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A Watershed Assessment Tool for Evaluating Ecological Condition, Proposed Impacts, and Restoration Potential at Multiple Scales

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INTRODUCTION: In rapidly developing regions of the United States, planning and regulatory agencies are faced with the difficult task of protecting and enhancing natural resources while accommodating economic development. There is a general consensus among resource management professionals that the most effective way to approach the complex issues involved is to consider them at the watershed level, where the fundamental connection among all components of the landscape is the network of streams that drain the basin (Heathcote 1998, National Research Council 1999, Newbold 2002, Ogg and Keith 2002). The watershed perspective promotes consideration of the linkages among landscape components, such as the effects of land use on stream water quality and discharge, or the potential influence of water diversions or storage on the habitat quality of downstream channels, wetlands, and riparian areas.

The ready availability of desktop Geographic Information Systems (GIS) and a wide variety of spatially explicit resource data make watershed-level analyses feasible for many professionals, but usually only with regard to highly focused tasks such as generating input to hydrologic and habitat models. However, planning and regulatory agencies require tools that address a broad range of watershed-scale issues, and which integrate a wide variety of spatial information to realistically assess complex and interrelated processes. The test of the utility of such a tool is whether it can be used to realistically assess the current condition of the watershed, and also estimate the likely effects of land use changes and restoration activities that may be proposed under various development scenarios.

An assessment approach that meets these criteria, Multi-scale Assessment of Watershed Integrity (MAWI), was developed by the Engineer Research and Development Center (ERDC) for use by the U.S. Army Engineer District, Los Angeles, which is charged with preparing a Special Area Management Plan (SAMP) for five watersheds in three southern California counties. The overall goal of the SAMP is to achieve a balance between aquatic resource protection and economic development. Specific objectives are to complement ongoing habitat conservation planning efforts, allow for a comprehensive approach for management of uplands and aquatic resources, streamline and provide better scientific information for decision-making under the Clean Water Act, Section 404 regulatory process, and reflect the needs of local citizens and provide them a greater level of regulatory predictability (USACE 2004). Because of resource priorities in the region, the southern California version of MAWI was constructed to focus specifically on the integrity and restoration potential of riparian systems, although non-riparian landscape conditions were incorporated into the overall assessment methodology. The following discussion highlights the components and capabilities of that methodology, but the MAWI approach can be adapted for use in watersheds nationwide, and with an equal emphasis on uplands and other non-riparian ecosystem elements. For example, a more broadly focused version of MAWI, currently in the design stage, will be used by the U.S. Army Engineer District, Buffalo, in the Onondaga Creek watershed in upstate New York.

STUDY AREA: The study area encompasses five watersheds in Orange, Riverside, and San Diego Counties ranging in size from 119 mi^2 (San Diego Creek watershed) to 969 mi^2 (San Jacinto River watershed) (Figure 1). The San Diego Creek watershed, which will be used as the primary example throughout this article, is part of the extensive urban corridor that occupies much of the coastal plain in Orange County south of Los Angeles (Figure 2). Land use in the San Diego Creek watershed consists primarily of residential, commercial, and light industrial developments mixed with agricultural operations, grazing land, plant nurseries, military facilities, and transportation. Native plant communities are largely restricted to the steepest hills and mountain slopes, and along some stream corridors.

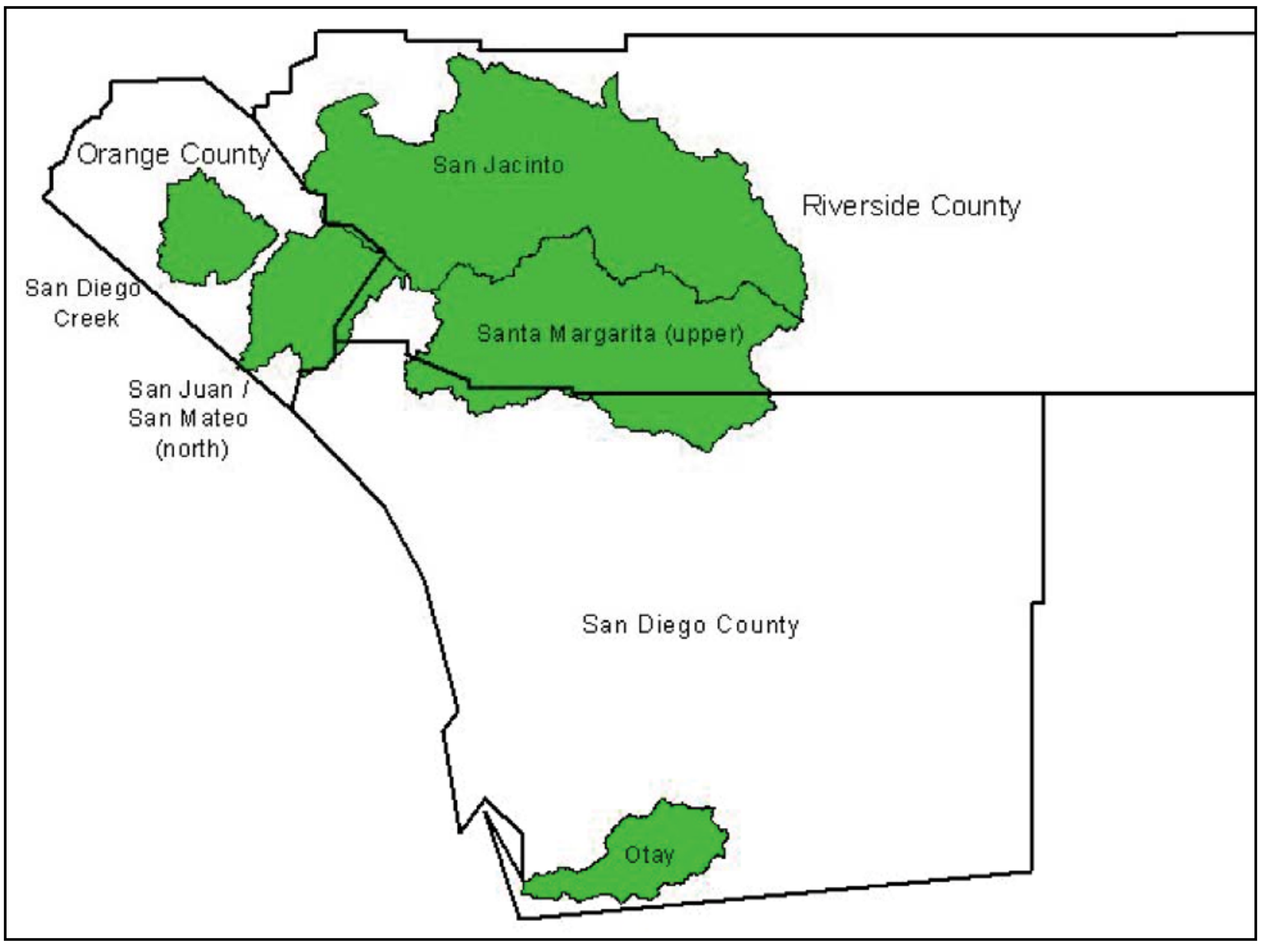

Figure 1. Location of southern California SAMP watersheds

The San Diego Creek watershed is in the California Chaparral Forest and Shrub Ecoregion (Bailey 1995), and has a climatic regime characterized by warm, dry summers and cool, moist winters (Trewartha 1968). Ephemeral and intermittent streams predominate, most of which originate in the Santa Ana Mountains or San Joaquin Hills and drain to Newport Bay. Geologically, the watershed is complex, reflecting crustal compression, faulting, uplift, subsidence, volcanism, and multiple periods of erosion and deposition in both marine and alluvial environments (Morton et al. 1976). Three major geomorphic settings occur and include the Mountains and Coastal Foothills Unit, the Alluvial Deposition Unit, and the Marine Terraces Unit (Wachtell 1978). Vegetation distribution is strongly influenced by topographic and climatic factors. Along the coast, sand dune communities occur near the beaches, and salt marshes are found behind natural beach barrier ridges. Drier areas along the coast support the coastal sage scrub community and nonnative grasslands. Further inland, alluvial valleys support riparian communities, with grasslands, oak woodlands, coastal sage scrub, and chaparral occurring along localized moisture/ elevation gradients.

