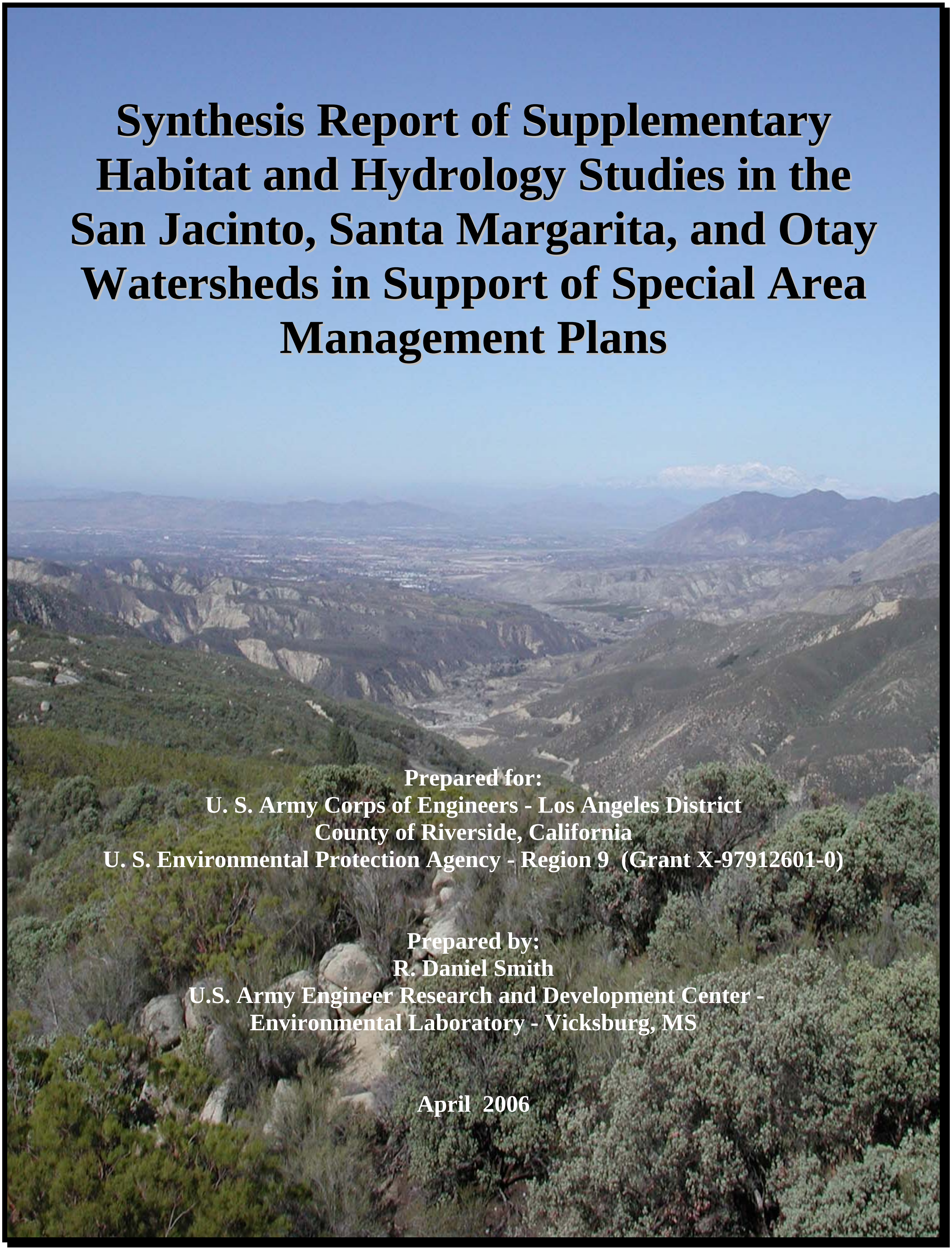
Synthesis Report of Supplementary Habitat and Hydrology Studies in the San Jacinto, Santa Margarita, and Otay Watersheds in Support of Special Area Management Plans



Prepared for:
U. S. Army Corps of Engineers - Los Angeles District
County of Riverside, California
U. S. Environmental Protection Agency - Region 9 (Grant X-97912601-0)

Prepared by:
R. Daniel Smith
U.S. Army Engineer Research and Development Center -
Environmental Laboratory - Vicksburg, MS

April 2006

Executive Summary

The Los Angeles District Corps of Engineers - Regulatory Branch is developing Special Area Management Plans (SAMP) for several watersheds in Orange, western Riverside, and San Diego Counties, California. The objective of a 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."

In support of these SAMP efforts, the Engineer Research and Development Center (ERDC) developed and applied four procedures. The first procedure was designed to identify the location and extent of aquatic resources at the watershed spatial scale. The three remaining procedures dealt specifically with riparian ecosystems, including procedures to: 1) assess baseline ecosystem integrity for riparian ecosystems throughout the watershed; 2) assess potential impacts of future alternative development scenarios on riparian ecosystems throughout the watershed; and 3) develop a restoration plan for riparian ecosystems throughout the watershed.

In addition to developing of these procedures, supplementary habitat and hydrology studies were conducted. These supplementary studies are the synthesized in this report. The objectives of the supplementary habitat studies were to: 1) develop an Index of Biological Integrity (IBI) for riparian ecosystems; 2) contribute information to bird and herptofauna (i.e., reptile and amphibian) databases of the San Jacinto and Santa Margarita watersheds; and 3) test the efficacy of the Habitat Integrity Index (HAII), used to assess baseline riparian ecosystem integrity, by comparing results of the HAII and IBI in the San Jacinto and Santa Margarita watersheds.

An initial IBI was developed based on bird and herptofauna data collected in the San Jacinto watershed. This initial IBI was then tested in the Santa Margarita watershed, and then modified based on data collected in the Santa Margarita watershed. The resulting IBI can be used to assess baseline biological integrity of riparian ecosystem integrity in the San Jacinto and Santa Margarita watersheds, as well as other similar areas in southern California. It can also be used to monitor changes in biological integrity of riparian ecosystem integrity resulting from specific project impacts, or over a longer period of time, to monitor cumulative impacts.

Comparing the results of the IBI to the HAII resulted in the following conclusions. First, based on the relatively high correlation of the IBI and the HAII with the non-metric multidimensional scaling (NMS) first axis ordination scores it appeared that both indices reflect a disturbance gradient of human activity with high index values indicating a low level of disturbance due to human activity. Second, high correlation coefficients between the two IBI and HAII ($r = 0.77$) indicate that even though the two indices were developed independently, and based on a different set of metrics and model formulations, both provided similar results. Third, reformulation of the HAII in various ways did not result in an increase in the correlation coefficient between the IBI and the HAII. Finally, the HAII, like the IBI, can be used to establish a baseline measure of riparian ecosystem integrity, monitor changes in riparian ecosystem integrity as a result of specific impacts, and over a longer period of time, monitor cumulative impacts. The choice of index will depend on the objectives of the end user, and the time and resources available.

Objectives of the supplementary hydrology studies in the San Jacinto, Santa Margarita, and Otay watersheds were to: 1) develop hydrologic models to characterization baseline conditions in the study areas to the extent possible with available hydrologic and water quality data; 2) provide information the could be used in conjunction with more specific applications such as the decision-making processes of the SAMP, and to support municipalities, counties, state and local agencies in activities related to habitat management, flood control, planning, erosion and sediment transport, point and non-point source pollution, Total Maximum Daily Loadings (TMDLs), Best Management Practices (BMPs), as well as other state, local, and federal regulatory compliance programs; and 3) to provide information that could be used to evaluate the hydrologic and water quality integrity indices being used to assess baseline riparian ecosystem integrity.

Two types of hydrologic models were deployed during the supplementary studies including “distributed” models that divide a watershed into a high number of grid cell elements, and a “lumped parameter” model in which the watershed is divided into homogeneous subbasins with average parameters and solution variables defined for each subbasin. In the San Jacinto watershed the distributed model Gridded Surface Subsurface Hydrologic Analysis (GSSHA) was used to model the Perris Valley drainage basin. Simulated hydrologic process included: 1) precipitation distribution, 2) infiltration, 3) 2-D lateral diffusive wave overland flow routing, 4)1-

D longitudinal diffusive wave channel routing, and 5) evapotranspiration. Parameters including soil moisture, channel roughness, soil saturated hydraulic conductivity, hydraulic conductivity of river bed material, and overland surface roughness were calibrated using the shuffled complex evolution (SCE) automated calibration method. Observed peak flows and volumes were compared to the simulated results, and time series flow data were tabulated for each subasin. Model performance was evaluated by the Percent Bias (-0.097) and Nash-Sutcliffe statistics efficiency Scores (0.9). The calibrated GSSHA model was setup, but not determined for a future build out condition representing an increase in urbanization from 38% to 76%.

In the Santa Margarita watershed the distributed model MIKE SHE Flow Modeling System was deployed. The original intent was to apply MIKE SHE to the whole Santa Margarita River watershed areas with the expectation that complete spatial and non-spatial data information necessary as model inputs would be available. When it became apparent that the required stream flow data was not available for the entire watershed, the Murrieta Creek drainage basin was selected for the MIKE SHE flow model evaluation. Available data, including meteorological data, topographical data, soil data, land use data, hydrogeological data, channel network, hydraulic data, and watershed characteristics data were used to establish a pilot MIKE SHE flow model for the Murrieta Creek subasin. Due to a lack of measured data, the model could not be calibrated. The Murrieta Creek drainage basin was discretized into a number of computational cells for the numerical solution of the governing equations, and then divided into polygons based on land use, soil type, and precipitation region. Each component of the model applied a range of input data types and parameters. The parameters were either physically measurable or an empirical specific to the equations solved in the model. The MIKE SHE simulation was controlled by several simulation control parameters including simulation period, the simulation time step, iteration stop criteria, data storage selection, and storage time step. The model was tested for one month, two month, three months, and one year time periods, and a representative sample of model results were presented for a one-year simulation.

Overall, the MIKE SHE modeling system was found to be capable of performing a variety of functions housed in its modular structure. However, the data set for the Santa Margarita watershed was inadequate making it difficult to apply the full MIKE SHE flow modeling system. A number of recommendations for application of the MIKE SHE to modeling watershed hydrology were made.

In the San Jacinto, Santa Margarita, and Otay watersheds the lumped parameter model Hydrologic Simulation Program - Fortran (HSPF) was used. Standard methods of collecting and preparing hydro-meteorological and other physical data were employed. Methods for parameter estimation evolved during the course of the studies. Ultimately, the model independent parameter estimation tool (PEST) was linked with the HSPF hydrologic model. PEST allowed for an assessment of simulation model parameter sensitivities and correlations resulting from the hydrologic simulation model parameter estimation process, and also supported subsequent model predictions. It also provided a credible means to assess the information content of available data and determine the validity of the hydrologic model relative to its structure and specified complexity. The calibrated HSPF hydrologic model calibration was then used to simulate hydrology under a historical, “culturally unaltered” scenario, and calculate Indicators of Hydrologic Alteration (IHA) parameters for both current and culturally unaltered conditions.

The HSPF hydrologic models developed for the San Jacinto, Santa Margarita, and Otay watershed provided an independent standard of comparison for testing the efficacy of the HYII used to assess baseline hydrologic integrity in riparian ecosystem in the SAMP watersheds. The late completion (April 2005) of the GSSHA hydrologic model , and the inability to calibrate the hydrology component of the MIKE SHE model, prohibited use of these results in testing the HYII. Comparison of the HSPF hydrologic models with the HYII resulted in the following conclusions. The HYII index was moderately to poorly correlated with most IHA parameters. This was due to several factors. First, the HYII includes indicators that are unrelated to flow regime and indicators at different spatial scales than the drainage basin scale of IHA parameters. Second, two indicators exhibited little change between pre-impact and post impact conditions and were therefore uncorrelated with IHA parameters that exhibited change due to other factors. Third, one of the indicators was shown to be relatively insensitive to pre-impact versus post-impact condition. As a result the lack of high correlations between HYII and IHA parameters was not unexpected. Conversely, several HYII drainage basin indicators were found to be highly correlated to key IHA parameters that had been found to be the best predictors of flow regime components. Analysis using multiple regression indicated that various linear combination of these indicators were able to predict the value of four out of five of the key IHA parameters with an $R^2 > 0.90$.

This report should be cited as:

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

Contents

Figures

Tables

1.0 Background

The Los Angeles District Corps of Engineers - Regulatory Branch is developing a Special Area Management Plan (SAMP) for several watersheds in Orange, San Diego, and western Riverside Counties, California (Figure 1). The objective of a 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 2000).

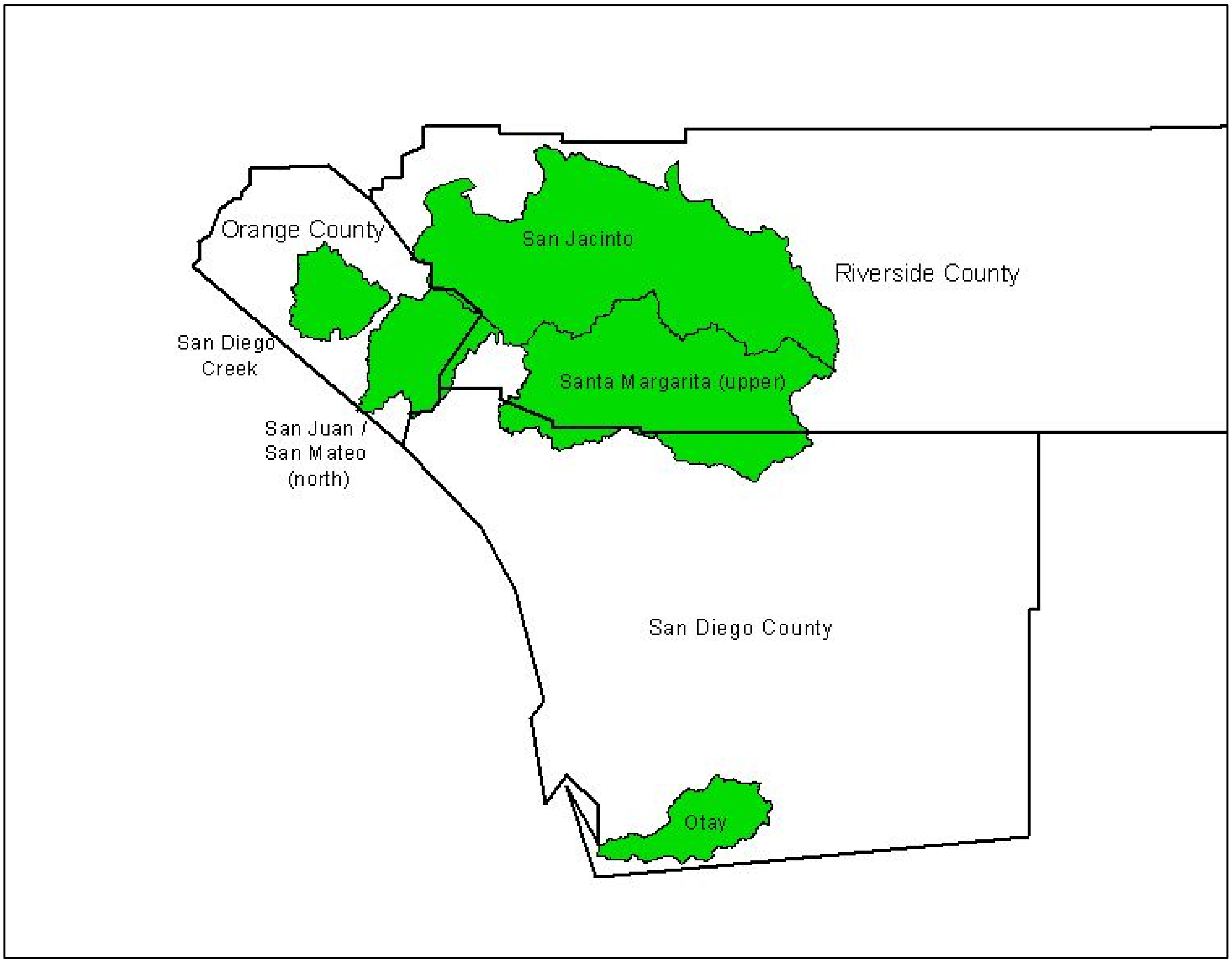


Figure 1. Location of SAMP watersheds

In support of the SAMP in these watersheds, the Engineer Research and Development Center (ERDC) developed and applied four procedures. The first procedure was designed to identify the location and extent of aquatic resources at the watershed spatial scale. The remaining procedures dealt specifically with riparian ecosystems. They included procedures to: 1) assess baseline ecosystem integrity for riparian ecosystems throughout the watershed; 2) assess potential impacts of future alternative development scenarios on riparian ecosystems throughout the watershed; and 3) develop a restoration plan for riparian ecosystems throughout the watershed. The first procedure is briefly described in the Section 1.1. The technical report in Appendix A provides a complete summary of the three procedures dealing specifically with riparian ecosystems. In addition complete descriptions of specific procedures are available in Lichvar et. al. (2003), Smith (2002, 2003, and 2004) and Smith and Klimas (2004 and 2006).

