	No	No
54	Bays and Estuaries	No	No	No	No	No	No
61	Forested Wetlands	No	No	No	No	No	No
62	Nonforested Wetlands	No	No	No	No	No	No
71	Dry Salt Flats	No	No	No	No	No	No
72	Beaches	No	No	No	No	No	No
73	Sandy Areas (non-Beach)	No	No	No	No	No	No
74	Exposed Rock	No	No	No	No	No	No
75	Strip Mines	Yes	Yes	Yes	Yes	Yes	Yes
76	Transitional Areas	Yes	Yes	Yes	Yes	Yes	Yes

and Rieger 1989), and fauna in general (Hubbard 1977; Faber et al. 1989; Knopf et al. 1988). This indicator was measured as the percent of floodprone area along the mainstem channel of the riparian reach occupied by native riparian vegetation communities. Under culturally unaltered conditions, a complex interaction of many factors such as the size of the watershed, discharge, channel geometry, substrate type, and slope determine the size of the area that typically supports riparian vegetation. In general however, as stream orders increase, the width of the bankfull channel increases, and the size of the area supporting riparian vegetation increases. Floodprone area represents a scaled metric that can be applied consistently in different stream orders throughout a watershed. Floodprone area was determined in the field by projecting the elevation corresponding to two times the maximum depth of the bankfull channel until it intersected the surface of the adjacent floodplain / terrace on both sides of the mainstem channel (Rosgen 1996; 5-20). The percent of floodprone area occupied by native riparian vegetation was estimated based on field observations, aerial photographs, and riparian vegetation communities mapped by Lichvar (2000).

The reference condition was defined as >95% of the floodprone width of the mainstem channel through the riparian reach occupied by native riparian vegetation communities. Indicator scores were assigned based on the range of indicator values in Table 12.

Table 12. Range of indicator values for scaling the native riparian vegetation indicator

Indicator Value Range	Score
>95% of floodplain occupied by riparian vegetation communities	5
<95 and >85 and % of floodplain occupied by riparian vegetation communities	4
<85 and >70 and % of floodplain occupied by riparian vegetation communities	3
<70 and >50 and % of floodplain occupied by riparian vegetation communities	2
<50% of floodplain occupied by riparian vegetation communities	1

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

Riparian Corridor Continuity indicates the degree to which the mainstem 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. 1993; Naiman et al. 1993), but see Simberloff et al. (1992). 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, agriculture activities, and urban/industrial development.

This indicator was measured at the riparian reach scale as the percent of floodprone area along the mainstem 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 - RR indicator, the vegetation corridor could be composed of native or non-native riparian species, whereas for the ANRV indicator, only native riparian vegetation communities were considered. The percent of floodprone area occupied by native riparian vegetation was estimated based on field observations, aerial photographs, and riparian vegetation communities mapped by Lichvar (2000). At the drainage basing 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:

$$\sum_{i=1}^{i_n}\left[RCC_{RR} * \left(ML_{RR} / ML_{DB}\right)\right] \quad (2)$$

Where: RRC_{RR} = % of mainstem in a riparian reach with vegetation corridor gaps
ML_{RR} = Length of mainstem channel in a riparian reach
ML_{DB} = Length of mainstem channel of all riparian reaches in drainage basin

The reference condition was defined as <5% of the floodplain of the mainstem channel of the riparian reach occupied with riparian vegetation communities. Indicator scores were assigned based on the range of indicator values in Table 13.

Table 13. 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

8.2.11 Culturally Altered Land Use / Land Cover at Riparian Reach Boundary (BND_{RR})

Land Use / Land Cover at Riparian Ecosystem Boundary indicates the presence of cultural features at the boundary of the riparian ecosystem that are likely to inhibit the normal movement of fauna between riparian and adjacent upland habitats. Land use / land cover at the boundary of the riparian ecosystem 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; Vought et al. 1994; Osborne and Kovacic 1993). Under natural conditions, riparian vegetation transitions gradually to native upland vegetation at the edge of the riparian ecosystem. A variety of cultural activities replace these native or naturalized vegetation communities with agriculture, urban/industrial, transportation corridors or other types of LULC that reduce the likelihood the animals can move freely between the riparian ecosystem and adjacent uplands.