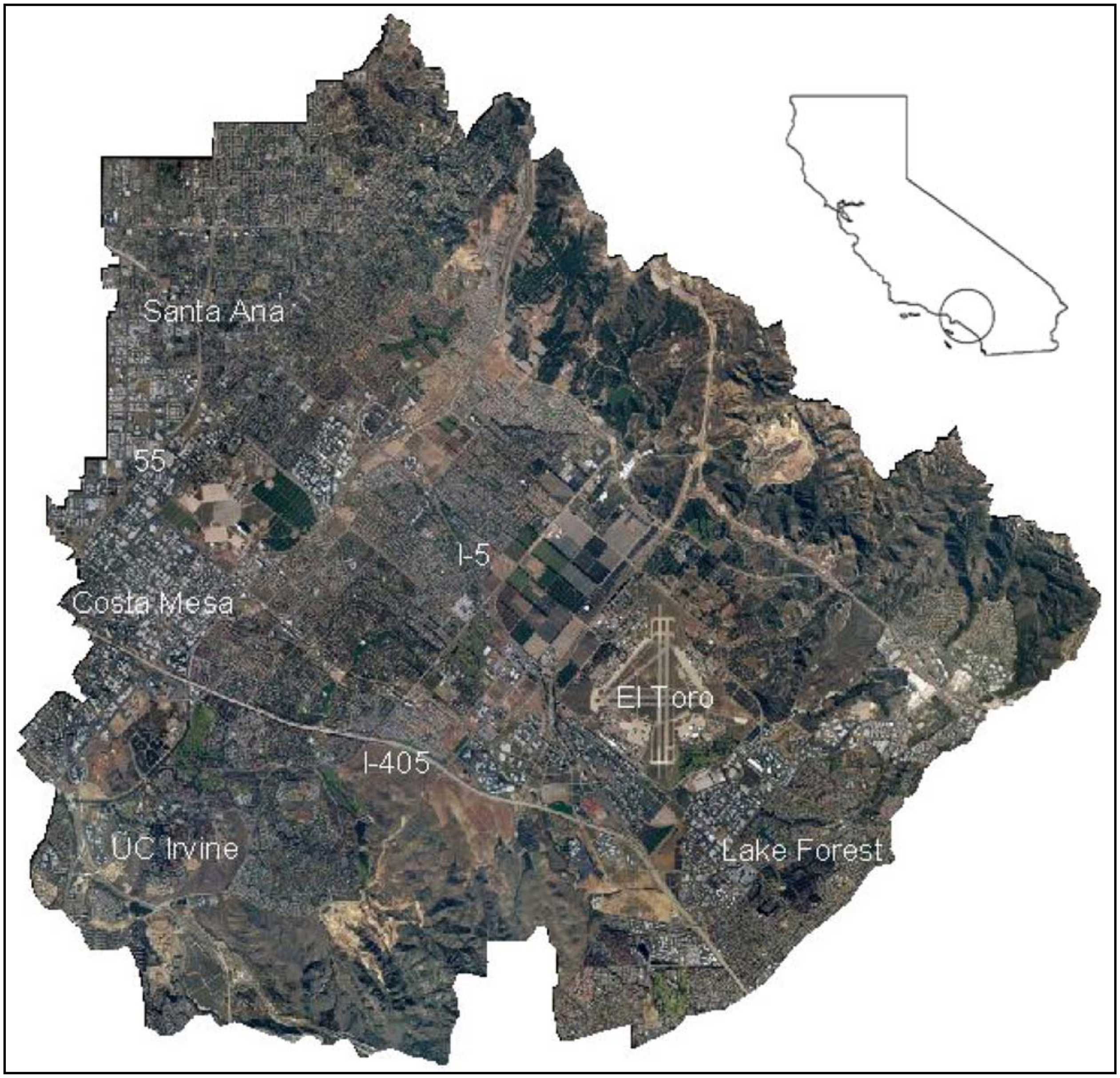

Figure 2. San Diego Creek watershed, Orange County, California

BASELINE ASSESSMENT: Development of the baseline watershed assessment in the San Diego Creek watershed involved three major steps, described below.

Identification and Characterization of Riparian Ecosystem Assessment Units. Riparian areas were defined from a functional perspective to include all of the terrain along and within perennial, intermittent, and ephemeral streams, where the interaction with surface and groundwater produces distinctive geomorphic features and plant communities. Thus, the riparian ecosystem includes the bank-full stream channel, active floodplain, and terraces (i.e., abandoned floodplains) (Figure 3). Within the riparian ecosystem, individual assessment units, called "riparian reaches," were established. Riparian reaches are defined as a segment of stream channel and the adjacent riparian ecosystem with relatively homogenous geology, geomorphology, soils, hydrologic regime, channel morphology, vegetation, and cultural alteration (Olson and Harris 1997).

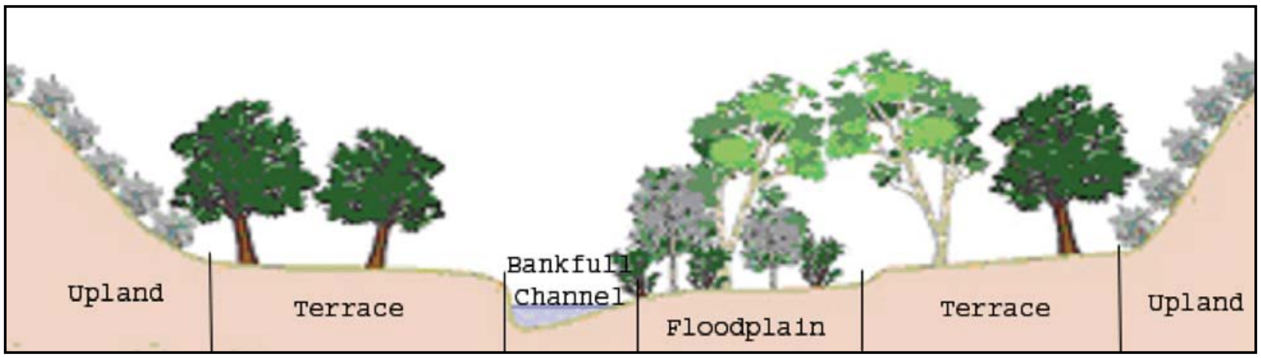

Figure 3. Illustration of riparian ecosystem geomorphic surfaces

For each riparian reach, a main stem channel, main stem tributaries, local drainage area, and drainage basin were identified (Figure 4). The main stem channel was the primary stream channel through the riparian reach. Main stem tributaries were those stream channels within the local drainage of the riparian reach draining directly to the main stem of the riparian reach. The local drainage was the area from which surface water drained directly to the main stem channel or main stem tributaries of a riparian reach. The drainage basin included the local drainage of a riparian reach as well as the local drainages of all upstream riparian reaches.

Riparian reaches were characterized in the field. The general strategy was to begin at the downstream end of the riparian reach and conduct a walking reconnaissance along the main stem channel of the reach. After reconnaissance, a decision was made to either accept the preliminary riparian reach boundaries, or to further divide the riparian reach into multiple riparian reaches. Based on the observations made during the reconnaissance, a representative portion of the riparian reach was selected for collecting characterization and indicator data.

Almost 200 riparian reaches were designated in the San Diego Creek watershed. The area of riparian ecosystem in riparian reaches ranged from 0 to 74 acres with a mean of 5 acres, and the length of the main stem channel in riparian reaches ranged from 463 to 4,935 ft with a mean of 3,708 ft. The size of riparian reach local drainages ranged from 7.4 to 7,243 acres, with a mean of 405 acres, and the size of riparian reach drainage basins ranged from 62 to 78,163 acres, with a mean of 3,175 acres.

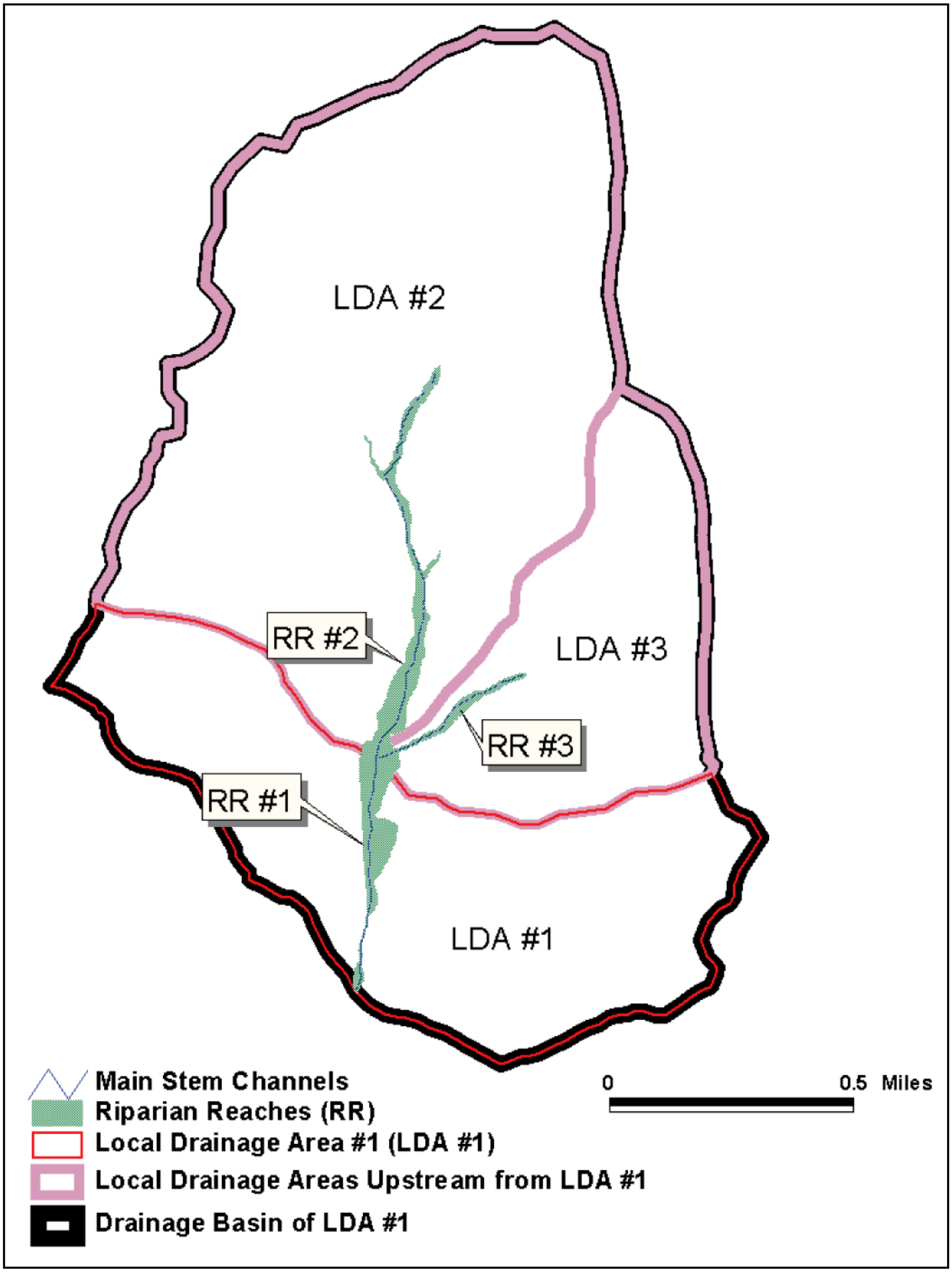

Figure 4. Relationship of riparian reaches, local drainage areas, and drainage basins