1.1 Identification of Aquatic Resources

The objective of this procedure was to identifying the location and extent of aquatic resources in riparian areas of the watershed. This information was essential for developing the watershed management plan for riparian ecosystems. Aquatic resources were identified using a watershed scale "delineation" procedure developed by Lichvar et al. (2003). The procedure began by mapping the bankfull channel, active floodplain, and terrace geomorphic surfaces in riparian areas as polygons in a geographical information system (GIS). Next, vegetation communities in riparian areas were mapped as polygons in a GIS theme. Finally, a number of polygons were sampled in the field to characterize hydrophytic plant, hydrologic, and soil wetland indicators for each of the geomorphic surface / vegetation community combinations. Based on the results of the characterization, each geomorphic surface / vegetation community combination was assigned a probability rating (i.e., <2%, 2-32%, 33-66%, 67-99%, and 100%) indicating whether or not the geomorphic surface / vegetation community combination met the criteria for a regulated jurisdictional wetland or non-wetland Waters of the United States (WoUS). Polygons assigned a rating of <2% indicated areas never regulated. The ratings of 2-32%, 33-66%, and 67-99% indicated an increasing likelihood of regulation, and a rating of 100% representing areas always regulated. Results were summarized in a map of the watershed showing aquatic resource polygons with associated rating (Figure 2)

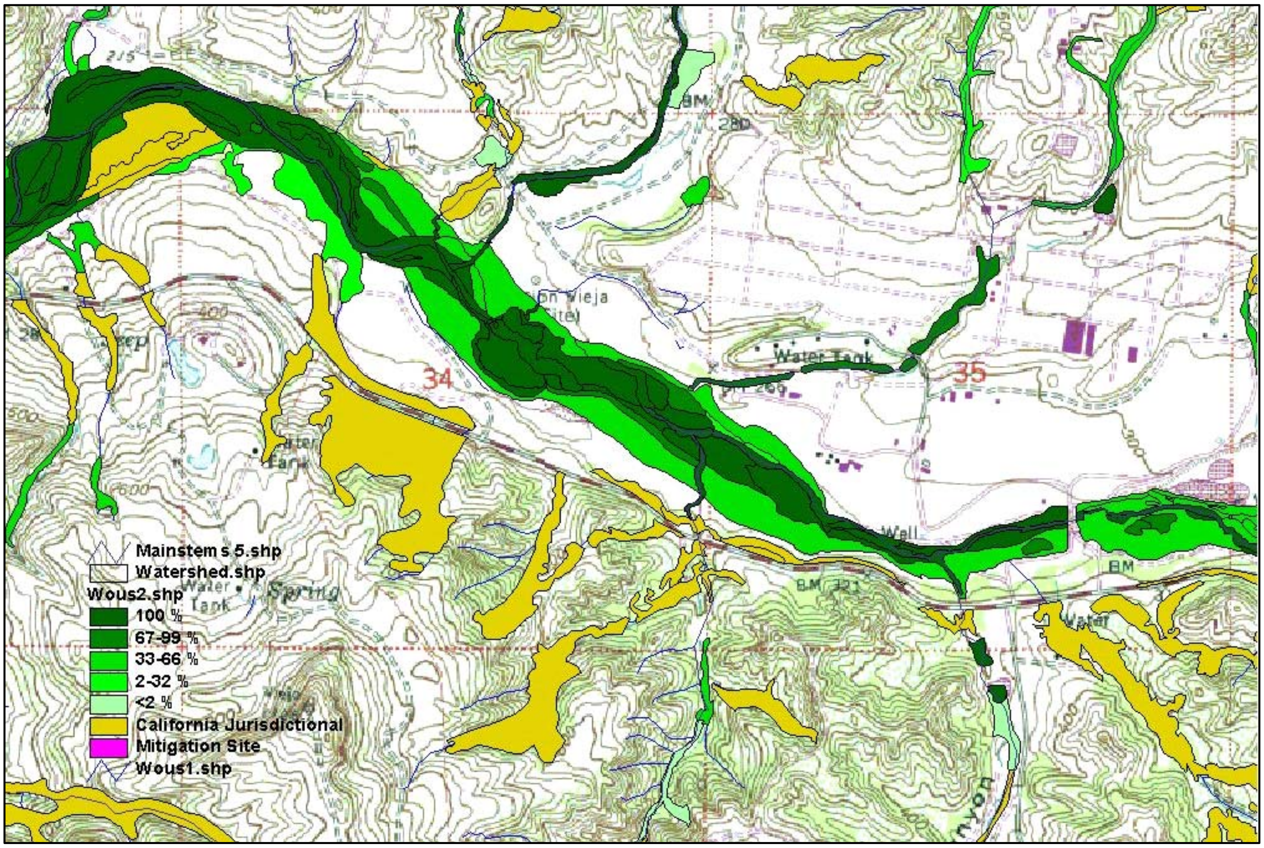


Figure 2. Aquatic resources polygons with associated probability ratings

2.0 Objectives and Context for Supplementary Studies

Supplementary studies were designed to achieve multiple objectives. The first objective was to collect, analyze, and synthesis general information on existing habitat and hydrologic conditions in each watershed. Field sampling conducted during habitat studies was designed to collect basic information on species occurrence and distribution that could be incorporated into bird and herpetofauna (i.e., reptile and amphibian) regional databases. Hydrology studies were designed to collect, analyze and synthesize basic information on stream flow and loadings. The second objective was to provide information that could be used for more specific applications such as the decision-making processes of the SAMP, and to support municipalities, counties, state and local agencies in activities related to habitat management, flood control, planning, erosion and sediment transport, point and non-point source pollution, total maximum daily loadings (TMDL), best management practices (BMP), as well as other state, local, and federal regulatory compliance programs. The third objective was to provide information that could be used to evaluate the habitat, hydrology, and water quality integrity indices being used to conduct baseline assessments of riparian ecosystem integrity (see Appendix A).

Several factors, related primarily to the third objective, dictated the unique spatial approach used during supplementary studies. First, in order to use the results of the habitat and hydrology studies as an independent standard of comparison for the riparian ecosystem integrity indices, it was necessary for supplementary studies to provide results at the spatial scale of the riparian reaches designated during baseline assessments (Smith et al. 2005) This was accomplished by using riparian reaches as the sampling units for habitat studies, and the downstream end of riparian reaches as model result output locations for hydrology modeling. Second, riparian ecosystem integrity indices are scaled to a reference condition designated as "culturally unaltered". It was necessary for supplementary studies to provide results that could be related to the same culturally unaltered used as reference condition by the integrity indices. In supplementary habitat studies this was accomplished by sampling a number of reaches that exist today in relatively unaltered condition, and by reconstructing the composition of unaltered riparian wildlife communities based on historical information and professional judgment. In the supplementary hydrology studies this was accomplished running the calibrated hydrologic models developed for current conditions with culturally unaltered land use and hydrologic conditions (i.e., removal of water storage facilities and water imports and exports). Third, the riparian ecosystem integrity indices employ indicators measured at three spatial scales, the riparian reach, local drainage, and drainage basin. It was desirable for supplementary studies to utilize information from these same spatial scales whenever possible. In supplementary habitat studies this was accomplished by developing a disturbance index based on multiple spatial scales. In the supplementary hydrology studies this was accomplished by the fact that multiple spatial scales are inherent to the hydrologic model algorithms.

3.0 Supplementary Habitat Studies

Specific objectives of supplementary habitat studies were threefold. The first was to: 1) develop an Index of Biological Integrity (IBI) for riparian ecosystems; 2) contribute information to bird and herptofauna (i.e., reptile and amphibian) databases of the San Jacinto and Santa Margarita watersheds; and 3) test the efficacy of the Habitat Integrity Index (HAII), used to assess baseline riparian ecosystem integrity, by comparing results of the HAII and IBI in the San Jacinto and Santa Margarita watersheds.

This section summarizes supplementary habitat studies for the San Jacinto and Santa Margarita watershed. Complete supplementary habitat study reports for these watersheds are available in Wakeley et al. (2003) and Wakeley et al. (2004) respectively. A peer-reviewed journal article describing the work is being prepared (Guilfoyle et al. in prep.)

3.1 San Jacinto Watershed

The primary focus of supplementary habitat studies in the San Jacinto watershed was on development of the IBI for riparian bird and herpetofauna communities. Birds and herptofauna were targeted because they are of considerable public and agency interest and the fate of many species in these groups are closely tied to the integrity of southern California riparian and aquatic ecosystems. Specific steps in developing the IBI included: (1) quantifying the species composition and relative abundance of breeding bird communities through field sampling in randomly selected riparian reaches representing different bioregions in the watershed, (2) evaluation of bird community metrics in relation to human disturbance, (3) compiling historic herpetological records in selected riparian reaches representing different bioregions in the watershed, (4) evaluation of herpetofauna community metrics in relation to human disturbance, (5) integration of relevant bird community and herpetofauna community metrics into an Index of Biological Integrity for riparian ecosystems in the study area.

Field sampling of birds took place during the spring of 2002 and 2003. A total of 102 reaches were sampled in the different bioregions as follows: Lowlands (21), Foothills (29), Mountains (28), and Badlands (24). Following the completion of bird field sampling and compilation of historical records for herpetofauna, the 65 bird and 25 herptofauna metrics were evaluated by calculating the Pearson correlation coefficient between the metric and an index of human disturbance (IHD) for each riparian reach. The disturbance index was calculated as the mean of two percentages: (1) the percentage of land in the local drainage of the riparian reach that was in agricultural, urban, or developed land, and (2) the average percentage of the area within 100-m radius circular plots around each sampling point that was in agricultural or developed land uses according to on-site sampling in July 2002. Therefore, the disturbance index was based on a combination of landscape-scale and immediate streamside land use.

Bird-community and herpetofaunal metrics that were significantly ($P < 0.05$) correlated with the disturbance index were evaluated further by plotting the metric value versus the disturbance index across all reaches sampled in a bioregion or in the entire watershed. These "ecological dose-response curves" reflect measured biological response to the cumulative effects of human use of the landscape (Karr and Chu 1999). Metrics showing strong responses and good separation between relatively undisturbed and highly disturbed reaches were potential components of the IBI. Final selection was made after checking to see that none of the identified metrics was highly correlated ($|r| > 0.80$) with another selected metric.

Dose-response curves for each of the selected metrics were then divided into three intervals and assigned a numeric score of 1, 3, or 5, where a score of 1 indicated a disturbed or impacted condition, a score of 5 indicated a relatively pristine or undisturbed condition, and a score of 3 indicated an intermediate condition. Intervals were based on natural breaks in the dose-response curves. This step was necessary to put all metrics on a common scoring basis despite differences in original metric units (Karr and Chu 1999).

The final combined Bird-Herpetofaunal IBI for the San Jacinto watershed was constructed of seven of the 65 bird metrics evaluated and two of the 25 herpetofaunal metrics evaluated. These included:

Bird Metrics
  Species of concern (% richness)
  Exotic species (% richness)
  Tree/shrub nesters (% abundance)
  Canopy foragers (% abundance)
  Ground foragers (% richness)
  Native cavity nesters (% richness)
  Native species richness

Herpetofauna Metrics
  Omnivores (% richness)
  Insectivores (% richness)

The bird portion of the IBI was based on community-level metrics that reflected the taxon richness, trophic structure, and behavioral diversity of riparian bird communities. Such metrics are likely to be more stable both temporally and geographically than metrics based on indicator species whose populations may vary greatly from year to year (Karr and Chu 1999). Results of the ANOVA checking for differences in the behavior of the IBI across bioregions found no reason to develop separate IBI formulations for different bioregions of the San Jacinto watershed. This is an important advantage for biologists and regulators who need only use a single IBI formula across the entire watershed. However, reaches with significant human impacts were relatively uncommon in the Foothills and Mountains bioregions, making ecological dose-response relationships difficult to assess and contributing to the variability seen in plots of IBI versus reach disturbance scores.

It is possible that the disturbance index failed to capture some kinds of human activity that have measurable impacts on bird communities. The reach disturbance index was based on land-use/land-cover information at two spatial scales including the local drainage of the riparian reach and the area within 100 m of each bird sampling point, and was based on the percentage of the area in agricultural, urban, and developed land uses. In general, low disturbance indices were shown to be associated with high IBI values. However, several Badlands reaches with low disturbance indices also had lower than expected bird IBIs. The reaches that exhibited this anomaly were known to be heavily impacted by off-road vehicles, a form of disturbance not captured in the disturbance index. However, the IBI, which integrates the effects of multiple stressors on biological communities (Karr and Chu 1999), gave each reach an appropriately reduced integrity index.

Overall, results of the study showed that IBI is a useful tool for assessing and monitoring terrestrial ecosystems, just as it has proved to be for aquatic systems (Karr and Chu 1999). Several bird and herpetofaunal metrics were significantly associated with the level of human impact of riparian reaches in the San Jacinto watershed, and the final combined Bird-Herptofauna IBI clearly showed the ability to discriminate between highly impacted and relatively pristine reaches.

The study also showed that further development and use of the riparian IBI can be simplified by focusing solely on birds. Little was gained by adding the two herpetofaunal metrics to the seven metrics derived from bird sampling alone. In general, reaches that had high scores for the herpetofaunal metrics also scored highly for birds. Furthermore, birds are more easily and efficiently sampled and, therefore, are more conducive to real-time monitoring of ecosystem integrity in a rapidly developing landscape. In contrast, a single estimate of herpetofaunal community composition may require multiple sampling techniques and accumulation of data over a period of years (Wakeley et al. 2003 Appendix E), making routine monitoring difficult. Using existing herpetofaunal distribution data for western Riverside County (Beaman et al., in prep.) was problematic due to the lack of consistent sampling effort across reaches. We could not tell whether low herpetofaunal species richness in a particular reach was due to habitat degradation or an inadequate sample. Furthermore, this unusual database is unlikely to be available for other areas where the IBI might be applied or tested. Therefore, an IBI formulation based on birds alone is more likely to be transferable to other watersheds or other regions.

Although as yet untested, the bird-based IBI developed in this study may be useful immediately to assess the biological integrity of other riparian reaches in the San Jacinto watershed or in similar habitats in nearby watersheds. Investigators should follow the same sampling procedures used to develop the IBI. Experienced birders able to identify all species by sound or sight are essential. In each reach, the investigator should establish four sampling points spaced at 250-m intervals along the stream, beginning approximately 125 m from the downstream end of the reach, and sample all points using 5-minute, unlimited-distance point counts, twice during the spring and early summer. Bird metrics then can be calculated from the field data, scored as shown in this report, and summed to estimate the final IBI for that riparian reach.

3.2 Santa Margarita Watershed

To a large extent, the objectives and methods used to develop the IBI in the San Jacinto watershed were also used in the Santa Margarita watershed with a few exceptions. An additional objective in the Santa Margarita was to test, and refine, the IBI developed for the San Jacinto watershed using the independent data set collected in the Santa Margarita watershed. In addition several modifications to the methods used in the San Jacinto watershed were made in the Santa Margarita watershed. The first modification was that herpetofauna community metrics were not used for the reasons discussed in Section 3.1. The second was that a modified index of human disturbance (IHD) was developed to include human disturbance factors observable during field sampling (i.e., all-terrain vehicle (ATV) trails, dirt roads, secondary paved roads ($\leq$2 lanes), main paved roads (>2 lanes), livestock grazing, mowing or clearing, presence of a houses or other structures, and presence of a public park or picnic areas). The third modification was that in the Santa Margarita watershed additional bioregions were encountered including the Santa Ana Mountains, the Agua Tibia Mountains, and the Desert Transition as well as the Riverside Lowlands, San Jacinto Foothills, and San Jacinto Mountains bioregions encountered in the San Jacinto watershed. The badlands bioregion did not occur in the Santa Margarita watershed.