This indicator was measured using the ArcView GIS themes of riparian reach and LULC. A one-meter wide buffer strip was created at the riparian ecosystem boundary to simulate a boundary condition. The percent of this area occupied by each LULC type was determined, and the LULC types considered to inhibit faunal movement in Table 10 were used to determine the value of the metric.

The reference condition was defined as <5% of the riparian ecosystem boundary composed of LULC types that inhibit faunal movement. Indicator scores were assigned based on the range of indicator values in Table 14.

Table 14. Range of indicator values for scaling the riparian ecosystem boundary indicator

Indicator Value Range	Score
<5% of the riparian boundary inhibits faunal movement	5
>5 and <15% of the riparian boundary inhibits faunal movement	4
>15 and <30% of the riparian boundary inhibits faunal movement	3
>30 and <50% of the riparian boundary inhibits faunal movement	2
>50% of the riparian boundary inhibits faunal movement	1

8.2.12 Culturally Altered Land Use / Land Cover in Upland Buffer (BUF_{RR})

Land Use / Land Cover in Upland Buffer indicates the degree to which the LULC in a buffer zone has been culturally altered. Land Use / Land Cover -Upland Buffer differs from the Land Use / Land Cover - Riparian Reach Boundary indicator in that it is concerned with LULC in the adjacent upland landscape and not just at the boundary of the riparian ecosystem and the adjacent upland. The values of two sub-indicators were summed to provide the value of this indicator. The first sub-indicator measured culturally altered Land Use / Land Cover types that are considered restorable. This includes grazed and agricultural lands that could be relatively easily and inexpensively restored to a natural condition. The second sub-indicator measure culturally altered Land Use / Land Cover types that are considered non-restorable. This includes roads, parking lots, residential developments, commercial developments, and other infrastructure which would be more difficult, costly, and economically impractical to restore.

Land use / land cover in upland areas adjacent to riparian ecosystems are important because of their ability to support the life requirements of a variety of native species. Under reference conditions the upland buffer consists of native vegetation communities. A variety of cultural activities replace these native or naturalized vegetation communities with agriculture, urban/industrial, transportation corridors or other types of land use. Changes in LULC in the buffer also have the potential to affect the rate at which water and sediment moves toward riparian areas from the uplands (Peterjohn and Correll 1984, 1986; Osborne and Kovacic 1993; Barling and Moore 1994).

This indicator was measured using field observation, aerial photographs, and the ArcView GIS themes of riparian reach and LULC themes. A buffer of 100 m width, or until an adjacent 2nd order or higher watershed boundary was encountered, was established around the riparian reach. The percent of the buffer area occupied by each LULC type was determined, and the LULC types considered to inhibit faunal use in Table 9 were used to determine the value of the indicator.

The reference condition was defined as <5% of the upland buffer with LULC types representing cultural alteration. Indicator scores were assigned based on the range of indicator values in Table 15.

Table 15. Range of indicator values for scaling the riparian ecosystem upland buffer indicator

Metric Value Category	Score
<5% of the buffer zone with culturally altered LULC	5
>5 and <15% of the buffer zone with culturally altered LULC	4
>15 and <30% of the buffer zone with culturally altered LULC	3
>30 and <50% of the buffer zone with culturally altered LULC	2
>50% of the buffer zone with culturally altered LULC	1

8.3 Integrity Indices

Integrity indices were developed for each of the hydrologic, water quality, and habitat integrity assessment endpoints. Each of these integrity indices are defined and discussed in terms of the assessment indicators in the following sections.

8.3.1 Hydrologic Integrity Index

Riparian ecosystems with high hydrologic integrity 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 bankfull discharges superimposed on a background of episodic, and often catastrophic, larger magnitude floods that inundate historical terraces (Graf 1979; Graf 1988; Harris 1987; Fisher et al. 1982; Friedman et al. 1996a, Friedman et al. 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, and the second group focused on the factors that influenced the hydrologic interaction between the stream channel, floodplain, and historical terraces. 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 an indirect estimate of deviation from reference condition can be made based on changes in specific characteristic 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 specific drainage basin characteristics, as represented by the indicators, and stream discharge, 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:

- Altered Hydraulic Conveyance (DB)
- Surface Water Retention (DB)
- Import, Export, or Diversion of Surface Water (DB)

A frequency, magnitude, and distribution of stream discharge in a riparian reach 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 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 degree of interaction between the stream channel and the floodplain at the riparian reach and riparian reach tributary spatial scale included:

- Altered Hydraulic Conveyance (RR)
- Perennialized Stream Flow (DB)
- Floodplain Interaction (RR)
- Imperviousness (DB)

These seven indicators were used to calculate the Hydrologic Integrity Index for each riparian reach using the procedure described Section 8.5.