Selection of Integrity Indicators. Assessment indicators reflected characteristics and processes that influence the integrity of riparian ecosystems at the riparian reach, local drainage, and drainage basin spatial scale. Potential indicators were gleaned from a review of existing assessment methods (Dinius 1987, Lee et al. 1997, Ladson et al. 1999), riparian ecosystem literature, field observations, and the collective experience of individuals participating in the project. Table 1 lists the indicators and their use in constructing overall indices of hydrologic, water quality, and habitat integrity. Detailed descriptions of indicators, including definitions, metrics, reference conditions and scaling procedures, are presented in Smith (2000, 2004).

Table 1
Indictors Used for Calculation of Integrity Indices

#	Indicators	Hydrologic Integrity Index Indicators	Water Quality Integrity Index Indicators	Habitat Integrity Index Indicators
1	Improved Hydraulic Conveyance - Riparian Reach (IHC_{RR})	X[1]	X[1]	
2	Improved Hydraulic Conveyance - Blue Line Tributaries (IHC_{RRT})	X[1]	X[1]	
3	Improved Hydraulic Conveyance - Drainage Basin (IHC_{DB})	X[1]	X[1]	
4	Perennialized Stream Flow - Riparian Reach (PSF_{RR})	X	X	
5	Perennialized Stream Flow (PSF_{DB})	X[1]	X[1]	
6	Floodplain Interaction (*FI*)	X	X	
7	Surface Water Retention - Riparian Reach (SWR_{RR})	X	X	
8	Surface Water Retention (SWR_{DB})	X[1]	X[1]	
9	Import, Export, or Diversion - Riparian Reach (IED_{RR})	X	X	
10	Import, Export, or Diversion - Drainage Basin (IED_{DB})	X[1]	X[1]	
11	Imperviousness - Local Drainage (IMP_{LD})	X	X	
12	Sediment Regime Index - Riparian Reach (SR_{RR})		X	
13	Exotic Plant Species - Riparian Reach (EXO_{RR})			X
14	Riparian Vegetation Condition - Floodprone Area ($RVCF_{RR}$)		X	X
15	Riparian Vegetation Condition - Terraces ($RVCT_{RR}$)			X
16	Riparian Corridor Continuity - Riparian Reach (RCC_{RR})			X
17	Riparian Corridor Continuity - Drainage Basin (RCC_{DB})			X
18	Riparian Buffer ($BUFF_{RR}$)			X
19	Land Use Land Cover - Nutrients - Drainage Basin ($LULCN_{DB}$)		X	
20	Land Use Land Cover - Pesticides - Drainage Basin ($LULCP_{DB}$)		X	
21	Land Use Land Cover - Hydrocarbons - Drainage Basin ($LULCH_{DB}$)		X	
22	Land Use Land Cover - Sediment - Drainage Basin ($LULCS_{DB}$)		X	
23	Land Use Land Cover - Nutrients - Local Drainage ($LULCN_{LD}$)		X	
24	Land Use Land Cover - Pesticides - Local Drainage ($LULCP_{LD}$)		X	
25	Land Use Land Cover -Hydrocarbons - Local Drainage ($LULCH_{LD}$)		X	
26	Land Use Land Cover - Sediment - Local Drainage ($LULCS_{LD}$)		X	
27	Wildlife Habitat - Local Drainage (WH_{LD})			X

[1] Indicators averaged in the index.

Several factors influenced the selection of indicators. The selected indicators must be applied over large areas, so low cost and rapid application were important criteria. It was also important that the relationship between the indicator and ecological function be clear, because the SAMP process includes participation and input from multiple stakeholders representing a wide range of perspectives and interests. Finally, the selected indicators had to be usable in a predictive mode, meaning that they had to be capable of reflecting changes due to proposed impacts and restoration actions.

Calculation of Integrity Indices. Indicator metric values were determined in the field during the characterization of riparian reaches as a percent deviation from reference condition. For example, for the Improved Hydraulic Conveyance - Riparian Reach indicator, the metric was the percent of the main stem channel within the riparian reach that had been modified (e.g. channelized) to improve hydraulic conveyance. Indicator metric values were subsequently converted to scores ranging from 1-5 based on a defined relationship between indicator metric values and scores. A score of 5 represented close concurrence with the reference condition (i.e., culturally unaltered), and a high level of integrity.

A score of 1 represented a deviation of 50 percent or more from the reference condition, and a low level of integrity. For example, Table 2 shows the relationship between indicator metric values and scores for the improved hydrologic conveyance indicator. If the value of the improved hydrologic conveyance indicator was 5 percent or less, a score of 5 was assigned. If the value of the altered hydrologic conveyance indicator was between 15 and 30 percent, a score of 3 was assigned.

Table 2
Range of Indicator Values for Scaling the Improved Hydraulic Conveyance Indicator

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

Once individual indicators had been scaled, overall integrity indices were calculated using the following equations:

Hydrologic Integrity Index

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

where

IHC_{RR} = Improved Hydraulic Conveyance of main stem in riparian reach
IHC_{RRT} = Improved Hydraulic Conveyance on blue-line tributaries
IHC_{DB} = Improved Hydraulic Conveyance in drainage basin
PSF_{RR} = Perennialized Stream Flow of main stem in riparian reach
PSF_{DB} = Perennialized Stream Flow in drainage basin
SWD_{RR} = Surface Water Detention of main stem in riparian reach
SWD_{DB} = Surface Water Detention in drainage basin
IED_{RR} = Import, Export, or Diversion of surface water of main stem in riparian reach

IED_{DB} = Import, Export, or Diversion of surface water in drainage basin
FI_{RR} = Floodplain Interaction of main stem in riparian reach
IMP_{LD} = Imperviousness of local drainage

Water Quality Integrity Index

$$\begin{aligned}&\left(\left(IHC_{RR}+IHC_{RRT}\right)/2\right)+PSF_{RR}+SWR_{RR}+IED_{RR}+SR_{RR}+RVCF_{RR}\\&\left(\left(IHC_{DB}+PSF_{DB}+SWR_{DB}+IED_{DB}\right)/4\right)+\\&FI_{RR}+IMP_{RR}+\left(\left(LULCN_{DB}+LULCP_{DB}+LULCH_{DB}+LULCS_{DB}\right)/4\right)+\\&\left(\left(LULCN_{LD}+LULCP_{LD}+LULCH_{LD}+LULCS_{LD}\right)/4\right)\end{aligned} \tag{2}$$

where

IHC_{RR} = Improved Hydraulic Conveyance of main stem in riparian reach
IHC_{RRT} = Improved Hydraulic Conveyance on blue-line tributaries
IHC_{DB} = Improved Hydraulic Conveyance in drainage basin
PSF_{RR} = Perennialized Stream Flow of main stem in riparian reach
PSF_{DB} = Perennialized Stream Flow in drainage basin
SWR_{RR} = Surface Water Retention of main stem in riparian reach
SWR_{DB} = Surface Water Retention in drainage basin
IED_{RR} = Import, Export, or Diversion of surface water of main stem in riparian reach
IED_{DB} = Import, Export, or Diversion of surface water in drainage basin
SR_{RR} = Sediment Regime Index
$RVCF_{RR}$ = Riparian Vegetation Condition – Floodprone Area
FI_{RR} = Floodplain Interaction of main stem in riparian reach
IMP_{LD} = Imperviousness of local drainage
$LULCN_{DB}$ = Land Use Land Cover in drainage basin increasing nutrients
$LULCP_{DB}$ = Land Use Land Cover in drainage basin increasing pesticides
$LULCH_{DB}$ = Land Use Land Cover in drainage basin increasing hydrocarbons
$LULCS_{DB}$ = Land Use Land Cover in drainage basin increasing sediments
$LULCN_{LD}$ = Land Use Land Cover in local drainage increasing nutrients
$LULCP_{LD}$ = Land Use Land Cover in local drainage increasing pesticides
$LULCH_{LD}$ = Land Use Land Cover in local drainage increasing hydrocarbons
$LULCS_{LD}$ = Land Use Land Cover in local drainage increasing sediments