Development of the IBI in the Santa Margarita watershed began by quantifying the species composition and relative abundance of breeding bird communities during different seasons through field sampling of 95 randomly selected riparian reaches representing different bioregions in the watershed. Next, the disturbance index developed for the San Jacinto watershed was modified. In the San Jacinto watershed, land-use data did not distinguish between low-density urban and full urban conditions, whereas in the Santa Margarita land cover data these two classes were distinguished. We took advantage of this additional information in the Santa Margarita watershed land cover data by giving full urban conditions greater weight in the disturbance index. In addition, as mentioned previously it had became clear during the analysis of the San Jacinto data that land-use coverage alone did not capture all of the types of human disturbance that potentially impacted riparian bird communities. Specifically, several reaches in the San Jacinto watershed were used heavily by ATV riders and, consequently, had lower-than-expected IBI values for the apparent level of disturbance indicated by land-use coverage alone. Thus in the Santa Margarita watershed the disturbance index was modified to include: 1) land use in the local drainage of the reach (LD); 2) land use in the immediate vicinity of bird sampling points (RR); and 3) other human activity within or immediately adjacent to the riparian zone (HA). The third component, an index of direct human activity in the riparian zone (HA), was calculated as the mean of the visual ratings of human activity across the four sampling points. IHD was calculated as the largest of these three components:

IHD = Maximum of LD, RR, or HA.

Testing of the San Jacinto Bird IBI formulation in the Santa Margarita watershed confirmed that several of the individual bird-community metrics identified in the San Jacinto watershed were also relevant to the assessment of riparian integrity in the Santa Margarita watershed. Four metrics including: 1) percent richness of bird species of conservation concern; 2) percent richness of exotic species; 3) percent abundance of canopy foragers; and 4) percent richness of native cavity nesters were important predictors of the level of human disturbance of riparian reaches in both watersheds. Therefore, these four metrics were retained in the IBI, although scoring thresholds were modified to fit both watersheds. Two other metrics identified in the San Jacinto watershed including: 1) percent abundance of tree and shrub nesters; and 2) native species richness were dropped when it was found that they showed no significant relationship to human disturbance in the Santa Margarita watershed. They were replaced by two other metrics including: 1) percent richness of granivores; and 2) percent abundance of granivores and omnivores combined that were significantly correlated with the disturbance index in both watersheds. A final variable, percent richness of ground foragers, was significant in both watersheds but contributed little to the overall correlation between IBI and the disturbance index, and was dropped to simplify the IBI formula. The goal of model testing is to evaluate model reliability when applied to new data, and to provide the information needed to refine the model to improve its performance (Overton 1977, O'Neil et al. 1988). To this end, the San Jacinto Bird IBI was refined to improve its reliability and ensure its applicability to both watersheds. The final IBI resulting from model testing was constructed of six of the 65 bird metrics evaluated including:

Species of concern (% richness)
Exotic species (% richness)
Canopy foragers (% abundance)
Native cavity nesters (% richness)
Granivores (% richness)
Granivores and omnivores (% abundance)

The final IBI is more likely to be useful in assessing riparian integrity in other similar southern California watersheds, but still should be verified again before applying it outside of the area where it was developed.

As a further test of the final IBI formula it was applied to the San Jacinto data to see whether its ability to predict the level of human disturbance of riparian reaches was as strong as the original IBI for the San Jacinto had been. Based on all 95 sampled reaches, the correlation coefficient between IBI and the San Jacinto reach disturbance index was $r = -0.73$ (53% of variance explained). Under the original IBI formula, the correlation had been $r = -0.74$ (Wakeley et al. 2003). Both of these correlations might have been higher if the San Jacinto index of human disturbance had taken into account other human activities within the riparian zone (e.g., ATV riding, etc.) that were not reflected in land-use coverage.

The sampling protocol and final Bird IBI developed during this study can be used to assess the current biological integrity of other reaches in the two watersheds, for example to identify candidate parks or conservation areas, or they can be incorporated into a continuing effort to monitor changes in riparian ecosystems over time. Both watersheds are experiencing rapid human population growth. Thus there is a critical need for tools to assess the effects of land-use changes on important ecosystem characteristics and services, and to help guide planning and conservation efforts and evaluate their success or failure. IBI can fill that need directly, or it can be used as a standard of comparison to validate more rapid indicator-based assessment methods (e.g., Smith 2003) that can be applied efficiently over large areas.

3.3 Habitat Integrity Index versus Index of Biological Integrity

The IBI developed for riparian ecosystems in the San Jacinto River and Santa Margarita watersheds can be used to establish a baseline measure of riparian ecosystem integrity, monitor the change in riparian ecosystem integrity as a result of specific impacts, or monitor cumulative impacts over a longer period of time. However, use of the IBI may not be practical or cost effective in all situations. This is due to the specialized personnel required to sample bird populations, the requirement to sample twice at prescribed times of the year, and the requirement of foot access to a kilometer of selected stream reaches. Thus, another objective of the supplementary habitat studies was to use the IBI as an independent standard of comparison for testing, and potentially improving, the accuracy and reliability of the more rapid, indicator-based HAII (Smith et al. 2005, see Appendix A).

In order to test the assumption that a disturbance gradient was an appropriate scaling mechanism for developing the IBI, and also to examine the relationship between the results of the IBI and the Habitat Suitability Index, the raw bird data from the Santa Margarita watershed was ordinated using the nonmetric multidimensional scaling (NMS) algorithm (Kruskal 1964a, Kruskal 1964b, Mather 1976) in the PC-ORD Software (McCune and Mefford 1999). The NMS ordination approach is well suited to data that is not normal, arbitrary, and discontinuous. The advantages of NMS include avoidance of the assumption of linear relationships among variables, allowance of any distance measure, and the use of ranked distances that tend to linearize the relationships between distances in species space (Clark 1993). It has been found to one of the most effective and defensible ordination methods for ecological community data based on peer review, and it is recommended as the method of choice unless specific analytical goals dictate the use of a different ordination method (McCune and Grace 2002).

The raw bird data was analyzed for outlying species and sample reaches with the outlier analysis procedure in PC-ORD with two standard deviations from the mean used as the outlier cutoff value. Based on this analysis, one species (Mourning Dove) was removed, and one sample reach (Hamilton 4) was removed from the dataset. After removing outliers, and columns with no species occurrence, the matrix consisted of 93 sample reaches and 117 species.

The matrix was then transformed using the Beals smoothing algorithm (Beals 1984). This technique replaces each cell value in the matrix with a probability of the target species occurring in that particular sample unit based on the joint occurrences of the target species with the species that are actually in the sample unit. The technique tends to reduce noise in the data by enhancing the strongest patterns (McCune and Grace 2002). The smoothing process did not alter the original ordination sequence, but reduced the coefficient of variation within the dataset from 169% to 107%.

The analysis was run under the “autopilot” mode of NMS in the PC-ORD with the following analysis options:

1. SORENSEN = Distance measure
2. 6 = Number of axes
3. 400 = Maximum number of iterations
4. RANDOM = Starting coordinates
5. 1 = Reduction in dimensionality at each cycle
6. 0.20 = Step length
7. USE TIME = Random number seeds
8. 40 = Number of runs with real data
9. 50 = Number of runs with randomized data
10. YES = Autopilot
11. 0.000010 = Stability criterion, standard deviations in stress over last 15 iterations.
12. THOROUGH = Speed vs. thoroughness

The Pearson correlation coefficient between the Santa Margarita watershed Bird IBI results and the first NMS ordination axis was $r = 0.85$, while the Pearson correlation coefficient between the HAII and first NMS ordination axis was $r = 0.74$. Correlations with the other NMS ordination axis were small ($r < 0.25$). These relatively high correlations indicated that the first NMS ordination axis, based solely on raw bird sampling data, represented a disturbance gradient similar to both the IHD used to scale variables in the IBI, and the disturbance gradient inherent in the HAII.

Comparison between the results of the IBI and the HAII in the San Jacinto watershed resulted in a Pearson correlation coefficient $r = 0.78$, and the same comparison in the Santa Margarita watershed resulted in a Pearson correlation coefficient $r = 0.77$. This relatively high correlation was not unexpected given the similarity of some of the variables used in the IHD (Wakeley et al. 2003) and (Wakeley et al. 2004) and the indicators used in the HAII. For example, the information in the land use in the local drainage of the reach (LD) variable in the IHD was similar to the wildlife habitat in local drainage (WH_{LD}) indicator in the HAII. Also, the information in the land use in the immediate vicinity of bird sampling points (RR) variable in the IHD was similar to the information captured in the riparian corridor connectivity of main stem in riparian reach (RCC_{RR}) in the HAII.

However, there are also some differences between the variables and indicators used in the two indices. For example, there is no indicator in the HAII that captures information similar to the human activity within or immediately adjacent to the riparian zone (HA) variable in the IHD. Also, the HAII has indicators that capture information on vegetation condition (RVC_{RR} - vegetation condition on floodplain and terrace), exotic vegetation (EXO_{RR} - exotic species in riparian ecosystem), and riparian buffers and connectivity with upstream and downstream riparian areas (RCC_{DB} - riparian corridor connectivity in drainage basin). In addition, the indicators in the HAII are designed to integrate the condition throughout the entire riparian reach, whereas, the RR and HA variables in the IHD are based on sample points separated by 250 m along the reach transect. It is difficult to assess what effect, if any, the different methods of sampling variables and deriving indicators have on the results of the two indices. Given the differences in variables and indicators with respect to specific metrics, spatial scale, and sampling methods it would be surprising if the two indices were perfectly correlated. Despite the fact that much of the information used by the two indices was based on different metrics and different model formulations, the relatively high correlation coefficients indicate that both indices are capturing and processing information in a manner that produces comparable results.

A variety of reformulations of the HAII were attempted, using data from the Santa Margarita watershed, to determine if adding, removing, or changing the weighting factor of indicators in the HAII would increase the correlation coefficient between the IBI and HAII. In one reformulation, the HAII was reduced to the two indicators shared with the IHD. That is, we reformulated the HAII with only the wildlife habitat in local drainage (WH_{LD}) indicator which corresponded to the land use in the local drainage of the reach (LD) variable in the IHD, and the riparian corridor connectivity of main stem in riparian reach (RCC_{RR}) which corresponded to the land use in the immediate vicinity of bird sampling points (RR) variable in the IHD. Under this reformulation, the Pearson correlation coefficient dropped from $r = 0.77$ to $r = 0.72$.

In another reformulation of the HAII, the index of direct human activity in the riparian zone (HA) developed for the IHA was added as an indicator in the HAII thereby increasing the number of indicators from 7 to 8. Under this reformulation, the Pearson correlation coefficient dropped from $r = 0.77$ to $r = 0.69$. In all other reformulations tried, the correlation coefficient between the Bird IBI and the reformulated HAII dropped from between $r = 0.65$ to $r = 0.43$ as compared to the correlation coefficient between the Bird IBI and HAII of $r = 0.77$.

Based on the forgoing analysis several conclusions are possible. First, the relatively high correlation of the IBI and the HAII with the NMS first axis ordination scores indicates that both indices reflect a disturbance gradient of human activity where high index values indicates a low level of disturbance due to human activity, and vice versa. Second, relatively high correlation coefficients between the two indices indicate that, despite the fact that much of the information used by the two indices was based on a different set of metrics and different model formulations, both indices capture and process information in a manner that produced similar results. Third, reformulation of the current HAII in various ways did not increase its correlation coefficient with the IBI. Finally, the IBI and HAII provide comparable measures of riparian ecosystem integrity with the ability to establish a baseline measure of riparian ecosystem integrity, monitor the change in riparian ecosystem integrity as a result of specific impacts, or monitor cumulative impacts over a longer period of time. The choice of index will depend on the objectives, time, and resources available to the end user.

4.0 Supplementary Hydrology Studies

Specific objectives of the supplementary hydrology studies in the San Jacinto, Santa Margarita, and Otay watersheds were to: 1) develop hydrologic models to characterization baseline conditions in the study areas to the extent possible with available hydrologic and water quality data; 2) provide information the could be used in conjunction with more specific applications such as the decision-making processes of the SAMP, and to support municipalities, counties, state and local agencies in activities related to habitat management, flood control, planning, erosion and sediment transport, point and non-point source pollution, Total Maximum Daily Loadings (TMDLs), Best Management Practices (BMPs), as well as other state, local, and federal regulatory compliance programs; and 3) to provide information that could be used to evaluate the hydrologic and water quality integrity indices being used to assess baseline riparian ecosystem integrity.

There are a variety of approaches to modeling water quantity and quality in a watershed. They can be generally classified into two categories with each category addressing specific issues based on a set of assumptions and varying input requirements. The first category includes lumped parameter models in which the watershed is divided into relatively homogeneous subbasins with average parameters and solution variables being defined for each subbasin. Computations are empirically based and normally reflect the output at the subbasin outlet, hence, deriving output from points within the subbasin is not possible and in some cases can be a severe limitation of the model. The second category includes distributed models that divide a watershed into a high number of grid cell elements. The watershed is simulated by solving physically based numerical equations describing the state of each individual element. While distributed models may provide more information than a lumped parameter model, in general, distributed models tend to require more data than do lumped models, tend to be more complicated to use, and tend to be more unstable with increasing watershed size. One shortcoming of distributed models is that the spatial variability of model parameters throughout the watershed may not be know, resulting in the model's capability exceeding data availability.

Sections 4.1, 4.2, and 4.3 below summarize supplementary hydrology studies for the San Jacinto, Santa Margarita, and Otay watersheds respectively. Complete supplementary hydrology reports for the San Jacinto watershed are available in Skahill (2002) and Fong (2005).

Supplementary hydrology reports for the Santa Margarita watershed are available in Skahill (2003) and (Zhonglong and Johnson 2003), and for the Otay watershed in Skahill (2005). A technical report based on supplementary hydrology studies summarizes the application of HSPF to watershed analysis in general, and to the San Jacinto and Santa Margarita watersheds specifically, is also available (Skahill and Kleiss 2003).

4.1 San Jacinto Watershed

The primary focus of supplementary hydrology studies in the San Jacinto watershed was to develop a calibrated and verified hydrologic model based on available flow, reservoir storage, sediment, inorganic nitrogen, and phosphorus data. Based on recommendations from the Coastal and Hydraulics Laboratory at ERDC two hydrologic methods were selected including the Hydrologic Simulation Program Fortran (HSPF), a lumped parameter model, and Gridded Surface Subsurface Hydrologic Analysis (GSSHA), a distributed model. The rationale for selecting two types of hydrologic models was to determine if either the lumped or distributed types of model was easier to develop and calibrate for the large watersheds being studied, and whether the results from either type of model would prove more satisfactory for testing the hydrologic integrity indices.

4.1.1 Hydrologic Simulation Program Fortran

The Hydrologic Simulation Program Fortran (HSPF), is a mathematical model that simulates water quantity and quality processes on a continuous basis in natural and man-made water systems (Johanson et al. 1980). HSPF uses meteorological input data and parameters related to land use patterns, soil characteristics, and agricultural practices to simulate the water quantity and quality processes that occur within a watershed. The HSPF model is generally classified as a lumped parameter model; however, the spatial variability in a watershed can be simulated if the watershed is appropriately divided into land segments which are generally hydrologically homogeneous. Donigian et al. (1995) lists a variety of potential applications and uses of the HSPF model.

Physical watershed-specific data relevant to HSPF model development and calibration such as elevation, channel geometry, soils, vegetation, and land use and land cover were obtained from GIS databases and field observations for the eastern portion of the San Jacinto watershed. Available funding prohibited developing an HSPF model for the entire San Jacinto watershed.

Meteorological data were collected from weather stations maintained by the Riverside County Flood Control District, the National Weather Service (NWS), the California Department of Water Resources, and other organizations within and surrounding the San Jacinto river basin. Calibration data (in this case, streamflow and reservoir storage data) were collected from the Riverside County Flood Control District, the USGS, California Department of Water Resources, and from the Lake Hemet Municipal Water District. The ANNIE, WDMUtil, and METCMP (USEPA 1999) utility software packages were used to input, manipulate, and subsequently manage these meteorologic and calibration time series data in a Watershed Data Management (WDM) file.