8.3.2 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 ecosystems in the region. Assessing changes in the range of loading in each pollutant category can be determined directly by comparing data on current loading with data on historical loading when such data is available. While there is some historical and recent monitoring data available for a limited number of stations in the watershed, little or no loading data is available at the riparian reach scale. Consequently, the assessment of water quality integrity was 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 focus on whether or not 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 or not the stream channel delivery system had changed in relation to reference condition in terms of frequency, magnitude, and temporal distribution of stream flow (Kuenzler 1977). The third group focused on whether or not 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 condition. A number of studies have shown that cultural alteration of these factors can lead to increased loading in one or more pollutant categories (Osborne and Wiley 1988; Allan and Flecker 1993; Hunsaker and Levine 1995; Perry and Vanderklein 1996; Richards and Host 1994; Allen 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).

One indicator was selected to reflect how the condition of land use in the drainage basin influences water quality integrity. It was:

- Land Use / Land Cover (DB)

This indicator was based on averaging the indicator values for four sub-indicators including:

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

Six indicators were selected to reflect the condition of the stream system that transports pollutants. They are the same indicators used to assess hydrologic integrity, with the exception of Floodplain Interaction, and included:

- Altered Hydraulic Conveyance (RR)
- Altered Hydraulic Conveyance (DB)
- Surface Water Retention (DB)
- Perennialized Stream Flow (DB)
- Import, Export, or Diversion of Surface Water (DB)

Indicators selected to reflect the condition of riparian ecosystem with respect to its ability to physically capture and biogeochemically process pollutants and influence water quality included:

- Floodplain Interaction (RR)
- Sediment Regime (RR)
- Area of Native Riparian Vegetation (RR)

These nine indicators were used to calculate the Water Quality Integrity Index for each riparian reach using the procedure described in Section 8.5.

8.3.3 Habitat Integrity Index

Riparian ecosystems 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 ecosystems in the region. Several 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 ecosystems.

- Area of Native Riparian Vegetation (RR)
- Riparian Corridor Continuity (RR)
- Riparian Corridor Continuity (DB)
- Culturally Altered Land Use / Land Cover at Riparian Reach Boundary (RR)
- Culturally Altered Land Use / Land Cover in Upland Buffer (RR)

This indicator was based on summing the values for the two sub-indicators including:

  - Restorable Culturally Altered Land Use / Land Cover in the Upland Buffer (RR)
  - Non-restorable Culturally Altered Land Use / Land Cover in Upland Buffer (RR)

These five indicators were used to calculate the Habitat Integrity Index for each riparian reach using the procedure described in Section 8.5. Table 16 summarizes the information on which indicators are used in each integrity index.

Table 16. Indictors used for calculation of integrity indices

Indicators	Hydrologic Integrity Index Indicators	Water Quality Integrity Index Indicators	Habitat Integrity Index Indicators
Altered Hydraulic Conveyance (AHC_{RR})	X	X	
Altered Hydraulic Conveyance (AHC_{DB})	X	X	
Surface Water Retention (SWR_{DB})	X	X	
Perennialized Stream Flow (PSF_{DB})	X	X	
Import, Export, or Diversion of Surface Water (IED_{DB})	X	X	
Floodplain Interaction (FI_{RR})	X	X	
Imperviousness (IMP_{DB})	X		
Sediment Regime (SR_{RR})		X	
Land Use / Land Cover ($LULC_{DB}$)		X	
Land Use / Land Cover ($LULC_{DB-N}$)		o	
Land Use / Land Cover ($LULC_{DB-P}$)		o	
Land Use / Land Cover ($LULC_{DB-H}$)		o	
Land Use / Land Cover ($LULC_{DB-S}$)		o	
Area of Native Riparian Vegetation (NRV_{RR})		X	X
Riparian Corridor Continuity (RCC_{RR})			X
Riparian Corridor Continuity (RCC_{DB})			X
Land Use / Land Cover at Boundary (BND_{RR})			X
Altered Land Use / Land Cover in Upland Buffer (BUF_{RR})			X
Restorable Altered Land Use / Land Cover in Upland Buffer (BUF_{RR-R})			o
Non-Restorable Altered Land Use / Land Cover in Upland Buffer (BUF_{RR-NR})			o
Possible Sum of Indicator Scores	35	45	25
X = Indicators o = Subindicator			