Habitat Integrity Index

$$RCC_{RR}+RCC_{DB}+RVCF_{RR}+RVCT_{RR}+EXO_{RR}+WH_{LD}+BUF_{RR} \tag{3}$$

where

RCC_{RR} = Riparian Corridor Connectivity of main stem in riparian reach
RCC_{DB} = Riparian Corridor Connectivity in drainage basin
$RVCF_{RR}$ = Vegetation Condition on floodplain
$RVCT_{RR}$ = Vegetation Condition on terrace
EXO_{RR} = Exotic Species in riparian ecosystem

WH_{LD} = Wildlife Habitat in local drainage
BUF_{RR} = Alterations to 300-ft Buffer

Calculating integrity indices for each riparian reach in the San Diego Creek watershed produced baseline condition assessment scores, representing the current functionality of each local drainage with respect to hydrology, water quality, and wildlife habitat. Figure 5 illustrates the baseline condition with respect to the hydrologic integrity index, where local drainages with the highest scores (approaching 1.0) are mostly in headwater areas, and usually within national forest lands. The lowest scores are found in the most heavily developed areas in the lower and central basin. Note that for each riparian reach, the three calculated integrity indices reflect conditions within the riparian corridor as well as conditions within the local drainage basin, and the hydrologic and water quality indices also reflect conditions in all upstream drainage basins. Therefore, where activities in the upper basin or on the uplands within a local drainage cause degradation of the adjacent riparian reach, that damage is reflected in the integrity indices downstream and in the watershed as a whole. It is this capability to account for offsite and landscape-level disruption of ecosystem patterns and processes that distinguishes true watershed assessment approaches from site-specific impact assessment methods.

IMPACT ASSESSMENT: Once the assessment tool has been structured and calibrated, and the baseline assessment has been conducted, MAWI can be used to evaluate proposed changes to land use or water flow in the watershed. Because the indicators and indices used are spatially explicit, various alternative development scenarios can be screened rapidly, and modifications can be tested for their overall effect on watershed integrity at multiple scales.

Five alternatives were proposed for the San Diego Creek watershed, reflecting various levels of development intensity and related impacts. Because riparian resources in the watershed were mapped as part of this effort, a simple first step for each assessment was to calculate actual losses of area within various resource categories (e.g. wetlands, sensitive species habitats) due to construction footprints. Then, each scenario was assessed for its effects on ecosystem integrity by projecting changes in indicator scores due to project impacts (e.g., changes in land use), calculating "with-project" indices at multiple scales, and comparing those to the baseline condition indices.

Table 3 illustrates how various project alternatives will affect the hydrologic integrity of directly impacted riparian reaches by comparing the number of baseline integrity units of a riparian reach to the number of predicted post-project integrity units of the same reach. Table 3 shows the change in hydrologic integrity units in riparian reaches directly impacted under each alternative.

Figure 6 illustrates how MAWI identified the local drainages that would experience direct impacts under one of the proposed alternatives. It also illustrates how MAWI can identify the local drainages that would experience indirect impacts. The magnitude of the impacts in each area is not reflected in the figure, but that information also was generated for each integrity index and each local drainage.

Because the indices that drive the MAWI analysis are transparent, and the outputs (direct and indirect impacts by functional category) are spatially explicit, this tool has particular utility in identifying the most (and least) damaging aspects of any particular development proposal. For example, the ability to identify indirect impacts to local drainages allows planners to recognize potential threats to critical resources such as endangered species, even where their habitat will not be directly affected by construction or land use changes. Where direct impacts in a particular local drainage are predicted to cause a cascade of indirect impacts through downstream or upstream local drainages, as in Figure 6, the model inputs for the source area can be examined to determine what aspect of the proposed development is triggering the offsite impacts, and appropriate adjustments can be made to the proposal if possible.

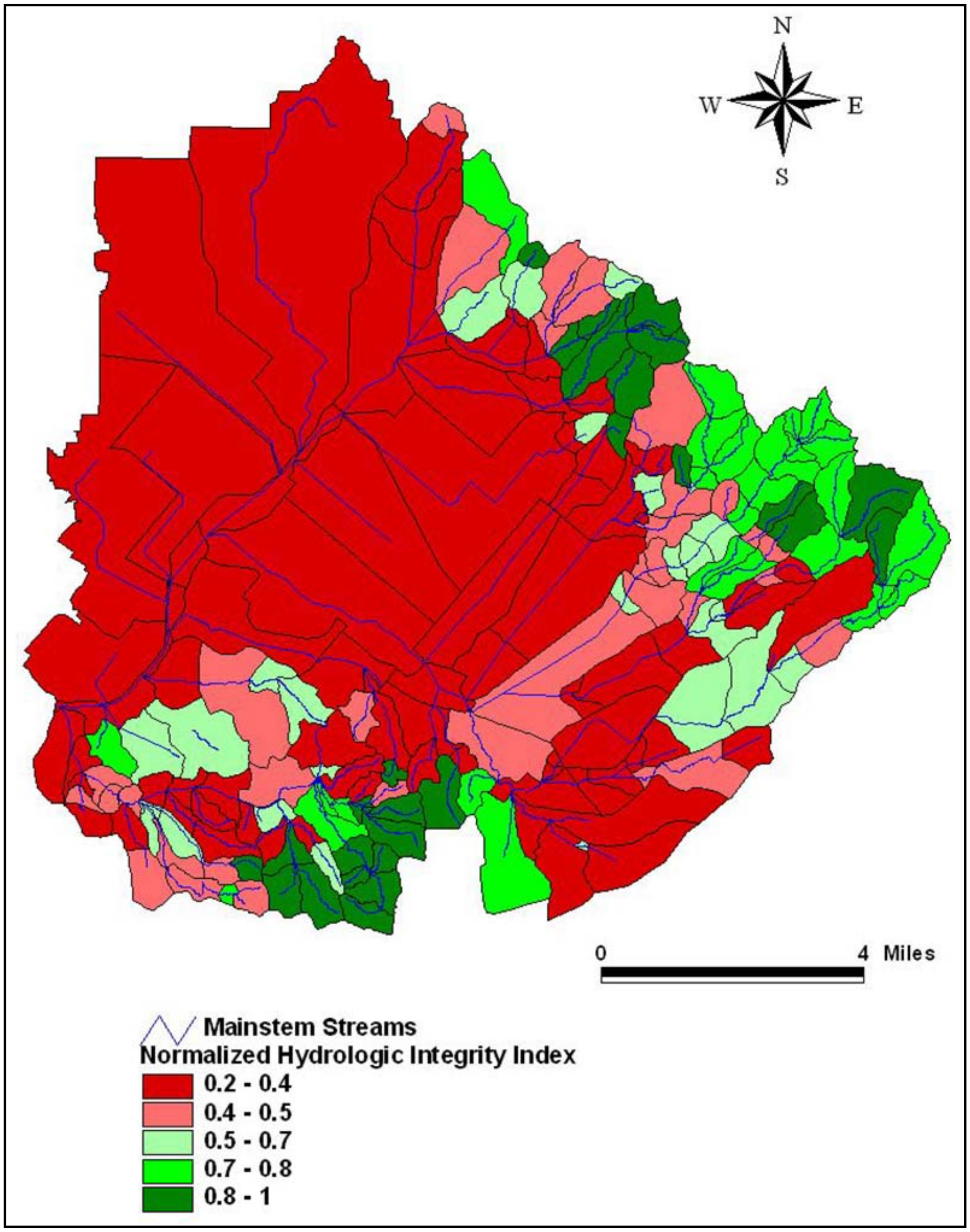

Figure 5. Hydrologic integrity indices (normalized) for riparian reaches in the San Diego Creek Watershed

Table 3
Total Change in Hydrologic Integrity Units in Riparian Reaches and Local Drainages Directly Impacted by Various Project Alternatives

Project Alternatives	Change in Hydrologic Integrity Units (direct impacts only)
2	1.1
3a	3.7
3b	3.5
4	28.3
5	17.7