Basin delineation for the study area was based on riparian reaches identified during the baseline assessment of riparian ecosystem integrity (See Appendix A). This information was manually translated into the appropriate blocks within the Users Control Input (UCI) file, the main HSPF model input file. For the eastern part of the San Jacinto watershed 331 RCHRESs were identified including 330 stream reaches and 1 lake reach (i.e., Lake Hemet). The land use land cover distribution within each sub-watershed was calculated using the Environmental Systems Research Institute, Inc. (ESRI) ArcView GIS. This information was subsequently manually mapped into the SCHEMATIC block of the UCI file. The land segmentation for the eastern part of the San Jacinto was developed to principally account for the available meteorological and calibration data.

Initial parameter estimates were based on guidance provided by USEPA (2000), Munson (1998), and USACE and USEPA (2000), among others, and GIS-based analysis. For example, the lower zone nominal soil moisture storage, LZSN, parameter values were initially based on the mean annual precipitation for the given watershed and guidance provided by USEPA (2000) and Donigian and Davis (1978). Stage-discharge relationships for each reach was specified based on application of Manning's equation and information obtained from field observations.

A WDM file was prepared to receive and store the simulated flow and volume data for each of the 331 modeled RCHRESs. The model was interfaced with GenScn (Kittle et al. 1998). GenScn is a public domain graphically-based modeling environment that supports scenario analysis (assessing the hydrologic and water quality impacts of land use change, for example), BMP analysis, and time series data analysis for the HSPF model, among others. GenScn also possesses animation capabilities, allowing one to visualize the spatial and temporal character of various model output.

HSPF model parameters were not available from field data, and were determined through model calibration. Model calibration was performed manually by comparing simulated and observed flows and volumes at annual, seasonal, and daily time scales. Other criteria that were also used to support the manual calibration for the HSPF model included visually inspecting the match of simulated and observed flows, and verification of the calibration results. HSPF model for the eastern part of the San Jacinto was calibrated to current land surface conditions.

R-squared and Nash and Sutcliffe efficiency (1970) scores, *ES*, were used to evaluate model performance. Values of *ES* range from 1 to $-\infty$. When model predictions equal observed values, *ES* equals 1. Negative values of *ES* imply that the model's predictive power is worse than simply using the mean of the observed values. The Nash and Sutcliffe efficiency score, *ES*, was selected as a model performance measure in addition to r-squared because a high r-squared value does not necessarily imply accuracy. A "good" HSPF hydrologic model calibration has r-squared values at annual, seasonal, and daily timescales of 0.9, 0.8, and 0.6, respectively (Munson 1998). Calibration results indicated a "good" hydrologic model calibration at each calibration endpoint within the eastern part of the San Jacinto watershed.

The HSPF model for the eastern part of the San Jacinto watershed was also setup to simulate sediment and inorganic nitrogen and phosphorous. The WDM file was also modified to receive and store simulated suspended sediment, nitrate, and orthophosphorus concentrations for each of the 331 modeled RCHRESs. For the eastern part of the San Jacinto, there were no data to calibrate to these simulated concentrations. As a result, parameter values were transferred from HSPFParm (Donigian et al. 1999) to support the simulation of the associated processes. In general, the simulation of sediment would involve calibration to computed target sediment loading rates, possibly based on application of the Universal Soil Loss Equation together with sediment delivery ratios, with subsequent focus on calibrating the channel processes of deposition, scour, and transport for the sand, silt, and clay fractions of the total input from the land surface. In general, the simulation of inorganic nitrogen and phosphorous would also involve the simulation of water temperature and dissolved oxygen.

Following the development and calibration of the HSPF model two scenarios, a historic "culturally unaltered" condition and a future build out condition, were modeled. Land use land cover for the culturally unaltered condition was based on an analysis of potential natural vegetation and soils. Land use land cover for the future build out condition was based on projections of urban development in Riverside County planning documents. The land use corresponding to each scenario was calculated and manually mapped into the SCHEMATIC block of the UCI file of the calibrated model. The other principal change to the calibrated model involved the possible modification of the FTABLE for a given RCHRES. For each scenario a separate WDM files were prepared to store and receive the simulated flows and volumes, and suspended sediment, nitrate, and orthophosphorous concentrations for each of the 331 modeled RCHRESs. The three modeled scenarios (historic, current, future) for the eastern part of the San Jacinto river basin were packaged within a single GenScn project file, thus allowing one to graphically select, within GenScn, a single sub-basin or multiple sub-basins, and retrieve some or all of the time series data that have been stored for the location(s) across the three scenario simulations. Model results from the historic to current scenario and the current to future build out scenario indicated that magnified peak flows and reduced time to peak can occur as a result of urbanization.

4.1.2 Gridded Subsurface Hydrologic Analysis

Gridded Surface Subsurface Hydrologic Analysis (GSSHA) is a physically based, distributed-parameter, structured grid, hydrologic model that simulates the hydrologic response of a watershed subject to given hydrometeorological inputs (Downer et al. 2002). Major components of the model include spatially and temporally varying precipitation, snowfall accumulation and melting, precipitation interception, infiltration, evapotranspiration, surface runoff routing, simple lake storage and routing, unsaturated zone soil moisture accounting, saturated groundwater flow, wetland peat layer hydraulics, overland sediment erosion, transport and deposition, in-stream sediment transport, and overland contaminant transport, and uptake. In GSSHA, each process has its own time-step and an associated update time. The update time or time-step of dependent processes may be modified as part of the process update. This formulation permits the efficient simultaneous simulation of processes that have dissimilar response times, such as overland flow, evapotranspiration (ET), and lateral groundwater flow.

This scheme also allows an integrated solution of processes coupled through boundary conditions and flux exchanges.

Watershed-specific data relevant to GSSHA model development and calibration such as elevation, channel geometry, soils, vegetation, and land use and land cover were obtained from GIS databases and field observations for the Perris Valley subasin of the San Jacinto watershed. Hydro-meterological including barometric pressure, relative humidity, total sky cover, wind speed, direct and global radiation, and temperature were obtained from the Air Force Combat Climatology Center. Channel cross sections were estimated from field data. Precipitation data from seven stations located in the San Jacinto watershed was provided by the Riverside Flood Control District for a period of record from July 1, 1990 - June 30, 2001. Streamflow data from the Riverside County Flood Control District was used for calibration.

The Watershed Modeling System (WMS) (Downer et al. 2002) was used to support model development. The WMS in conjunction with USGS 10 meter Digital Elevation Model was used for stream network creation and basin delineation, and define a spatial grid with a resolution of 75 meters (66,304 cells). The WMS was also used in conjunction with land use land cover and soil data was used to define surface roughness, infiltration parameters, and also to incorporate break point cross sections from field data.

Simulated hydrologic process included: 1) precipitation distributed with inverse distance squared weighting; 2) infiltration using Green and Ampt with redistribution (Ogden and Saghafian 1997); 3) 2-D lateral diffusive wave overland flow routing using Alternating Direction Explicit with prediction-correction (ADE-PC) method (Downer 2002); 4)1-D longitudinal diffusive wave channel routing; and 5) evapotranspiration with Penman-Montieth (Montieth 1975) method.

Model parameters were determined using the shuffled complex evolution (SCE) automated calibration method (Duan 1992). Calibrated parameters included soil moisture, channel roughness, soil saturated hydraulic conductivity, hydraulic conductivity of river bed material, and overland surface roughness. Observed peak flows and volumes were compared to the simulated results, and time series flow data were tabulated for subwatershed locations correspond to the downstream end of riparian reaches identified during the baseline assessment of riparian ecosystem integrity (See Appendix A). Model performance was evaluated by the

Percent Bias (PBIAS) and Nash-Sutcliffe statistics efficiency Scores (NS). Optimum values for PBIAS is zero, with positive values overestimating and negative values underestimating the observed, and optimum values for NS is 1.0. Values of -0.097 and 0.9 were calculated for PBIAS and NS respectively for the model developed for the Perris Valley portion of the Santa Margarita watershed. The calibrated GSSHA model was setup, but not determined for a future build out condition representing an increase in urbanization from 38% to 76%.

4.2 Santa Margarita Watershed

In the Santa Margarita watershed, as in the San Jacinto watershed, the primary focus of supplementary hydrology studies to develop a calibrated hydrologic model based on available flow, reservoir storage, sediment, inorganic nitrogen, and phosphorus data. As in the San Jacinto, two hydrologic methods were selected including the Hydrologic Simulation Program Fortran (HSPF) and a different distributed hydrologic model, the MIKE SHE Flow Modeling System was substituted for the GSSHA distributed model due to problems with completion of the GSSHA model in the San Jacinto watershed. As in the San Jacinto watershed, the rationale for selecting two types of hydrologic models was to determine if either the lumped or distributed types of model was easier to develop and calibrate for the large watersheds being studied, and whether the results from either type of model would prove more satisfactory for testing the hydrologic integrity indices.

4.2.1 Hydrologic Simulation Program Fortran

Experience in the San Jacinto watershed made it possible for the evolution of a modified approach for developing the HSPF model in the Santa Margarita watershed. This included developing a fairly parsimonious HSPF model relative to the typical HSPF model complexity, and use of the model-independent parameter estimation tool (PEST). With respect to HSPF model complexity, there are dozens of parameters that must be estimated during development of the HSPF model. A notable strength of the HSPF model is its ability to account for a multiplicity of spatial factors relevant to the hydrologic and water quality response within a given modeled watershed. Hence, for a mixed land use system, there could be up to 12 x *x* parameters to estimate, where *x* is the number of unique hydrologic response units within the modeled watershed. Given that only 4-5 adjustable parameters are needed to calibrate a well designed rainfall-runoff model against a stream flow hydrograph (Jakeman and Hornberger

1993, Beven 2001), there is little point in attempting to incorporate and manage all the parameters unless there are specific requirements guiding model development (e.g., key desired model predictions). Hence, with respect to the parameters relevant to the partition of precipitation on the land surface, the HSPF model developed for Murrieta Creek subasin treated the entire watershed as a homogenous system.

Data collected for developing the HSPF model in the Murrieta Creek subasin was similar to those described above for the San Jacinto watershed with respect to physical watershed-specific data, meteorological data, and streamflow and reservoir storage data (see Section 4.1.1). The ANNIE, WDMUtil, and METCMP (USEPA 1999) utility software packages were used to input, manipulate, and subsequently manage these meteorologic and calibration time series data in a Watershed Data Management (WDM) file.

The Murrieta Creek drainage basin below Diamond Valley Lake and Lake Skinner was discretized into 106 subasins based on riparian reaches identified during the baseline assessment of riparian ecosystem integrity (See Appendix A). This information was manually translated into the appropriate blocks within the Users Control Input (UCI) file, the main HSPF model input file. Land use distribution in each subasin was classified as urban or non-urban land using GIS analysis, and subsequently mapped into the SCHEMATIC block of the UCI file. Stage discharge relations for each reach were specified base on Manning's equation, information from GIS databases and field observations. Simulation time step was one hour, which equaled the temporal resolution of the meteorological data. A WDM file was set up to receive and store simulated flow date for the 106 subasins at a daily time step, which equaled the temporal resolution of observed discharge data. The HSPF hydrologic model was interfaced with GENeration and analysis of model simulation SCeNarios (GenScn) (Kittle et al. 1998), a public domain, graphically based modeling environment that supports scenario analysis such as the effect of land use change on hydrology.

Most of the HSPF model parameters related to water budget computations are not available from data and must be determined through model calibration. The HSPF hydrologic model developed for the Murrieta Creek drainage basin was interfaced with model-independent parameter estimation tool (PEST) (Doherty 2002). The PEST software is based on a robust implementation of the Gauss-Marquardt-Levenburg method that adjusts model parameters and/or excitations until the fit between the model outputs and observed data is optimized in the weighted least squares sense. Normally, the Gauss-Marquardt-Levenburg method will find the objective function minimum in fewer model runs than any other parameter estimation method (Doherty 2002).

For the Murrieta Creek drainage basin HSPF hydrologic model, the parameter estimation entailed comparing simulated results for two calendar years (1992 and 1994) against observed daily streamflow data from the USGS streamflow gaging station on Murrieta Creek in Temecula (11043000). The specified multi-component objective function consisted of daily streamflow data, aggregation of the daily streamflow data to a monthly time step, aggregation of the daily streamflow data to an annual time step, and the inclusion of exceedence times for various flow thresholds with equal weight assigned to each data group. Residuals were analyzed and standard methodologies performed to ensure appropriate application of the method of least squares, thus ensuring an unbiased parameter set.

Fifteen adjustable parameters were estimated for the Murrieta Creek drainage basin HSPF hydrologic model (Table 1). These parameters were set to a range from 0.1 to 0.9. Urban land within each of the 106 Murrieta Creek subasins was partitioned between pervious land area and directly connected impervious land area. Application of the PD_MS2 multi-start driver resulted in identification of an optimized objective function value of 1578 in 6953 model calls. Table 1 shows the optimized parameter set values, and Table 2 summarizes Nash and Sutcliffe efficiency scores, correlation coefficients, and coefficients of determination based on a comparison of the computed flows against observed flow at the daily and monthly time step. The observed "fair" model performance was attributed to the fact that data from just a single precipitation gage was available to support simulation for the entire Murrieta Creek drainage basin.

Table 1. Optimized parameter set values

Parameter	Optimized Value	Parameter	Optimized Value	Parameter	Optimized Value
imp	0.88765	basetp	0.00165	intfw	1
agwrctrns	999	agwetp	0.08	irc	0.662
lzsn	5.7048	cepsc	0.00306	lzetp	0.6
infilt	0.0532	uzsnrat	0.2648	insur	0.14532
deepfr	0.20223	nsur	0.14584	retsc	0.3

Table 2. Computed Nash and Sutcliffe efficiency scores, correlation coefficients, and coefficients of determination for optimized HSPF hydrologic model

	Daily		Monthly	
	1992	1994	1992	1994
Nash and Sutcliffe Efficiency	0.69	-0.12	0.77	0.97
Correlation Coefficient	0.85	0.56	0.89	0.99
Coefficient of Determination	0.72	0.32	0.79	0.99

In summary, a simplified HSPF hydrologic model was developed for the Murrieta Creek drainage basin below Diamond Valley Lake and Lake Skinner. The model independent parameter estimation tool (PEST) was linked with the HSPF hydrologic model and shown to be a credible means to assess the information content of available data to determine the hydrologic model relative to its structure and specified complexity. The linkage between HSPF and PEST allowed for an assessment of simulation model parameter sensitivities and correlations resulting from the hydrologic simulation model parameter estimation process, and also supported the subsequent credible prediction of a key model outcome. Factors that impeded watershed scale simulation included inadequate forcing and calibration data.

4.2.2 MIKE SHE Flow Modeling System

MIKE SHE is an integrated distributed watershed modeling system that simulates all important hydrologic processes and their dynamic interaction (surface flow, unsaturated zone flow, and groundwater flow). This would be particularly helpful for simulating land use changes and surface and groundwater interaction problems. It utilizes spatial and temporal data easily, and is capable of providing a variety of output types. MIKE SHE possesses distinct advantages over other models based on the complexity of the governing physical equations and its physically realistic representation of hydrological and solute transport processes, instead of the eclectic and often ad hoc conceptual representations used by lumped process models.

Under the MIKE SHE system used to develop a model for the Santa Margarita watershed, the water quality module had not been released, despite indications otherwise. Therefore, the MIKE SHE model for the Santa Margarita River watershed only includes the major flow processes: evapotranspiration, overland flow, channel flow, unsaturated zone flow and saturated zone flow.

Prior to the MIKE SHE model development all the data layers required to run he model were prepared in a GIS format and then transformed into MIKE SHE formats. This included sub-watershed boundary, stream network, land use land cover, States Soil Geographic soils (STATSGO), United States Geological Survey (USGS) National Elevation Dataset (NED), USGS National Hydrography Dataset, USGS stream flow gages, National Climatic Data Center (NCDC) precipitation stations, and EPA BASINS water quality monitoring stations. A Watershed Data Management (WDM) file was created to manage the existing meteorological, precipitation and stream flow data for the Santa Margarita River watershed.