8.4 Characterization and Assessment of Riparian Reach Assessment Units

Characterization of riparian reaches was accomplished during a site visit to each reach. Several reaches in roadless areas were not visited due to difficult accessibility and time constraints. For these reaches, the characterization was completed to the extent possible using aerial photographs and topographic maps. Table 17 provides a listing of the information collected as part of riparian reach characterization.

The general strategy during a site visit was to begin at the downstream end of the riparian reach and conduct a walking reconnaissance of the mainstem channel through the riparian reach.

On longer reaches we drove to representative sections of the riparian reach and conduct separate walking reconnaissance. On headwater reaches the walking reconnaissance included at least the lower-third of the mainstem channel of the riparian reach. Time constraints precluded conducting a walking reconnaissance of the entire mainstem channel of headwater reaches in several roadless areas. In these situations, field observations were supplemented with interpretations based on aerial photographs.

After reconnaissance through a riparian reach, a decision was made to either retain the preliminary riparian reach boundaries, or to further divide the riparian reach into two or more riparian reaches. Based on the observations made during reconnaissance, a representative portion of the riparian reach was selected and a riparian reach characterization data sheet was completed. The characterization included notes on the species and location of the dominant or characteristic vegetation in terms of geomorphic features (i.e., bankfull channel, floodplain, terrace), measurement of channel characteristics, general field notes about the nature of the riparian reach, and indicator values for those integrity indicators measured in the field.

Indicators were assessed during the field site visit and using spatial analysis in ArcView. The second column in Table 17 indicates the method by which indicators were assessed. Based on field observation and/or spatial analysis, each indicator was assigned a value representing the percent deviation of the indicator from the reference condition in that reach. For example, if the mainstem of a riparian reach was completely channelized, an indicator value of 100 was assigned to the Altered Hydraulic Conveyance – Riparian Reach indicator. The assignment of values to indicators was based on an assumed, relative, categorical relationship defined between indicators and assessment endpoints. The assumption was that an increase in the deviation from the reference condition represented an equivalent decrease in the level of riparian ecosystem integrity in terms of the specific indicator. For example, in comparing two riparian reaches in terms of the land use / land cover indicator, the riparian reach with the larger percentage of urban land use / land cover in the drainage basin would be assumed to have lower integrity, at least in terms of the contribution of the indicator to endpoint integrity. This approach to scaling indicators to reference condition was possible because of the way indicators were defined (i.e., always measurable as a percent deviation from reference condition), and based on information from published studies, field data and observations, and professional judgment.

Table 17. List of data for characterizing riparian reaches and indicators

Field Description	Method
Riparian Reach ID	Field
Drainage Basin	Field
USGS 7.5 Minute Topograpic Quad	GIS
Mainstem Downstream End Coordinates (UTM)	GIS
Mainstem 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
Mainstem Downstream End Elevation (m)	GIS
Mainstem Upstream End Elevation (m)	GIS
Valley Slope (%) (Estimated From 7.5 Minute Topo)	Calculated
Engineered Channel Type or Rosgen Stream Type	Field
Mainstem Channel Length in (m) (Smith)	GIS
Mainstem Channel Length in DB (m) (Smith)	GIS
Mainstem and Tributary Channel Length in Local Drainage (m) (Lichvar)	GIS
Mainstem and Tributary Channel Length in Drainage Basin (m) (Lichvar)	GIS
Mainstem Channel Length / Mainstem Channel and Tributary Channels Length	Calculated
Drainage Density	Calculated
Channel Slope	Calculated
Sinuosity	Calculated
Bankfull Width (ft)	Field
Bankfull Width (m)	Calculated
Floodprone Width (ft)	Field
Floodprone Width (m)	Calculated
Bankfull Maximum Depth (in)	Field
Bankfull Maximum Depth (cm)	Calculated
Bankfull Mean Depth (in)	Field
Bankfull Mean Depth (cm)	Calculated
Bankfull Cross-Sectional Area (m^2)	Calculated
Width / Depth Ratio	Calculated
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