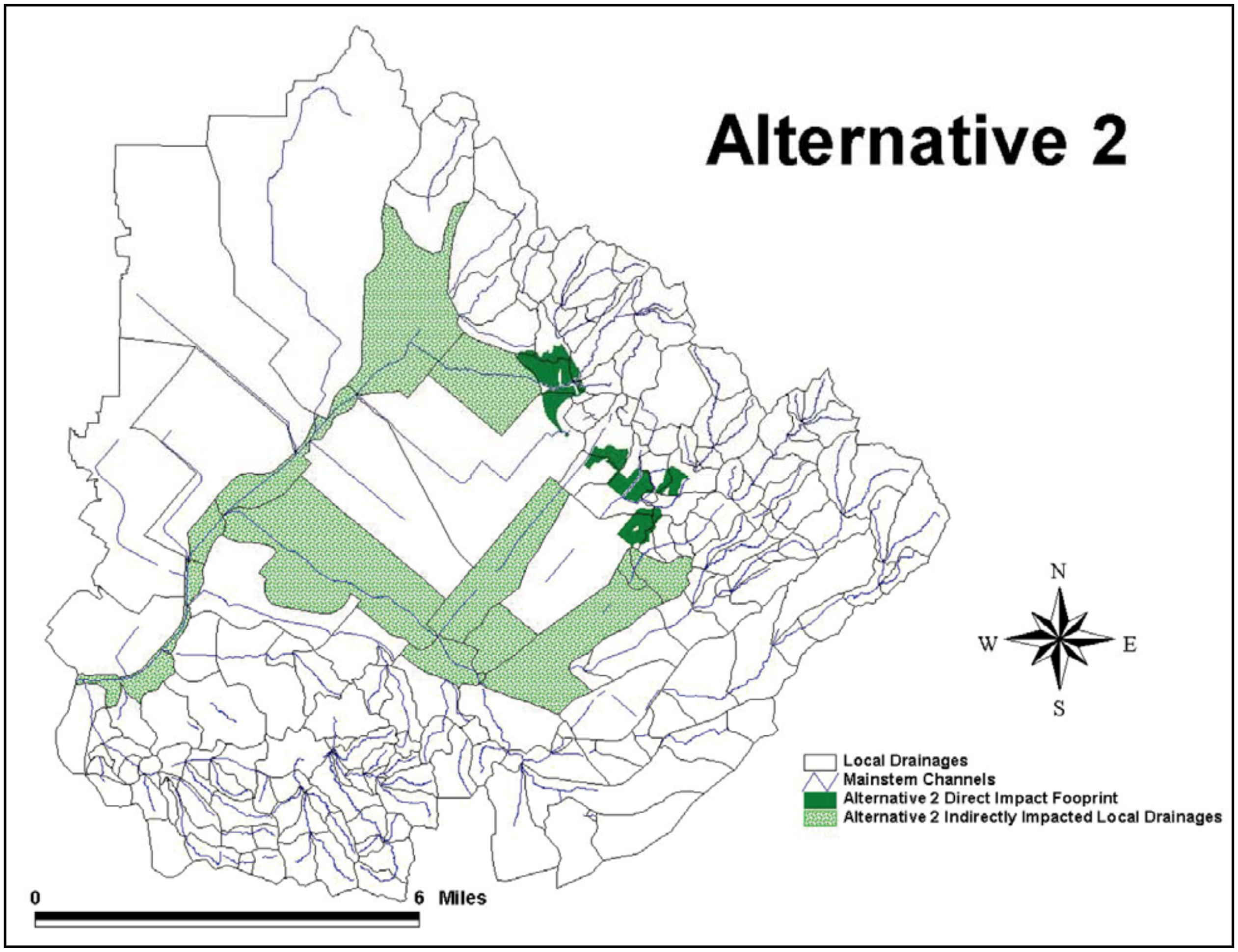

Figure 6. Alternative development scenario direct impact footprint and indirectly impacted local drainages

WATERSHED RESTORATION ASSESSMENT: The baseline assessment allows examination of potential project impacts, as described previously, but it also provides a basis for evaluating various alternative ecosystem restoration scenarios for the watershed. Regardless of whether restoration is proposed to mitigate project impacts, to address critical habitat needs, or to be part of an overall watershed restoration program, MAWI can provide a basis for focusing restoration efforts where they will be most effective and efficient.

In order to use MAWI in a restoration planning mode, it is necessary to first classify the baseline study assessment units (in the case of San Diego Creek, the assessment unit is the riparian reach) in terms of their restoration potential. As the baseline assessment documented, the San Diego Creek watershed includes riparian areas ranging from nearly pristine mountain headwaters to severely incised channels through farmed areas to engineered concrete floodways through urbanized areas. Riparian vegetation condition varies from the full complement of diverse plant communities on floodplains, terraces, and footslopes to narrow strips of one or two species through many farmed or grazed areas to complete loss of vegetation, or replacement of native species with nonnatives through some residential areas. Some of these conditions require no restoration, others can be fully restored through site contouring and planting, while still others can never be fully restored, but can recover some lost functionality through partial restoration. Certain stream reaches, such as those that have been buried as underground storm drains beneath residential areas, cannot reasonably be considered restorable for the foreseeable future.

Once a level of restorability has been assigned to each riparian reach, the effect of the restoration action on the assessment indicators can be estimated, and “post-restoration” integrity indices can be calculated and compared to the baseline assessment. Just as with the “post-project” impact analyses described previously, various restoration scenarios can be tested and examined for their overall effectiveness, both direct and indirect. In addition, where a level of effort can be associated with the restoration potential of each riparian reach, a general indicator of the magnitude of effort can be generated in association with each postulated restoration scenario. This allows planners to consider both cost and effectiveness in choosing alternatives, thereby assembling potential restoration projects that will provide the maximum extent of watershed restoration for the funding available.

In the San Diego Creek watershed, restoration potential was assigned to riparian reaches based on the range of natural conditions appropriate for the geomorphic zone where the reach occurred, the current condition of the reach, expressed in terms of “restoration templates” that reflect the extent to which natural conditions can be reestablished, and the level of effort that would likely be required to accomplish the restoration.

Figure 7 illustrates the geomorphic zones established for the San Diego Creek watershed and Figure 8 shows their distribution within the watershed. Field studies established a general range of physical and plant community characteristics typical of sites in good condition within each zone. For example, Table 4 presents typical terrace and floodplain dimensions associated with the least-disturbed examples of riparian reaches in each geomorphic zone. These types of information, and similar characterizations of plant communities, provide a target for restoration of sites that have been degraded in various ways.

In order to realistically estimate the effect of restoration actions within the watershed, each riparian reach was assigned to one of six templates, which reflect the potential of a given site to be restored to the target (natural) condition. These templates were designated as: 1) natural, 2) incised, 3) constrained, 4) aggraded, 5) engineered, and 6) impractical. Assigning a reach to the natural template (Figure 9) meant that, regardless of its current condition, it was feasible to completely restore the reach to natural conditions. This means that all channel, floodplain, and terrace features as well as vegetation appropriate to the geomorphic zone either were present, or could be reasonably reestablished. A typical example would be a farm field where a small channel had been straightened and deepened, but with some earthwork, a meandering pattern could be recreated and a riparian zone vegetated appropriately. Assigning a reach to any of the other templates implied that the restored site, though improved, would never function at the full level as natural systems in one regard or another, due to limitations on recovery potential. For example, reaches were assigned to the constrained template (Figure 10) where major infrastructure (roads, homes, etc.) was located within the normal range of the riparian zone, and it would be impossible to fully restore the entire historic width of the geomorphic surfaces and native vegetation. Other templates reflect similar limitations on recovery. Figure 11 shows the restoration template assigned to each reach in the watershed. Each reach also was assigned a level of effort score, reflecting the relative magnitude of work required to modify the reach from its existing (baseline) condition to the condition represented by the assigned restoration template.

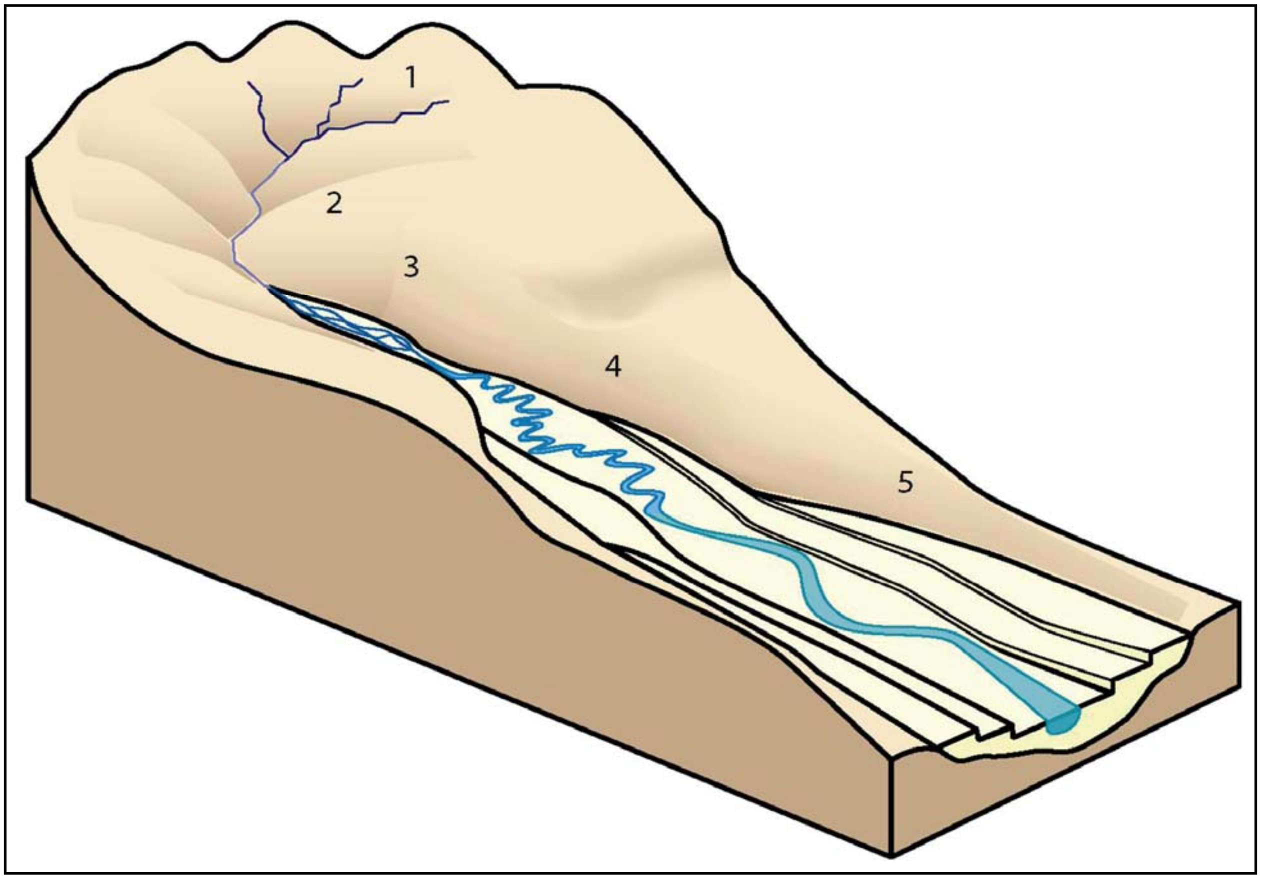

Figure 7. Generalized representation of landscape settings associated with geomorphic zones