The original intent was to apply MIKE SHE to the whole Santa Margarita River watershed areas with the expectation that complete spatial and non-spatial data information necessary as model inputs would be available, and with the expectation that MIKE SHE would be tractable to use with the resources (funding and time) available to the project. Initial data review revealed that there were only a few USGS stream flow discharge gages within the Santa Margarita River watershed. MIKE 11 requires detailed stream flows at the upstream and downstream boundaries and thus this lack of data does not satisfy the MIKE 11's channel boundary condition data requirements. MIKE SHE's subsurface and aquifer data requirements also limit its application to the Santa Margarita River watershed areas where no such information was available at the time of model setup. When it became apparent that the input data would not be complete, an approximately 140,000 acres sub-basin of Murrieta Creek, within the Santa Margarita River watershed, was selected for the MIKE SHE flow model evaluation.

In order to evaluate the functionality of each component within the MIKE SHE flow modeling system, available data, including meteorological data, topographical data, soil data, land use data, hydrogeological data, channel network, hydraulic data, and watershed characteristics data were used to establish a pilot MIKE SHE flow model for the Murrieta Creek subasin. It should be noted that due to a lack of measured data, this model was not calibrated.

MIKE SHE includes a number of flow component modules, which may be combined to describe flow within the watershed. For the Santa Margarita River watershed MIKE SHE flow model evaluation, the modeling components applied included: 1) soil and water surface evaporation and and plant transpiration (MIKE SHE ET); 2) overland sheet flow, water depth, and depression storage (MIKE SHE OL); 3) fully dynamic river hydraulics (MIKE 11); 4) flow and water moisture content of the unsaturated zone, infiltration, and groundwater recharge (MIKE SHE UZ); 5) ground flows and water levels (MIKE SHE SZ). The Murrieta Creek subasin was discretized into a number of computational cells for the numerical solution of the governing equations, and then divided into polygons based on land use, soil type, and precipitation region. Model input files were generated by overlaying the model input parameters with a grid network. A grid network represents spatial distributions of the model parameters, inputs, and results with vertical layers for each grid. The input data requirements and model parameters for the fully integrated MIKE SHE model were comprehensive. Each component of the model applied a range of input data types and parameters. The parameters were either physically measurable or an empirical specific to the equations solved in the model. Data preparation and model set-up was completed using ArcView GIS and MIKE SHE's built-in graphic pre-processor.

The MIKE SHE simulation was controlled by several simulation control parameters including simulation period, the simulation time step, iteration stop criteria, data storage selection, and storage time step. These parameters can impact the simulation run time, water balance error, and size of the stored results file. The time step was chosen from the time scales and numerical constraints. Three series of time steps were specified for a model run. The time scale of the surface water regime and the groundwater regime are different. The model allows use of different time steps for simulation of e.g. overland flow, channel flow and groundwater flow. For this study, the MIKE 11 river hydraulics model was simulated using the Kinematic Routing method in 4 hours computational time steps, while overland water depth, flow velocities, unsaturated flow, and water content were simulated with a maximum time step of 4 hours. Saturated flow was simulated using a maximum time step of 24 hours. The computational time steps were automatically updated during the simulation to avoid numerical instability following high rainfall inputs. The model was tested for one month, two month, three months, and one year time periods, and a representative sample of model results were presented for a one-year simulation.

In summary, the MIKE SHE modeling system is a complex system that has its strengths and weaknesses. It is capable of performing a variety of functions housed in its modular structure. Model performance depends on accuracy of the input data derived based on measurements of physical characteristics of the watershed, and monitoring of the hydrological and meteorological conditions. Applying such a complex modeling system requires a great deal of effort including extensive model data and physical parameters collection, model development, and model calibration. In the development of the MIKE SHE model, for this study area, available data was utilized to this greatest extent possible. A number of general assumptions and approximations were made due to conceptualization, limitation in available input data, and distribution of model parameters. This evaluation study demonstrates that the data set for the Santa Margarita River watershed is inadequate for applying the full MIKE SHE flow modeling system. In order to provide meaningful results, the following enhancements are recommended:

- Collect additional localized precipitation and meteorological time series data including: air temperature, wind speed, dew point temperature, pan evaporation, and solar radiation.
- Collect additional stream flow measurements at all USGS gage sites. Discharge data from the watershed outlet of was available, however discharge data from the Santa Margarita Lagoon, Vail Lake, Skinner Reservoir, and Diamond Valley Lake Reservoir were not available. The data collection frequency, for these data, should be at least on a daily time scale.
- Collect critical stream water levels data to satisfy the MIKE 11 boundary requirements
- Collect bathymetry data for the lakes and reservoirs within the watershed.
- Channel cross section data were not sufficient to simulate the dynamics of channel flow and water levels in the watershed. More data should be provided to obtain reliable flood mapping and detailed simulation of water levels and flows.
- Obtain the more detailed SSURGO soil layer data specifying the soil variation in the vertical direction and the hydraulic properties in order to refine the unsaturated zone model.
- The aquifer groundwater model should encompass multiple layers rather than the one computation layer and one geological layer assumed for this study. If geological layer and groundwater level data are collected and reinterpreted the geological model may be extended and refined.
- The groundwater drainage component is an important component to the model results. Identification of local areas with lower or higher conductivity could affect the groundwater flow and level and should be investigated further.

The MIKE SHE modeling system has extensive, menu-driven, graphical capabilities for pre- and post-processing, which make the modeling process much easier when compared to other models with only limited processing ability. However, some critical functions are not ready to use for the current version, which is the first MIKE Zero platform based version and will be upgraded in the next release. For example, the ArcGIS shapefile to grid mapping routine causes a stack overflow although there are very few categories in the land use shapefile for the Santa

Margarita River watershed. The modular structure, of MIKE SHE, allows users to apply only the modules necessary for their projects, however MIKE SHE still requires a great deal of technical expertise and the learning curve is steep for new users.

Finally, the following MIKE SHE limitations were recognized that either prevented the modeling of the watershed as planned, or required variation of parameters outside of normal limits:

- The over parameterization of MIKE SHE due to the distributed and physically-based nature of the model resulted in assumed inputs and model parameters which in turn resulted in more uncertainty in the prediction. For example, the requirement of the stream channel water level data, detailed cross section geometries, soil profile, and aquifer geological data directly affected the application of the 3D groundwater module. Assumptions and errors in these data tend to propagate to the groundwater results.
- MIKE SHE is known to have instability problems in the Overland Flow component.
- MIKE SHE was designed to simulate all the hydrological processes that occur within a watershed, however it was not designed to specifically model urbanized areas. For example, there was not a specific component for simulating runoff and infiltration changes due to partially paved (impervious cells).
- Though MIKE SHE has an extensive ET module it was highly dependent on potential ET inputs provided by the user.
- The lens option of MIKE SHE was not calculated as a separate unit. The hydraulic properties of the lens and surrounding aquifer had to be averaged. This constraint prevents variation of parameters and retrieval of results for the aquifer areas above and below the lens.
- Both physical and computational limits exist in MIKE SHE. The total number of cells, and therefore the grid cell size must be moderated to prevent run times from being too long. This prevents the level of detail the model can represent.

4.3 Otay Watershed

In the Otay watershed, as in the San Jacinto and Santa Margarita watersheds, the primary focus of supplementary hydrology studies to develop a calibrated hydrologic model based on available flow, reservoir storage, sediment, inorganic nitrogen, and phosphorus data. Unlike, the San Jacinto and Santa Margarita watersheds only the HSPF model was used in the Otay watershed.

4.3.1 Hydrologic Simulation Program - Fortran

Standard methods were used to collect and prepare hydro-meteorological and other physical data necessary as input to the HSPF hydrologic model for the Otay watershed.

Precipitation and potential evapotranspiration data for 5 gages was obtained from the San Diego County Flood Control/Hydrology Office, U. S. EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), and the California Irrigation Management Information System (CIMIS). Daily maximum temperature, minimum temperature, mean dew point temperature, and mean wind speed were obtained from the National Climatic Data Center (NCDC). Solar radiation data were obtained from CIMIS. Daily streamflow data was obtained from USGS, monthly reservoir storage data was obtained from the California Department of Water Resources and the City of San Diego, and monthly draft data for the Barret reservoir was obtained by the City of San Diego. Subasins within the Otay watershed were based on the local drainages identified by during the baseline assessment of riparian ecosystems in the Otay watershed (Smith 2004a). Stream channel information for each subasin (e.g., bankfull width, bankfull mean depth, bankfull maximum depth, floodprone width, and channel substrate) was also based on field observations collected during the baseline assessment. Soils data was obtained from National Resource Conservation Service Soil Survey Geographic (SSURGO) database. A thirty meter Digital Elevation Model (DEM) was obtained from USGS. Land use land cover data for the year 2000 was obtained from the San Diego Association of Governments (SANDAG). Physical values for interception and hydrologic response in the Otay watershed were gleaned from the literature. The ANNIE and WDMUtil utility software packages were used to input, manipulate, and subsequently manage the time series data in a Watershed Data Management (WDM) file.

The Otay watershed was discretized into 156 subasins based on riparian reaches identified during the baseline assessment of riparian ecosystem integrity (See Appendix A). Subasins were assigned a unique numeric ID, and together with the hydrographic data, model topology was manually determined. Landscape features in the models reflected a blending of vegetation cover, land cover data, and soils created in a GIS analysis. This information was mapped into the SCHEMATIC block of the UCI file. Urban areas within each subasin were partitioned between pervious land and directly connected impervious land.

Stage-discharge relationships for non-reservoir subasins were specified based on Manning's equation, information obtained from GIS analysis, and stream channel information from field observations collected during baseline assessment. The storage capacity curve and spillway capacity was the basis for defining the FTABLE for the Lower Otay reservoir subasin. The storage capacity curve, surface area at capacity, and field observations were the basis for defining the FTABLE for the Upper Otay reservoir subasin. WDM files were set up to receive and store simulated flow date for the 106 subasins at a daily time step, which equaled the temporal resolution of observed discharge data.

The HSPF hydrologic model was interfaced with the PEST software to support model calibration and prediction. A total of 29 model parameters required estimation through the calibration process (Table 3). Values for the 29 adjustable model parameters were estimated through simultaneous calibration against : 1) non-zero mean daily discharge data from the USGS streamflow-gaging station 11014000 (Group 1); 2) non-zero monthly discharge data from the USGS streamflow-gaging station 11014000 (Group 2); and 3) expected annual runoff coefficient data relationships for the Brush and Grass (Group 3) and Oak and Grass (Group 4) land cover types. A weight of one was assigned to each element of the above noted four groups that constituted the objective function. However, prior to initiating the parameter estimation process, weights were uniformly adjusted within each group such that the parameter estimation engine saw each of them as of equal importance. A weight of zero was assigned to elements of Group 1 when drafts from Barrett Reservoir via Dulzura Creek were present.

Parameter estimation was conducted by comparing nine years (1987-1995) of model results against observed flow data from the Lower Otay reservoir. Model verification was for the period October 1, 1995 to June 30, 2001. Table 4 shows the parameter set resulting from the calibration and verification exercise. This parameter set was transferred to the Lower Otay model to support prediction of the Otay watershed below the Lower Otay reservoir.

In addition, for the portion of the watershed above the Lower Otay reservoir, a model was prepared representative of the culturally unaltered condition. Preparation of this model involved: 1) modification of the SCHEMATIC block of the UCI file for the calibrated and verified model to include land cover for the culturally unaltered condition and soil data; 2) removal of drafts from the Barrett reservoir via Dulzura Creek; and 3) removal of the Upper and Lower Otay reservoirs. This model was run using the parameter set identified from the model calibration and verification and the meteorological data used for model calibration and verification. Results are presented that show the hydrologic alterations that have occurred in each subasin as a result of the transition from the culturally unaltered condition to the current conditions.

Table 3. Adjustable parameters for model calibration

Parameter Name	Parameter Function	Bounds Imposed During Calibration
a	precipitation gage weighting factor	0 – 1
LZSN08	lower zone nominal storage – oak cover	2 – 15 in
LZSN11	lower zone nominal storage – brush cover	2 – 15 in
LZSN12	lower zone nominal storage – grass cover	2 – 15 in
INFILTA	related to infiltration capacity of the soil (for Hydrologic Soils Group A)	0.40 – 1.00 in/hr
INFILTB	related to infiltration capacity of the soil(for Hydrologic Soils Group B)	0.10 – 0.40 in/hr
INFILTC	related to infiltration capacity of the soil(for Hydrologic Soils Group C)	0.05 – 0.10 in/hr
INFILTD	related to infiltration capacity of the soil(for Hydrologic Soils Group D)	0.005 – 0.05 in/hr
DEEPFR08	fraction of groundwater inflow that goes to inactive groundwater – oak cover	0.0 – 0.5
DEEPFR11	fraction of groundwater inflow that goes to inactive groundwater – brush cover	0.0 – 0.5
DEEPFR12	fraction of groundwater inflow that goes to inactive groundwater – grass cover	0.0 – 0.5
AGWETP08	fraction of ET taken from groundwater (after accounting for that taken from other sources)– oak cover	0.0 – 0.2
AGWETP11	fraction of ET taken from groundwater (after accounting for that taken from other sources)– brush cover	0.0 – 0.2
AGWETP12	fraction of ET taken from groundwater (after accounting for that taken from other sources)– grass cover	0.0 – 0.2
CEPSC	Interception storage	0.005 – 0.400 in
UZSN08	upper zone nominal storage – oak cover	0.0500 – 2.000 in
UZSN11	upper zone nominal storage – brush cover	0.0500 – 2.000 in
UZSN12	upper zone nominal storage – grass cover	0.0500 – 2.000 in
NSUR08	Manning's n for overland flow plane – oak cover	0.0500 – 0.500
NSUR11	Manning's n for overland flow plane – brush cover	0.0500 – 0.500
NSUR12	Manning's n for overland flow plane – grass cover	0.0500 – 0.500
INTFW08	interflow inflow parameter – oak cover	1.0 – 10.0
INTFW11	interflow inflow parameter – brush cover	1.0 – 10.0
INTFW12	interflow inflow parameter – grass cover	1.0 – 10.0
IRC08	interflow recession parameter – oak cover	0.30 - 0.85 day^{-1}
IRC11	interflow recession parameter – brush cover	0.30 - 0.85 day^{-1}
IRC12	interflow recession parameter – grass cover	0.30 - 0.85 day^{-1}
LZETP08	lower zone ET parameter - an index of the density of deep-rooted vegetation – oak cover	0.1 - 0.9
LZETP11	lower zone ET parameter - an index of the density of deep-rooted vegetation – brush cover	0.1 - 0.9
LZETP12	lower zone ET parameter - an index of the density of deep-rooted vegetation – grass cover	0.1 - 0.9

Table 4. Parameter set resulting from the calibration and verification exercise

Parameter Name	Estimated Value
a	0.372988
LZSN08	4.09593
LZSN11	6.72035
LZSN12	2.00000
INFILTA	0.400000
INFILTB	0.100000
INFILTC	5.000000E-02
INFILTD	9.770815E-03
DEEPFR08	3.347792E-04
DEEPFR11	3.086089E-04
DEEPFR12	3.982721E-04
AGWETP08	1.106308E-02
AGWETP11	3.018885E-04
AGWETP12	4.931614E-04
UZSN08	0.410336
UZSN11	0.502542
UZSN12	0.269221
NSUR08	0.119441
NSUR11	5.000000E-02
NSUR12	5.000000E-02
INTFW08	1.79939
INTFW11	2.23190
INTFW12	1.99942
IRC08	0.300000
IRC11	0.300000
IRC12	0.300000
LZETP08	0.733343
LZETP11	0.722382
LZETP12	0.598440

In summary, an HSPF hydrologic model was developed for the Otay watershed. The model independent parameter estimation tool (PEST) was linked with the HSPF hydrologic model and shown to be a credible means to assess the information content of available data to determine the hydrologic model relative to its structure and specified complexity. Model calibration and verification results indicate that the calibrated and verified HSPF hydrologic model had predictive value and that it is was also "physically-based" relative to the data that was available to discern differences across the landscape features reflected in the model.