Table 17 cont. List of data for characterizing riparian reaches and indicators

Field Description	Method
Indicator 1 % of Mainstem Channel of RR with Altered Hydraulic Conveyance	Field
Indicator 2 % of Mainstem Channels of DB with Altered Hydraulic Conveyance	Field/GIS
Indicator 3 % of DB with Surface Water Retention	GIS
Indicator 4 % of Mainstem Channel of RR with Perennialized Stream Flow	Field
Indicator 5 % of Mainstem Channel of DB with Perennialized Stream Flow	GIS
Indicator 6 % of DB with Surface Water Imported, Exported or Diverted	GIS
Indicator 7 % of Floodplain Present and not Isolated from Channel	Field
Indicator 8% Imperviousness	GIS
Indicator 9 Sediment Regime Condition Index of Mainstem Channel in RR	Field
Indicator 10% Land Use / Land Cover in Drainage Basin	GIS
Sub-indicator 10a % of LULC Contributing to Nutrient Increase	GIS
Sub-indicator 10b % of LULC Contributing to Pesticide Increase	GIS
Sub-indicator 10c % of LULC Contributing to Hydrocarbon Increase	GIS
Sub-indicator 10d % of LULC Contributing to a Sediment Increase	GIS
Indicator 11 % of Flood Prone Area of RR with Native Riparian Vegetation	Field/GIS
Indicator 12 % of Flood Prone Area in RR with Riparian Corridor Breaks	Field
Indicator 13 % of Flood Prone Area in DB with Riparian Corridor Breaks	Field/GIS
Indicator 14 % of RR with a Culturally Altered LULC Types at Boundary	Field/GIS
Indicator 15 % of RR Buffer with Culturally Altered LULC Types	Field/GIS
Sub-indicator 16a % of RR Buffer with Restorable LULC Types	Field/GIS
Sub-indicator 16b % of RR Buffer with Non-restorable LULC Types	Field/GIS

8.5 Assigning Indicator Scores and Calculation of Integrity Indices

To calculate integrity indices, indicator values (i.e., percent deviation from reference condition 0-100) were converted to scores. Indicator values were assigned a score of 1-5 based on the relationship between indicator values and scores defined in Tables 3-15. Using the altered hydrologic conveyance indicator as an illustration (see Table 3), if the value of the altered hydrologic conveyance indicator for a riparian reach was <5%, a score of 5 was assigned to that riparian reach. If the value of the altered hydrologic conveyance indicator for a riparian reach was >30% and <50%, a score of 2 was assigned to that riparian reach. A score of 5 represented close concurrence with the reference condition, and consequently a high level of integrity. A score of 1 represented a deviation of 50% or more the reference condition, and consequently a low level of integrity.

Initial category ranges for indicator values were based on the natural groupings of the data collected during the project, and the subjective integration of numerous field observations relating indicator values to endpoint integrity. Testing of other category ranges (i.e., correlation analysis using quartiles and quintiles) showed no significant change in the relationship between riparian reaches in terms of either indicator scores or endpoint indices. Thus, initial category ranges were retained.

Integrity indices were calculated using the following equations.

Hydrologic Integrity =

$$AHC_{RR} + AHC_{DB} + SWR_{DB} + PSF_{DB} + IED_{DB} + FI_{RR} + IMP_{DB}$$

Water Quality Integrity =

$$AHC_{RR} + AHC_{DB} + SWR_{DB} + PSF_{DB} + IED_{DB} + FI_{RR} + LULC_{DB} + SR_{RR} + NRV_{RR}$$

Where: $$LULC_{DB} = \frac{LULC_{DB-N} + LULC_{DB-P} + LULC_{DB-H} + LULC_{DB-S}}{4}$$

Habitat Integrity =

$$NRV_{RR} + RCC_{RR} + RCC_{DB} + BND_{RR} + BUF_{RR}$$