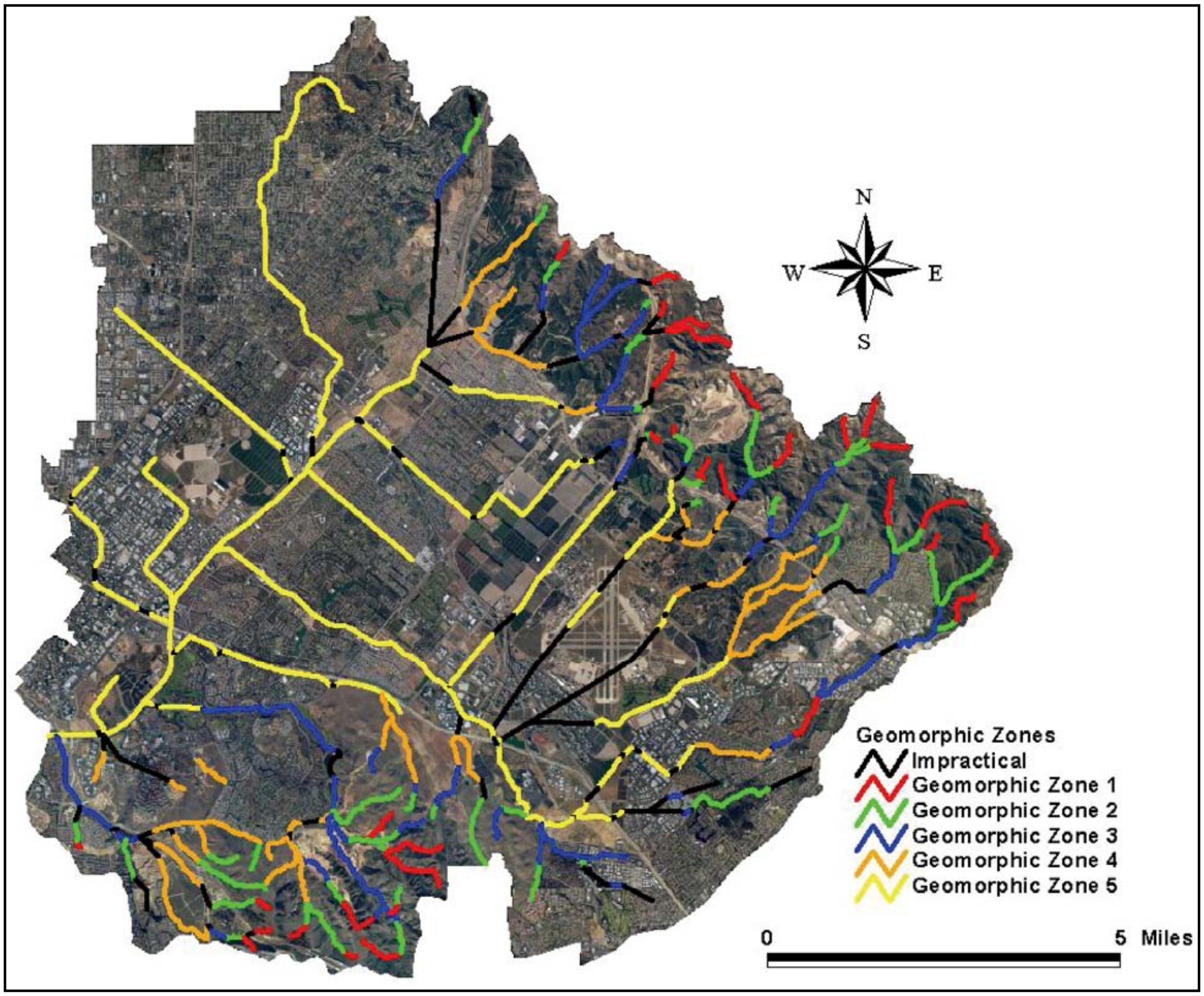

Figure 8. Geomorphic zones for riparian reaches in San Diego Creek watershed

Table 4
General Specifications for Features as Measured in Least-Disturbed Riparian Reaches

Feature	Dimensions	Geomorphic Zone				
		1	2	3	4	5
Bank-full width (ft)	Range	1-3	1-9	2-7	4-18	10-18
	Average	2.5	4.4	4.6	10.7	13.8
Bank-full maximum depth (in)	Range	3-4	2-7	3-7	3-4	6-10
	Average	3.5	3.6	5.3	3.3	8.0
Bank-full mean depth (in)	Range	2-3	1-4	3-4	2-4	4-8
	Average	2.5	4.1	3.5	2.7	5.5
Floodprone width (ft)	Range	2-4	2-8	2-5	6-40	20-25
	Average	3.0	3.1	3.3	18.5	22.3
Terrace 1 width (ft)	Range	NA[1]	0-40	60-150	3-125	50-100
	Average	NA	9.6	105	40.8	80
Terrace 1 height above bank-full (ft)	Range	NA	1-4	1.5-7	1-2	1.5-3.5
	Average	NA	2.2	4.6	1.4	2.6
Terrace 2 width (ft)	Range	NA	0-40	30-80	130-600	25-300
	Average	NA	56.7	55	295	144
Terrace 2 height above bank-full (ft)	Range	NA	3-4	8-11	4-6	4-8
	Average	NA	3.7	9.5	4.5	5.8
Terrace 3 width (ft)	Range	NA	NA	NA	0-350	50-200
	Average	NA	NA	NA	250	125
Terrace 3 height above bank-full (ft)	Range	NA	NA	NA	6-9	7-20
	Average	NA	NA	NA	7.5	14.4

[1] NA = Not applicable.

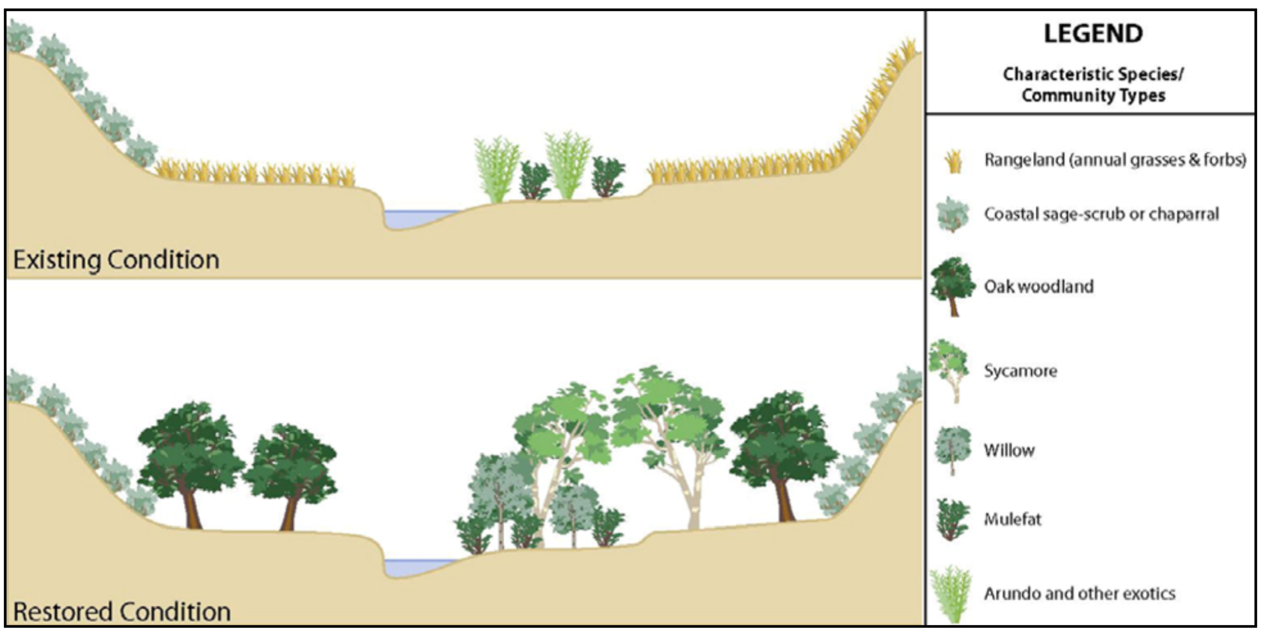

Figure 9. Typical pre- and post-restoration conditions of riparian reaches assigned to the natural template