Simulated flow predictions were made for the portion of the watershed above the Otay reservoir to represent culturally unaltered condition using the calibrated and verified HSPF hydrologic model. These predictions provided an opportunity to examine the relationship between the HSPF hydrologic model results and the Hydrologic Integrity Index (HYII). Specifically, the Hydrologic Integrity Index, represents current (i.e., post-impact conditions) for each subasin (i.e., local drainage). Using simulated flows generated from the calibrated and verified HSPF hydrologic model under current (i.e., post-impact) and culturally unaltered conditions (i.e., pre-impact) Indices of Hydrologic Alteration (The Nature Conservancy 2005) can be calculated for pre-impact and post-impact condition and compared to the Hydrologic Integrity Index for each subasin.

4.4 Hydrologic Integrity Index versus Hydrologic Models

As indicated previously, one of the objectives of the supplementary hydrology studies was to use the results of the hydrologic/water quality models to test, and potentially improve, the accuracy and reliability of the more rapid, indicator-based Hydrologic and Water Quality Integrity Index (Smith et al. 2005, see Appendix A). In the San Jacinto, Santa Margarita, and Otay watersheds the lack of adequate water quality data prohibited development of the water quality component of the HSPF, GSSHA, and MIKE SHE models, and therefore, testing of the Water Quality Integrity Index. The late completion (April 2005) of the hydrology component of the GSSHA model (Fong 2005), and the inability to calibrate the hydrology component of the MIKE SHE model (Zhonglong and Johnson 2003), prohibited use of these results in testing the Hydrology Integrity Index. For these reasons, testing of the Hydrologic Integrity Index was based on the results of the HSPF hydrologic models in the three watersheds.

Initial attempts to compare the results of the HSPF hydrologic model developed for the eastern portion of the San Jacinto watershed to the Hydrologic Integrity Index focused on comparing specific HSPF model parameters with specific Hydrologic Integrity Index indicators. This approach proved unsatisfactory because none of model parameters corresponded well to the physical characteristics measured by the Hydrologic Integrity Index indicators, and therefore direct comparisons were not possible.

The approach was expanded in the Santa Margarita watershed. In this watershed the focus was on a comparison of the change in hydrologic conditions under existing and "culturally unaltered" conditions as predicted by the calibrated HSPF hydrology model against the change in hydrologic integrity as predicted by the Hydrologic Integrity Index. In the Santa Margarita, PEST was used in its predictive analysis mode to assess for the range of model predictions for key model outcomes. Predictive analysis model runs in PEST were based on the arbitrary specification that the model was still assumed to be calibrated for the objective function values five percent greater that the minimum objective function value obtained for the calibrated model. Figure 3 shows PEST predictive analysis results, based on maintaining desired model complexity for the 106 subasins in the Murrieta Creek drainage basin, for the differences in total summed 1996 annual flow between current and culturally unaltered conditions. The culturally unaltered condition was simulated by setting the directly connected impervious cover in the drainage basin to zero. The PEST predictive analysis results indicated that the calibrated hydrology model was able to detect change in hydrology between the current and the culturally unaltered condition.

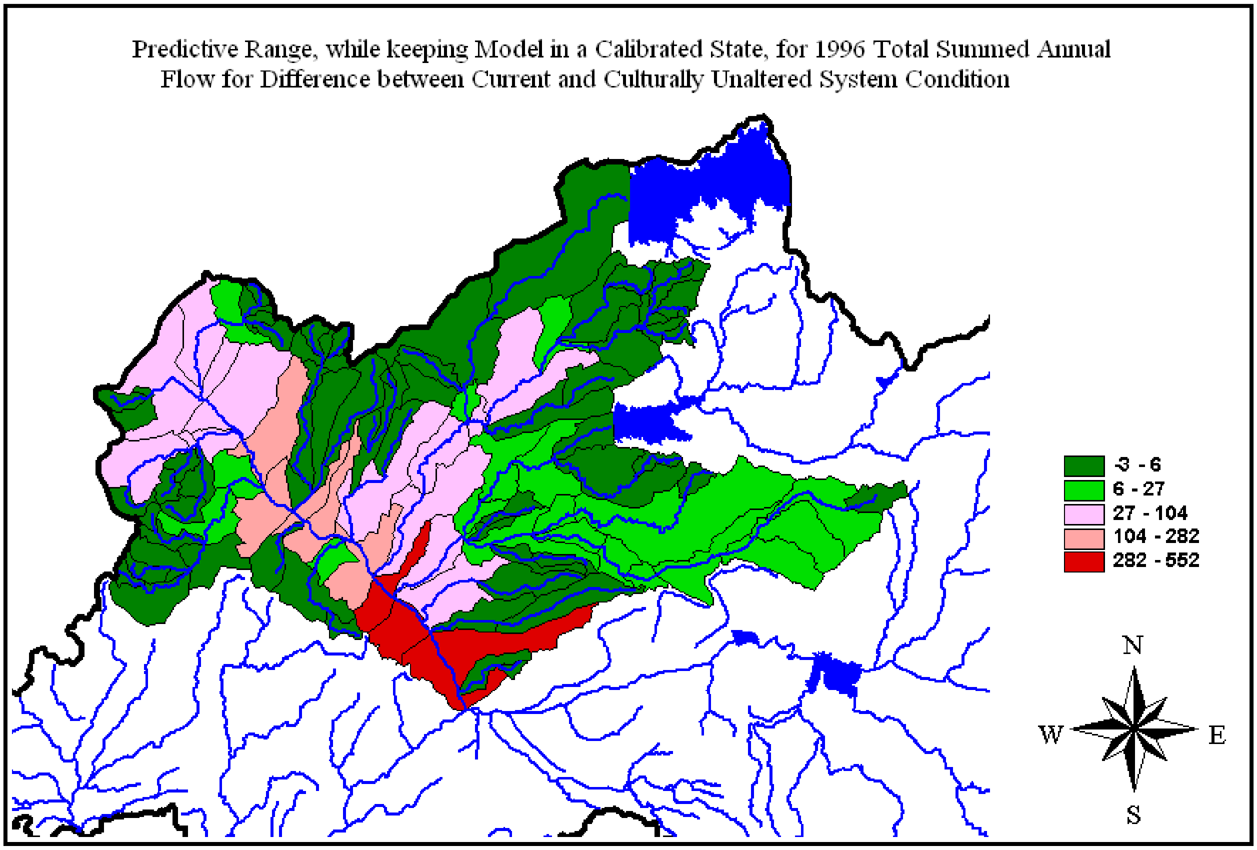


Figure 3. PEST predictive analysis results for Murrieta Creek drainage basin

Figure 4 shows the Hydrologic Integrity Indices for the 106 subasins in the Murrieta Creek drainage basin. These indices reflect deflection of the current condition from the culturally unaltered condition, and thus should be comparable to differences in summed 1996 annual flow shown in Figure 3. Examination of the two figures reveal some similarities and well as some differences. For example, many of the subasins show similar trends between the differences in summed annual flow and the Hydrologic Integrity Index. Other subasins, notably, 3, 4, 6, 84, and 106 show little change based on summed annual flows, but relatively significant changes based on the Hydrologic Integrity Index. These differences most likely reflect the influence of indicators in the index that are unrelated to changes in land use land cover (i.e., shift from directly connected impervious cover to pervious).

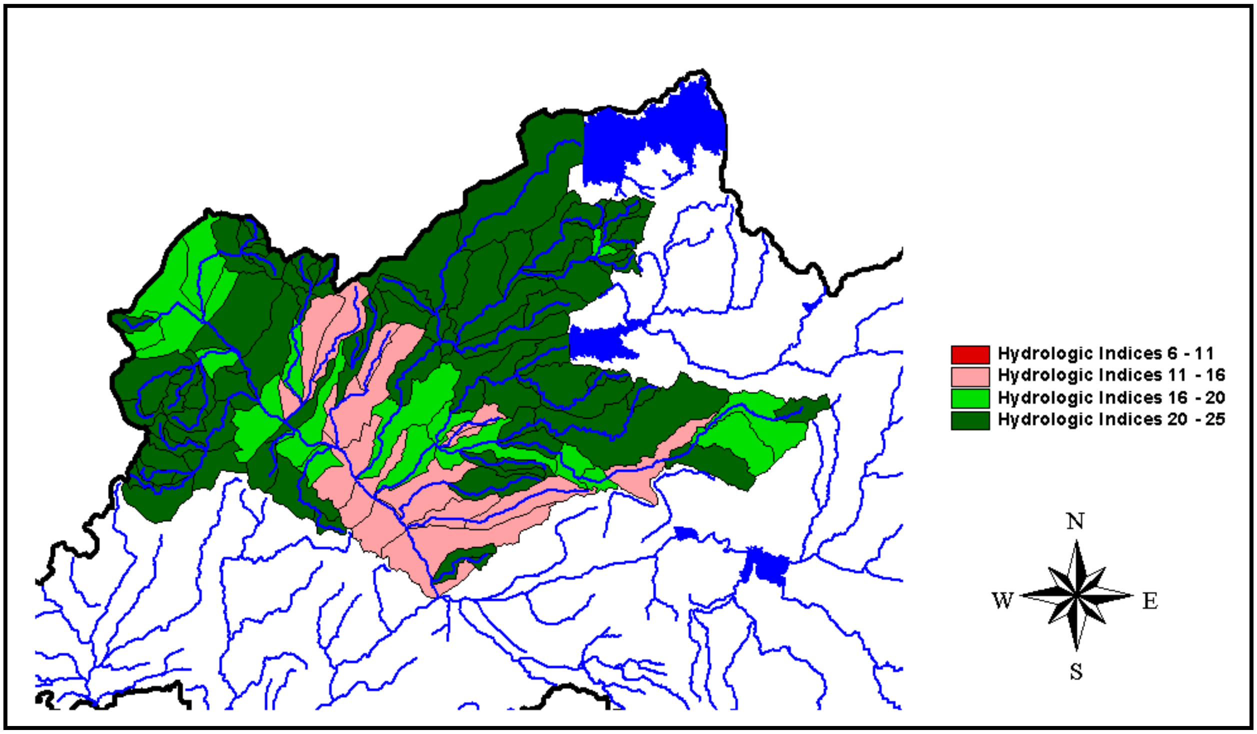


Figure 4. Hydrologic Integrity Indices for Murrieta Creek drainage basin

The approach was expanded further in the Otay watershed. In this watershed the focus remained on a comparison of the change in hydrology under existing and "culturally unaltered" conditions as predicted by the calibrated and verified HSPF hydrologic model against the change in hydrologic integrity as predicted by the Hydrologic Integrity Index. However, we also calculated indicators of hydrologic alteration (IHA) (Richter et al. 1996, Nature Conservancy 2005) and compared selected IHA parameters under the current and culturally altered condition.

The concept of natural flow regime inherent to IHA focuses on the importance of the range of natural variation in hydrologic regimes (Poff et al. 1997). Inter-annual and intra-annual variation such as seasonal flow patterns; frequency, duration, and predictability of floods, droughts, and intermittent flows, timing of extreme flows; daily, seasonal, and annual flow variability; and rates of change play a critical role in maintaining biodiversity and the evolutionary potential of aquatic, riparian, and wetland ecosystems (Poff and Ward 1989, Poff et al. 1997, Richter et al. 1996).

A daily streamflow data file for the water years October 1986 through September 1996 was prepared for input to the IHA Version 7 software for the subasins above the Lower Otay reservoir. The calibrated and verified Otay HSPF hydrologic model, and the meteorological data used to calibrate and verify this model were used to generate the data. A second daily streamflow data file representing the culturally altered condition was also prepared for the same time period. The calibrated and verified Otay HSPF hydrologic model, and the meteorological data used to calibrate and verify this model were used to generate the data with the following modifications: 1) changes to the SCHEMATIC block of the UCI file to include land cover and soils for the culturally unaltered condition; 2) removal of drafts from the Barrett reservoir via Dulzura Creek; and 3) removal of the Upper and Lower Otay reservoirs. In order for the IHA software to analyze the culturally altered conditions and current condition as two distinct time periods (i.e., pre-impact vs post-impact) the dates of the daily streamflow file for the culturally unaltered condition (pre-impact time period) were set to reflect water years October 1976 through September 1986, and the dates for the current condition (post-impact time period) remained water years October 1986 through September 1996. The IHA software was used to calculate 33 IHA parameters. The non-parametric option was selected for calculating parameters statistics. An additional 12 parameters were calculated using the mean monthly flow output from the IHA software. These additional parameters were the mean the coefficient of variation of monthly flow.

In order to compare the change IHA parameter values and HYII values under pre-and post-impact conditions a spreadsheet was constructed to subtract post-impact values from pre-impact values for IHA parameter values and HYII values. Using statistical software (Data Desk® 6.0) a Pearson Product-Moment correlation coefficient was calculated between the change in each IHA parameter and the change in the HYII for each subasin above the Lower

Otay reservoir. Some of the HYII indicators and IHA parameters were transformed to improve normality. Table 5 shows the result of this analysis for drainage basin scale indicators versus selected IHA parameters. Low flow IHA parameters that showed no change under pre-impact and post-impact condition were not included in Table 5. Only the drainage basin scale indicators were analyzed because they reflect the same spatial scale as the IHA parameters. That is, IHA parameters for each subasin were based on flow at the downstream end of each subasin which included the entire unstream drainage basin (i.e., all upstream subasins) from that point.

The low to moderate correlations coefficients between HYII and IHA parameters (Table 5, Column 8) reflects the differences in IHA parameters and HYII. The IHA parameters focus strictly on different components of the flow regime including: 1) magnitude of monthly water conditions, 2) magnitude and duration of annual extreme water conditions, 3) timing of annual extreme water conditions, 4) frequency and duration of high and low pulses, and 5) rate and frequency of water condition changes. The HYII, on the other hand, measures the hydrologic integrity of the riparian ecosystem, and includes indicators at the riparian reach, local drainage, and drainage basin scale (Appendix A) some of which are not, or only indirectly, related to flow regime or the drainage basin spatial scale (i.e., Floodplain Interaction indicator, Impervious Land in the Local Drainage, and Import, Export, and Diversion in the Riparian Reach). Thus the formulation of the HYII reflects the fact that while flow regime in the stream channel adjacent to a riparian ecosystem plays a significant role in maintaining the hydrologic integrity of riparian ecosystems, other factors at different spatial scales must should be considered. Consequently, the low to moderate correlations between the HYII and IHA parameters are not unexpected.

The five individual drainage basin indicators related to flow regime (Table 5, Columns 3-7) showed a variety of correlation coefficients to different IHA parameters ranging from r = 0.07 to 0.98. Two if these five indicators, Perennialized Stream Flow and Import, Export and Diversion had high correlation coefficients with a number of IHA parameters. The remaining three indicators, Improved Hydraulic Conveyance, Surface Water Detention, and Impervious Land Cover had generally moderate to low correlation coefficients with IHA parameters.

There are several possible explanations to account for the moderate to low correlations. In the case of the Improved Hydraulic Conveyance indicator, the indicator is not designed to reflect the quantity of flow, rather the velocity at which water moves downstream. Thus it could

Table 5. Correlation coefficients between IHA parameters, Hydrologic Integrity Index, and selected indicators

Olden and Poff (2003) Code	IHA Parameter Description	Improved Hydraulic Conveyance (Drainage Basin)	Perennialized Stream (Drainage Basin)	Import, Export, Diversion (Drainage Basin)	Surface Water Detention (Drainage Basin)	Impervious Land (Drainage Basin)	Hydrologic Integrity Index
M_A13	(1) Mean Monthly Flow - November	-0.07	0.96	0.97	0.30	0.18	0.49
M_A14	(1) Mean Monthly Flow - December	0.11	-0.98	-0.98	0.37	0.38	0.41
M_A15	(1) Mean Monthly Flow - January	0.47	-0.87	-0.89	0.20	0.54	0.34
M_A16	(1) Mean Monthly Flow - February	0.16	-0.82	-0.82	0.47	0.36	0.48
M_A17	(1) Mean Monthly Flow - March	0.16	-0.97	-0.97	0.44	0.33	0.45
M_A18	(1) Mean Monthly Flow - April	0.46	-0.78	-0.76	0.19	0.64	0.36
M_A19	(1) Mean Monthly Flow - May	-0.10	-0.88	-0.87	0.63	0.33	0.49
M_A20	(1) Mean Monthly Flow - June	-0.66	0.95	0.97	0.00	0.83	-0.13
M_A21	(1) Mean Monthly Flow - July	-0.65	0.96	0.97	0.00	0.80	-0.17
M_A22	(1) Mean Monthly Flow - August	-0.66	0.95	0.96	0.00	0.84	-0.14
M_A23	(1) Mean Monthly Flow - September	-0.65	0.96	0.97	0.00	0.81	-0.17
M_A24	(1) CV of Mean Monthly Flow - October	0.38	0.98	0.99	0.19	-0.02	-0.04
M_A25	(1) CV of Mean Monthly Flow - November	0.47	0.79	0.79	0.24	0.10	0.11
M_A26	(1) CV of Mean Monthly Flow - December	0.63	-0.10	-0.12	0.41	0.21	0.05
M_A27	(1) CV of Mean Monthly Flow - January	0.15	0.00	0.00	-0.23	0.36	-0.06
M_A28	(1) CV of Mean Monthly Flow - February	-0.37	0.00	0.00	-0.19	-0.41	-0.25
M_A29	(1) CV of Mean Monthly Flow - March	-0.28	0.00	0.00	-0.27	-0.05	0.07
M_A30	(1) CV of Mean Monthly Flow - April	0.11	0.95	0.96	0.17	-0.04	-0.06
M_A31	(1) CV of Mean Monthly Flow - May	0.14	0.97	0.98	-0.04	0.01	0.15
M_A32	(1) CV of Mean Monthly Flow - June	0.04	0.98	0.98	0.02	-0.04	0.00
M_A33	(1) CV of Mean Monthly Flow - August	0.09	0.98	0.98	0.27	0.46	0.35
M_A34	(1) CV of Mean Monthly Flow - September	0.50	0.98	0.98	0.57	0.47	0.43
(1) Magnitude of Monthly Conditions, (2) Magnitude and Duration of Annual Extremes, (3) Timing of Annual Extremes, (4) Frequency and Duration of High and Low Pulses, and (5) Rate and Frequency of Change							

Table 5. cont.

Olden and Poff (2003) Code	IHA Parameter Description	Improved Hydraulic Conveyance (Drainage Basin)	Perennialized Stream (Drainage Basin)	Import, Export, Diversion (Drainage Basin)	Surface Water Detention (Drainage Basin)	Impervious Land (Drainage Basin)	Hydrologic Integrity Index
D_H1	(2) Annual Maxima 1-day Mean	0.29	-0.93	-0.93	0.30	0.62	0.36
D_H2	(2) Annual Maxima 3-day Mean	0.38	-0.51	-0.48	0.44	0.61	0.41
D_H3	(2) Annual Maxima 7-day Mean	0.37	-0.94	-0.95	0.45	0.57	0.45
D_H4	(2) Annual Maxima 30-day Mean	0.32	-0.83	-0.82	0.29	0.60	0.38
D_H5	(2) Annual Maxima 90-day Mean	0.34	-0.83	-0.86	0.45	0.40	0.43
D_L18	(2) Number of Zero Flow Days	1.00	0.00	0.00	0.07	-0.53	-0.29
T_H1	(3) Julian Date 1-day Maximum	0.19	0.00	0.00	0.13	0.09	0.03
F_H1	(4) High Pulse Count	0.44	-0.71	-0.70	0.43	0.48	0.15
D_H15	(4) Mean Duration of High Pulse	0.01	0.29	0.29	0.00	0.68	0.64
R_A1	(5) Rise Rate	0.14	-0.96	-0.96	0.19	0.43	0.28
R_A3	(5) Fall Rate	1.00	0.00	0.00	-0.39	-0.25	0.12
R_A8	(5) Number of Reversals	0.05	0.69	0.71	0.05	0.44	0.36

(1) Magnitude of Monthly Conditions, (2) Magnitude and Duration of Annual Extremes, (3) Timing of Annual Extremes, (4) Frequency and Duration of High and Low Pulses, and (5) Rate and Frequency of Change

be expected to be reflected in the IHA parameters related to timing, frequency and duration, and rates of change, and not magnitude. The correlation coefficients between this indicator and these types of timing, frequency, and duration, and rates of change were all low to moderate. The most likely explanation for this is that there were few channels with improved hydraulic conveyance in the subasins above the Lower Otay reservoir. Thus, while changes in IHA parameters did occur between pre-impact and post-impact condition, little of the change that occurred could be tied to improved hydraulic conveyance, and therefore, low to moderate correlation coefficients would be expected. In the case of the Surface Water Detention indicator, the situation was similar to that of Improved Hydraulic Conveyance. There were only a few small surface water detention areas in the subasin above the Lower Otay reservoir and therefore little of the observed change in IHA parameters could be tied to changes in Surface Water Detention. In the case of the Impervious Land Surface indicator, it is possible that the indicator is insensitive in the current formulation. Testing with a reformulated indicator has taken two approaches. One approach which incorporates pre-impact changes from naturally vegetated lands to agricultural and grazing lands into the indicator has shown promise in two northern California watersheds. The other approach, as yet untested, involves utilized runoff coefficients based on land use and soils data.

A wide variety of indices to characterize flow regimes have been developed over the years, but little guidance has been developed to answer the question of which indices and how many are necessary to adequately represent the characteristics of flow regime (Olden and Poff 2003). To address this question, Olden and Poff (2003) conducted a comprehensive review and analysis of 171 hydrologic indices using long-term flow records from 420 sites across the continental United Stated. They classified streams into six types including: 1) harsh intermittent, 2) intermittent flashy or runoff, 3) snowmelt, 4) snow and rain 5) stable groundwater, and 6) perennial flashy or runoff. For each stream type they identified the hydrologic indices with the largest absolute loading for each of the two to four statistically significant principal components in terms of the five flow regime components including: 1) Magnitude of Monthly Conditions, 2) Magnitude and Duration of Annual Extremes, 3) Timing of Annual Extremes, 4) Frequency and Duration of High and Low Pulses, and 5) Rate and Frequency of Change. The intent of the analysis was to highlight patterns of redundancy among the indices, provided recommendations for selecting a reduced set of indices that simultaneously explain the dominant proportion of statistical variation present in a complete set of indices, and minimize multicollinearity, while still adequately representing the critical attributes of flow regime.

Based on the Olden and Poff's (2003) analysis six IHA parameters were selected (Table 5 shaded rows) to test the ability of HYII drainage basin indicators to predict the change in IHA parameters under pre-impact versus post-impact conditions using multiple regression. The six parameters were those with the largest absolute loading on the first or second statistically significant principal component for the harsh intermittent stream type of which the Otay watershed is an example. The selection process was constrained by the fact that Olden and Poff (2003) included a number of hydrologic indices other that the IHA parameters in their analysis, and by the fact that in the IHA analysis conducted for the subasins above the Lower Otay reservoir, several low flow IHA parameters showed no change under pre-impact and post-impact condition and therefore could not be used. The six parameters selected represented four of the five flow regime components including: 1) Magnitude of Monthly Conditions; 2) Timing of Annual Extremes; 3) Frequency and Duration of High and Low Pulses; and 4) Rate and Frequency of Change. It was not possible to conduct the analysis for Magnitude and Duration of Annual Extremes because of the constraints identified above.

Tables 6-9 provide representative results of multiple regression analysis for the four flow components. Various combinations of HYII drainage basin indicator predictor variables

Table 6. Regression of HYII indicators against M_A16 IHA parameter representing (1) Timing of Annual Extremes flow regime component

Dependent variable: M_A16				
$R^2 = 92.0\%$	R^2 (adjusted) = 86.7%	s = 0.04232 with 11 - 5 = 6 df		
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.12346	4	0.0308645	17.2
Residual	0.01074	6	0.00179061	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-0.22930	0.201	-1.14	≤ 0.297
Perennialized Stream	16.7522	6.299	2.66	≤ 0.035
Import Export Diversion	-18.8483	5.689	-3.31	≤ 0.016
Impervious Land	-3.40352	1.191	-2.86	≤ 0.029
Hydraulic Conveyance	-1.37449	0.331	-4.15	≤ 0.006

Table 7. Regression of HYII indicators against D_H5 IHA parameter representing (3) Rate and Frequency of Change flow regime component

Dependent variable: D_H5				
$R^2 = 96.4\%$	R^2 (adjusted) = 94.9%	s = 0.2165 with 11 - 4 = 7 df		
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	8.81177	3	2.93726	62.7
Residual	0.32812	7	0.0468739	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	14.7457	0.3842	38.4	≤ 0.0001
Perennialized Stream	269.678	31.48	8.57	≤ 0.0001
Import Export Diversion	-266.105	28.5	-9.34	≤ 0.0001
Hydraulic Conveyance	-4.43385	1.095	-4.05	≤ 0.0049

Table 8. Regression of HYII indicators against T_H1 IHA parameter representing (4) Frequency and Duration of High and Low Pulses flow regime component

Dependent variable: T_H1				
$R^2 = 94.7\%$	R^2 (adjusted) = 92.5%	s = 0.8336 with 11 - 4 = 7 df		
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	87.2717	3	29.0906	41.9
Residual	4.8647	7	0.694957	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	4.60126	3.949	1.17	≤ 0.2821
Import Export Diversion	-82.6827	10.84	-7.62	≤ 0.0001
Hydraulic Conveyance	26.0846	6.388	4.08	≤ 0.0047
Impervious Land	98.8455	22.92	4.31	≤ 0.0035

Table 9. Regression of HYII indicators against R_A1 IHA parameter representing (5) Rate and Frequency of Change flow regime component

Dependent variable: R_A1				
$R^2 = 95.8$	R^2 (adjusted) = 94.9%	s = 0.005346 with 13 - 3 = 10 df		
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.00647651	2	0.00323826	113
Residual	0.0002858	10	0.00002858	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.0083136	0.004194	1.98	≤ 0.0756
Impervious Land	-0.158709	0.06043	-2.63	≤ 0.0253
Import Export Diversion	0.76675	0.06298	12.2	≤ 0.0001

resulted in a linear multiple regression equation with an $R^2 > 0.90$. This indicates that in the subasin above the Lower Otay reservoir, various combinations of HYII drainage basin indicators provide a good prediction of four out of five flow regime components.

In summary, the HYII index was moderately to poorly correlated with most IHA parameters. This was due to several factors. First, the HYII includes indicators that are unrelated to flow regime and indicators at different spatial scales than the drainage basin scale of IHA parameters. Second, two indicators exhibited little change between pre-impact and post impact conditions and were therefore uncorrelated with IHA parameters that exhibited change due to other factors. Third, one of the indicators was shown to be relatively insensitive to pre-impact versus post-impact condition. As a result the lack of high correlations between HYII and IHA parameters was not unexpected. Conversely, several HYII drainage basin indicators were found to be highly correlated to key IHA parameters that had been found to be the best predictors of flow regime components. Analysis using multiple regression indicated that various linear combination of these indicators were able to predict the value of four out of five of the key IHA parameters with an $R^2 > 0.90$.

Literature Cited

Beals, E. W. 1984. Bray-Curtis ordination: an effective strategy for analysis of multivariate ecological data. Advances in Ecological Research 14: 1-55.

Beven, K. 1998. Generalized Likelihood Uncertainty Estimates (GLUE). Department of Environmental Science, Institute of Environmental and Natural Sciences, Lancaster University, Lancaster, UK.

Clark, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18: 117-143.

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

Doherty, J. 2002. PEST-ASP User's Manual. Watermark Numerical Computing, Brisbane, Australia.

Donigian, A.S. Jr., Bicknell, B.R., and Imhoff, J.C. 1995. Hydrologic Simulation Program - FORTRAN. Computer Models of Watershed Hydrology. Pages 395-442 in V.P. Singh (ed.). Water Resources Publications, Highlands Ranch, Colorado.

Donigian, A.S. Jr., and Davis, H.H. 1978. User’s Manual for Agricultural Runoff Management (ARM) Model. EPA-600/3-78-080. U.S. Environmental Research Laboratory, Athens, GA.

Donigian, A.S. Jr., Imhoff, J.C., and Kittle, Jr., J.L. (1999). “HSPF-Parm: An Interactive Database of HSPF Model Parameters.” Version 1.0, EPA-823-R-99-004.

Downer, C. W. 2002. Identification and Modeling of Important Stream Flow Producing Processes in Watersheds. PhD Dissertation. University of Connecticut.

Downer, C. W., Nelson, E. J., and Byrd, A. 2002. Primer: Using Watershed Modeling System (WMS) for Gridded Surface Subsurface Hydrologic Analysis (GSSHA) Data Development—WMS 6.1 and GSSHA 1.43C. ERDC/CHL TR-02-XX.

Duan, Q. S., Sorooshian, and H. V. Gupta. 1992. Effective and efficient global optimization for conceptual rainfall-runoff models. Water Resources Research 28: 1015-1031.

Fong, M. 2005. Gridded Surface Subsurface Hydrologic Analysis of the Perris Basin of the San Jacinto River Watershed. US Army Engineer Research and Development Center Coastal and Hydraulics Laboratory. Vicksburg, MS

Guilfoyle, M. P., Wakeley, J. S., and Fisher, R. A. In Prep. Development, testing, and refinement of an avian index of biological integrity for riparian ecosystems in southern California.

Jakeman, A. J. and G. M. Hornberger. 1993. How much complexity is warranted in a rainfall-runoff model? Water Resources Research 29: 2637-2649.

Johanson, R. C., J. C. Imhoff, and H. H. Davis. 1980. User's Manual for the Hydrologic Simulation Program - Fortran (HSPF). EPA-600/9-80-105. U. S. EPA Environmental Research Laboratory, Athens, GA.

Karr, J. R. and E. W. Chu. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Washington, DC.

Kittle, Jr., J.L., Lumb, A.M., Hummel, P.R., Duda, P.B., and Gray, M.H. (1998). “A Tool for the Generation and Analysis of Model Simulation Scenarios for Watersheds (GenScn).” U.S. GEOLOGICAL SURVEY, Water-Resources Investigations Report 98-4134, Reston, Virginia.

Kruskal, J. B. 1964a. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 29: 1-27.

Kruskal, J. B., 1964b. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29: 115-129.

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

Lichvar, R, G. Gustina, and M. Ericsson. 2003. Planning Level Delineation and Geospatial Characterization of Aquatic Resources for San Jacinto and Portions of Santa Margarita Watersheds, Riverside County, California. Technical Report ERDC/CRREL TR-03-4. U.S. Army Corps of Engineers, Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Los Angeles District Corps of Engineers. 2000. Draft Scope of Work, Special Area Management Plan, Santa Margarita and San Jacinto Watersheds, Riverside County, California.

Mather, P. M., 1976. Computational Methods of Multivariate Analysis in Physical Geography. John Wiley and Sons, London.

McCune, B. and M. J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Gleneden Beach, Oregon, USA.

McCune, B. and J.B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design. Gleneden Beach, Oregon.

Montieth, J. L. 1975. Vegetation and the Atmosphere. Volume 2: Case Studies. Academic Press, New York.

Munson, A.D. 1998 . HSPF Modeling of the Charles River Watershed. M.S. Thesis, Department of Civil Engineering, Massachusetts Institute of Technology.

Nature Conservancy. 2005. Indicators of Hydrologic Alteration User's Manual, Version 7. The Nature Conservancy with Smythe Scientific Software and Totten Software Design.

Ogden, F. L. and B. Saghafian. 1997. Green and Ampt Infiltration with Redistribution. Journal of Irrigation and Drainage Engineering 123: 386-393.

Poff, N. L. and J. V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow pattern. Canadian Journal of Fisheries and Aquatic Sciences 46: 1805-1818.

Nash, J.E. and Sutcliffe, J.V. 1970. River Flow Forecasting Through Conceptual Models. Part 1 - A Discussion of Principles. Journal of Hydrology 10: 282-290.

Olden, J. D. and N. L. Poff. 2003. Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Research and Applications 19: 101-121.

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

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

Skahill, B. E. 2002. HSPF Modeling of the Eastern Part of The San Jacinto River Basin, Riverside County, California. U. S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS

Skahill, B. E. 2003. Watershed Modeling Demonstration Study in the Santa Margarita River Basin. U. S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

Skahill, B. E. and B. A. Kleiss. 2003. Use of the Hydrological Simulation Program – Fortran (HSPF) Model for Watershed Analysis. Technical Report ERDC TN-SMART-03-1. U. S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS. http://el.erdc.usace.army.mil/publications.cfm?Topic=technote&Code=smart

Skahill, B. E. 2005. HSPF Hydrologic Model Development, Calibration, Verification, and Prediction for the Otay River Basin. U. S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS

Smith, R. D. 2002. Alternatives Analysis for San Diego Creek Watersheds, Orange County, California: Potential Impacts to Waters of the United States and Riparian Ecosystems. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Final Report to the U. S. Army Corps of Engineers, Los Angeles District.