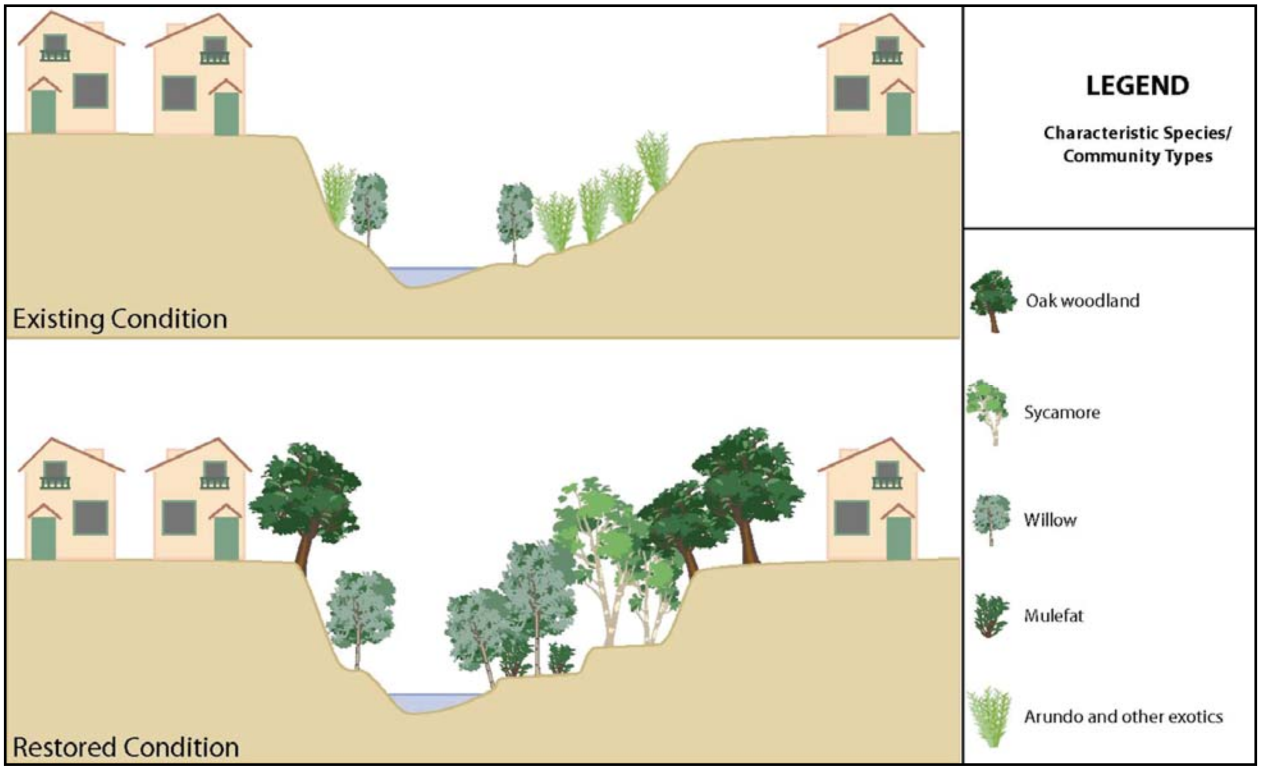

Figure 10. Typical pre- and post-restoration conditions of riparian reaches assigned to the constrained template

Once restoration templates are assigned to each reach, the baseline integrity indices can be recalculated to reflect the functionality of the postulated restored condition. Thus, a reach with a very low baseline integrity index for the habitat function, if restorable to the natural template, is rescored for the post-restoration condition as fully functional for all indicators that are calculated at the local drainage scale. Note that the overall integrity indices may still not be maximized (index = 1.0) if other local drainages in the subbasin or watershed have less than maximum scores, because indicators concerned with offsite conditions, such as corridor continuity, may continue to depress the overall integrity index for the local drainage being restored. If the reach being restored is assigned to a template other than the natural template (such as the constrained template) one or more of its local-drainage-level indicator values will be assumed to be less than maximum in the post-restoration, and the overall integrity indices affected by that indicator also will remain at a level less than the maximum.

Figure 12 shows the increase in the hydrologic integrity index for riparian reaches following simulation of the prescribed restoration templates. In the figure, darker shades indicate a greater increase in hydrologic integrity. Various possibilities are presented by this analysis: restoration can focus on those reaches that will individually experience the greatest degree of change; the focus can be on improving the condition of large numbers of reaches each of which might experience modest levels of improvement; or, subareas within the watershed can be selected for special attention, creating areas where overall hydrologic integrity is maximized along the full length of a major stream network.

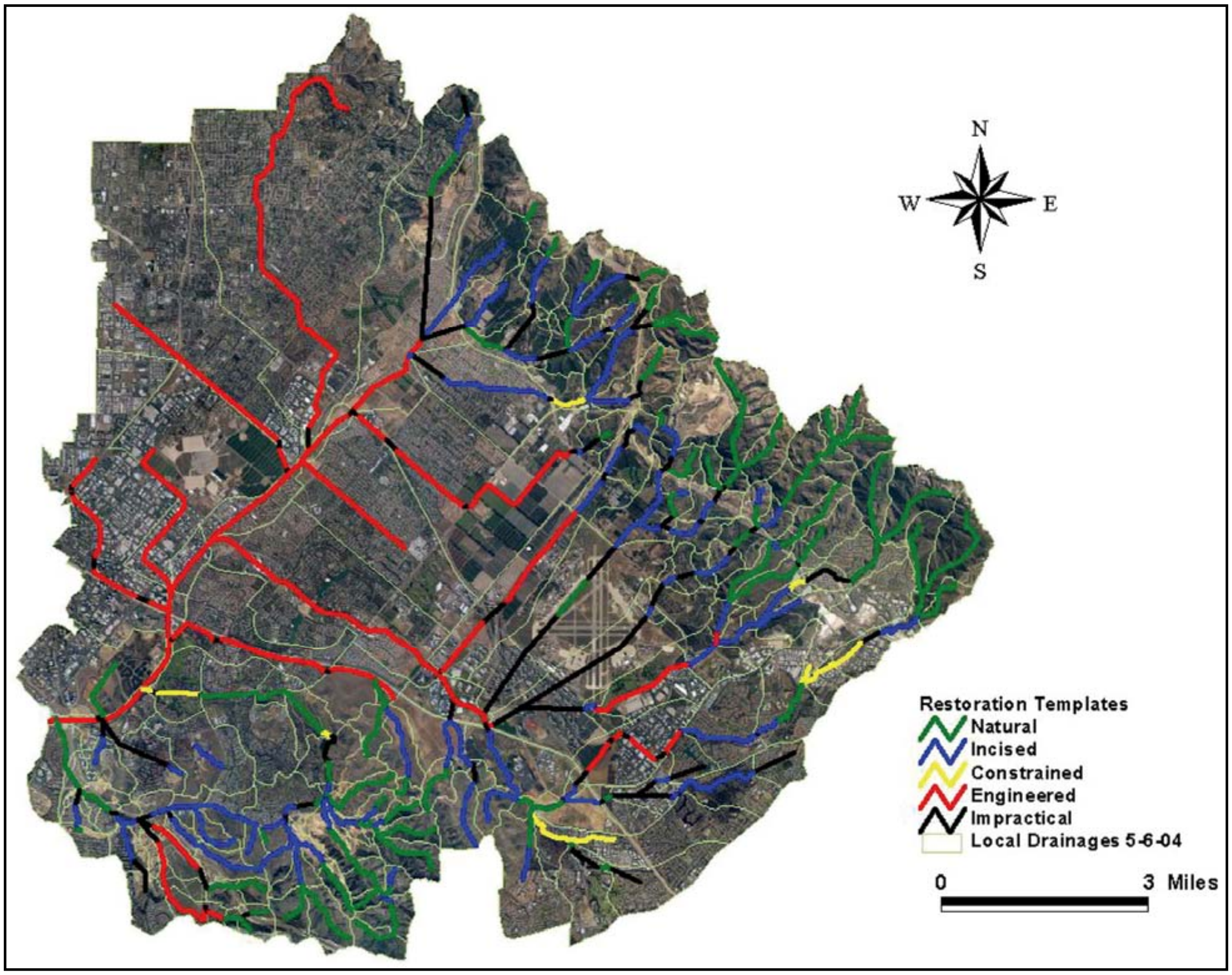

Figure 11. Restoration template assignments for riparian reaches in San Diego Creek watershed

Adding the level-of-effort factor to these analyses further increases the options available for consideration. Figure 13 illustrates the increase in post-restoration hydrologic integrity index divided by the level of effort required to restore each reach, where darker shades indicate a greater increase in hydrologic integrity per unit effort. Comparing these results with Figure 12 shows that when level of effort is considered, a substantially different set of potential restoration opportunities is presented. This analysis allows planners to consider the same types of alternate strategies discussed in the previous example, but with the additional ability to maximize return on investment. Within the context of resource protection and management priorities, restoration decisions can be made that provide the most gain in ecosystem function per dollar spent.

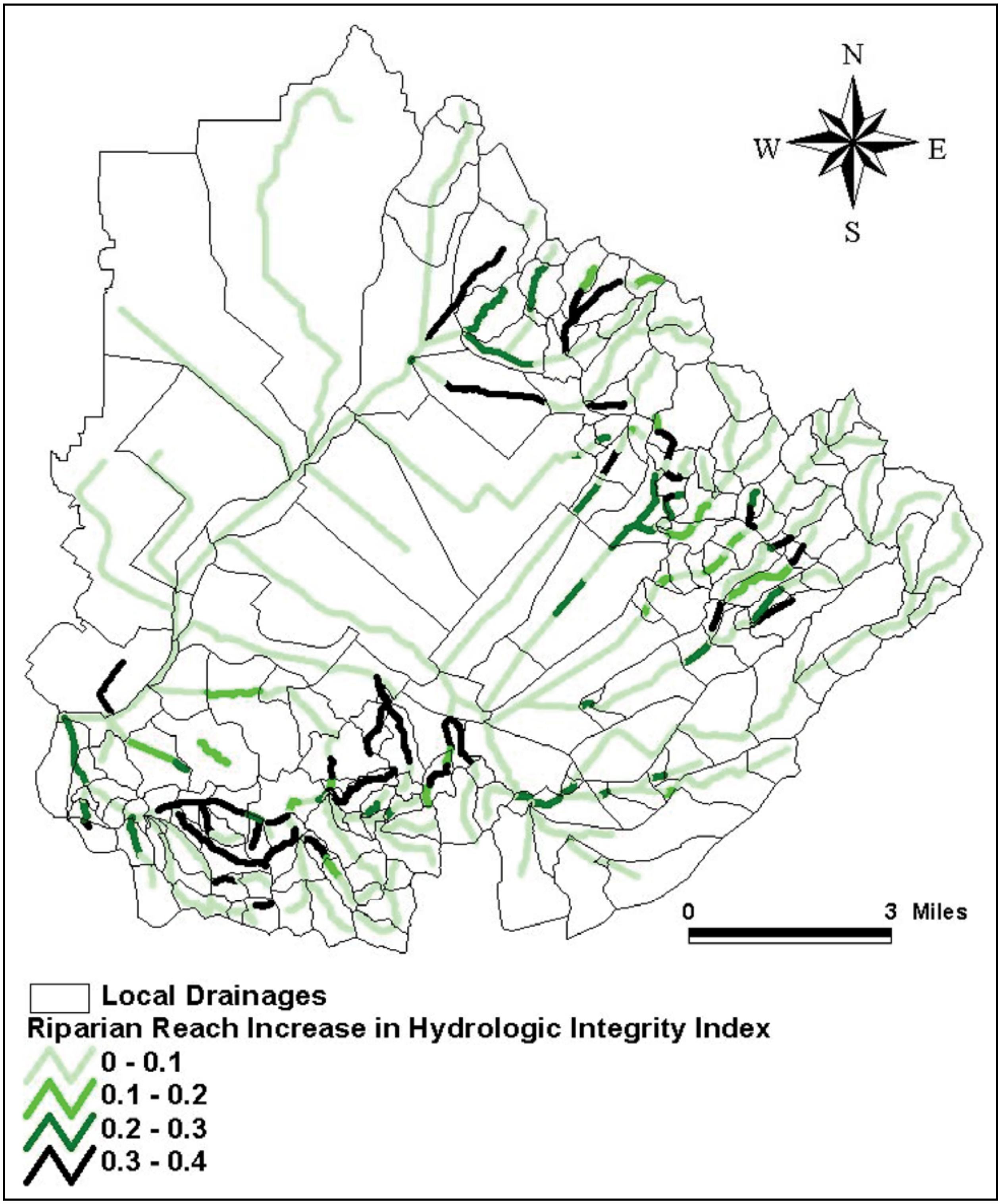

Figure 12. Hydrology index increase following restoration for riparian reaches

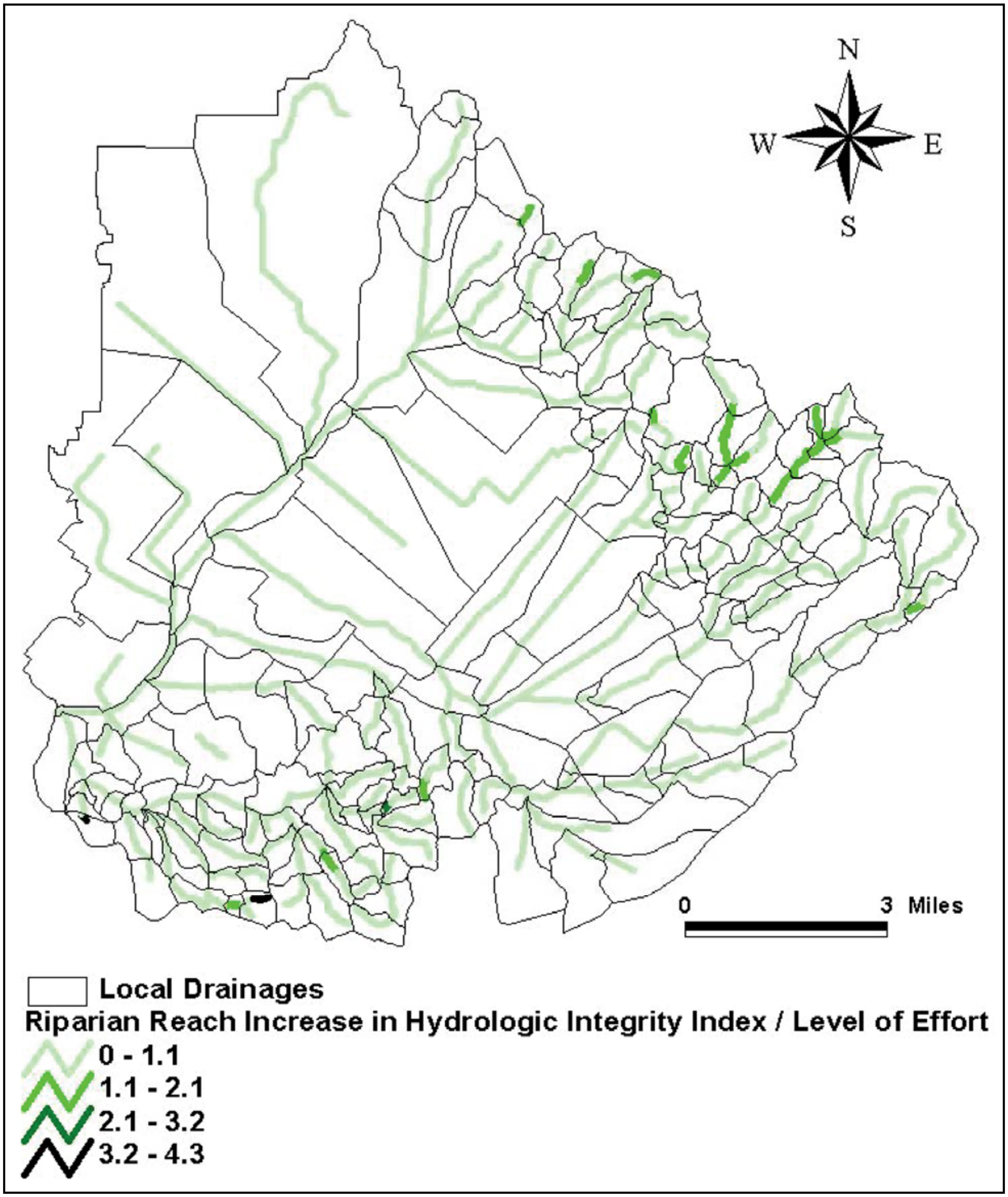

Figure 13. Hydrology index increase divided by level of effort following restoration for riparian reaches

Additional possible applications of MAWI to restoration planning are numerous. One is to maximize restoration efficiency by targeting restoration on local drainages where the greatest offsite effects will be realized. For example, planners can identify critical breaks in wildlife movement corridors, postulate restoration of those critical breaks, and examine the indirect effects on all other local drainages within the subbasin and watershed to see which restoration options most efficiently and effectively restore corridor continuity over long distances and among different habitat types.

The San Diego Creek examples given here focus on restoration of riparian areas, because that was the priority resource category in the southern California watersheds used to develop the technique. However, many of the indicators used included watershed conditions far removed from the riparian zone, such as upland land use, so the MAWI analysis fully reflects watershed-level considerations. Restoration of upland areas could easily be considered in addition to the riparian areas that were the focus of the initial assessment.

SUMMARY: Planners and natural resource professionals often are urged to adopt a watershed perspective when considering the condition of ecosystems, proposed impacts due to development, management options, and restoration opportunities, but few tools exist that can address all of these concerns. The approach described in this technical note is designed to accomplish these objectives and more. By describing baseline conditions at the scale of the local drainage, and using indicators of ecosystem integrity that can be accumulated over multiple scales, the MAWI approach allows consideration of the interactions among components of the watershed. The spatial distribution and linkages among resources and degraded areas are examined in the context of a GIS, and the integrity of ecosystem processes is evaluated using the drainage network as the primary integrating landscape feature. Careful selection of the primary indicators used in the assessment models allows future conditions to be estimated under various development scenarios, including indirect effects on portions of the watershed far removed from the area targeted for modification. Where restoration is a consideration in the planning process, the baseline assessment database can include information needed to assign potential restoration effectiveness and level of effort indices to each local drainage. This allows restoration scenarios to be postulated and tested for their ability to address a wide variety of possible priorities, also at multiple scales, and including consideration of offsite effects and relative costs.

The example application of the MAWI process presented in this paper focuses on riparian ecosystem components of the San Diego Creek watershed in southern California. However, similarly structured tools can be developed for all landscape components of any watershed if the required baseline data are assembled and evaluated appropriately. Much of the required data is available for many areas in digital form, but field studies are required to develop certain specialized indicators and restoration templates. However, once the baseline assessment has been completed, and restoration templates have been assigned to local drainages, the MAWI platform can be used to examine, test, and reformulate a wide variety of proposals from development plans to natural resource management and restoration.

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