Smith, R.D. 2003. Assessment of Riparian Ecosystem Integrity: San Jacinto and Upper Santa Margarita River Watersheds, Riverside County, California. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Final Report to the U. S. Army Corps of Engineers, Los Angeles District.

Smith, R.D. 2004a. Assessment of Riparian Ecosystem Integrity: Otay River Watershed, San Diego County, California. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Final Report to the U. S. Army Corps of Engineers, Los Angeles District.

Smith, R. D. 2004b. Alternatives Analysis for San Juan and Western San Mateo Creek Watersheds, Orange County, California: Potential Impacts to Waters of the United States and Riparian Ecosystems. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Final Report to the U. S. Army Corps of Engineers, Los Angeles District.

Smith, R. D. and C. V. Klimas. 2004. Riparian Ecosystem Restoration Plan for the Santa Margarita River Watershed: General Design Criteria and Site Selection. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Final Report to the U. S. Army Corps of Engineers, Los Angeles District.

Smith, R. D., C. V. Klimas, and B. A. Kleiss. 2005. A Watershed Assessment Tool for Evaluating Ecological Condition, Proposed Impacts, and Restoration Potential at

Multiple Scales. Technical Report ERDC TN-SWWRP-05-3. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. http://el.erdc.usace.army.mil/publications.cfm?Topic=technote&Code=smart

Smith, R. D. and C. V. Klimas. 2006. Riparian Ecosystem Restoration Plan for the San Jacinto River Watershed: General Design Criteria and Site Selection. U. S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Final Report to the U. S. Army Corps of Engineers, Los Angeles District.

USACE (United States Army Corps of Engineers), and USEPA (United States Environmental Protection Agency). 2000. HSPF/WMS Training Workshop. Vicksburg, MS, September 19 – 21.

USEPA (United States Environmental Protection Agency). 1999. WDMUtil Version 1.0 (BETA) A Tool for Managing Watershed Modeling Time-Series Data User's Manual (DRAFT). Exposure Assessment Branch Standards and Applied Science Division Office of Science and Technology Office of Water 401 M Street, SW Washington, DC 20460.

USEPA (United States Environmental Protection Agency). (2000). “BASINS Technical Note 6 Estimating Hydrology and Hydraulic Parameters for HSPF.” Office of Water, July. (http://www.epa.gov/waterscience/ftp/basins/training/tutorial/TN6-final.htm)

Zhonglong, Z. and B. E. Johnson. 2003. MIKE SHE Flow Modeling System Evaluation for the Santa Margarita River Watershed. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

6.0 Appendix A

ERDC TN-SWWRP-05-3
December 2005

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

by R. D. Smith, C. V. Klimas, and B. A. Kleiss

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.

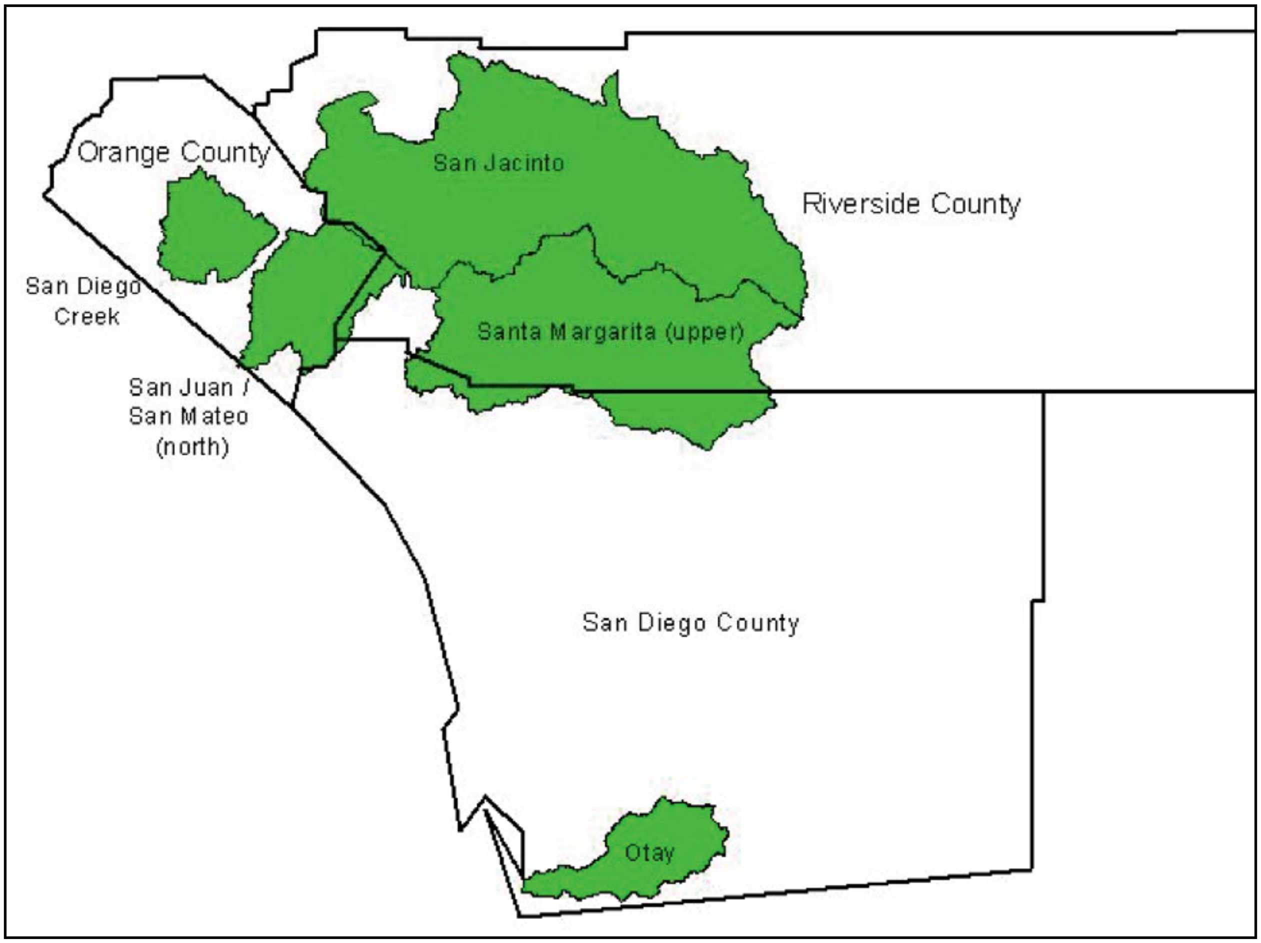


Figure 1. Location of southern California SAMP watersheds

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.

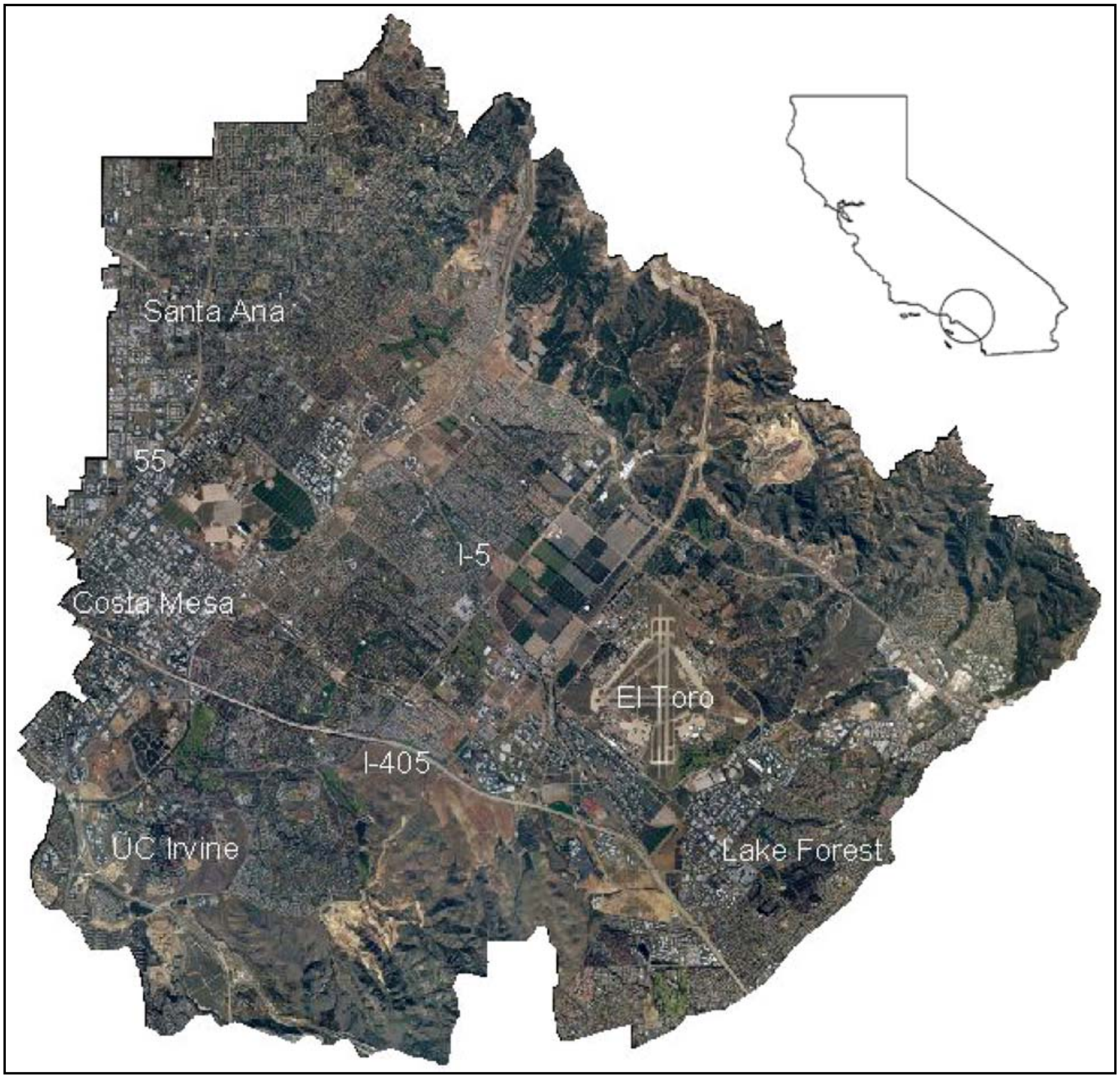


Figure 2. San Diego Creek watershed, Orange County, California

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).

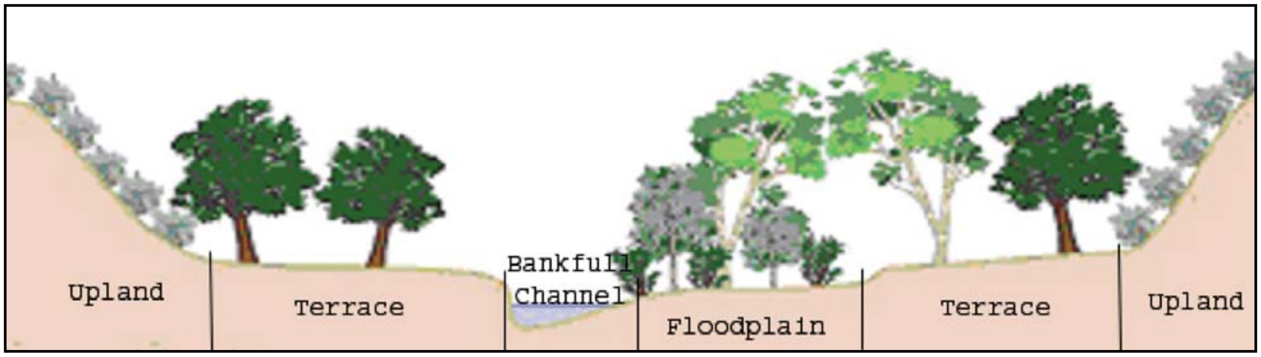


Figure 3. Illustration of riparian ecosystem geomorphic surfaces

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.

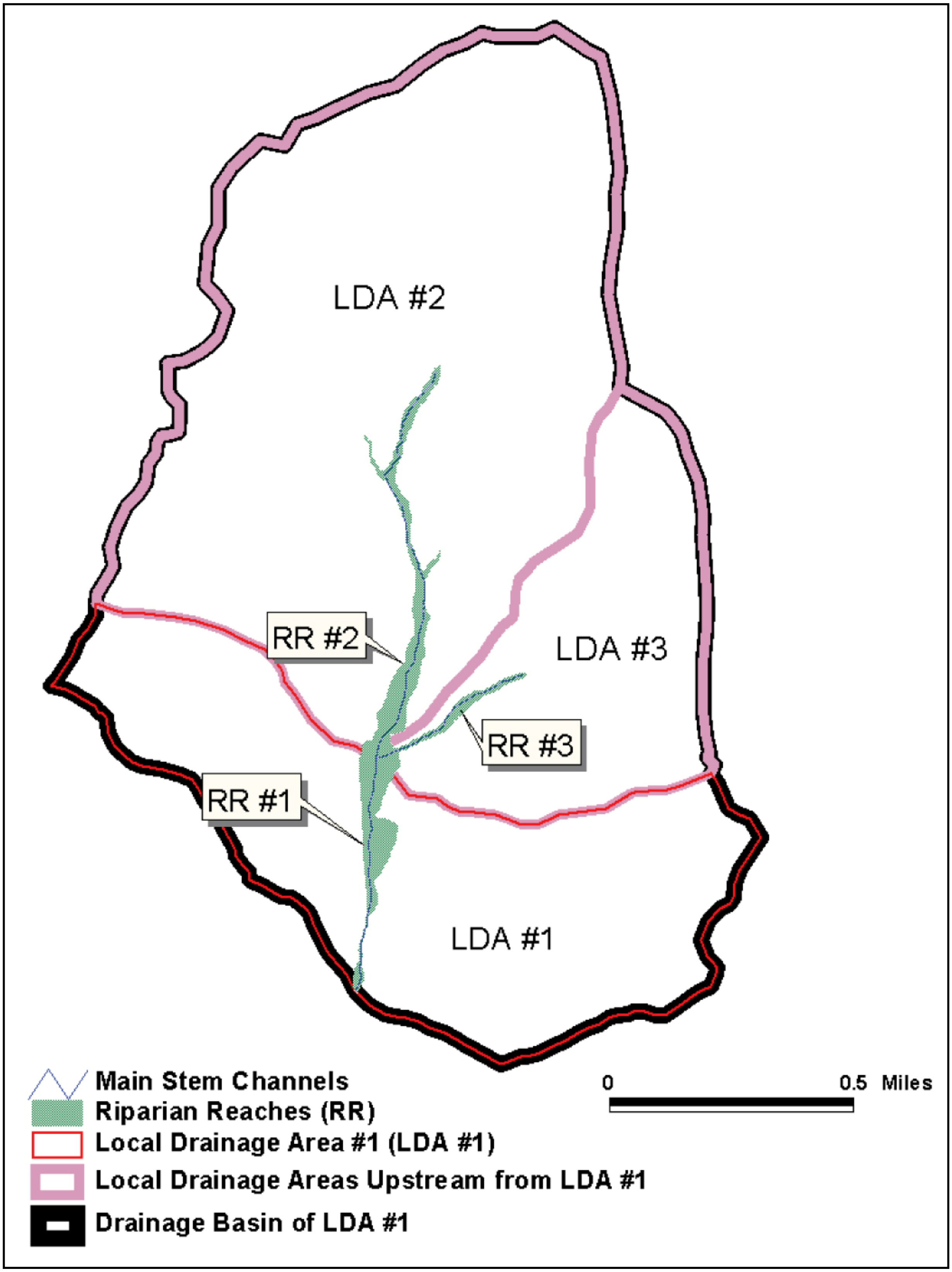


Figure 4. Relationship of riparian reaches, local drainage areas, and drainage basins

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

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

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

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

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.

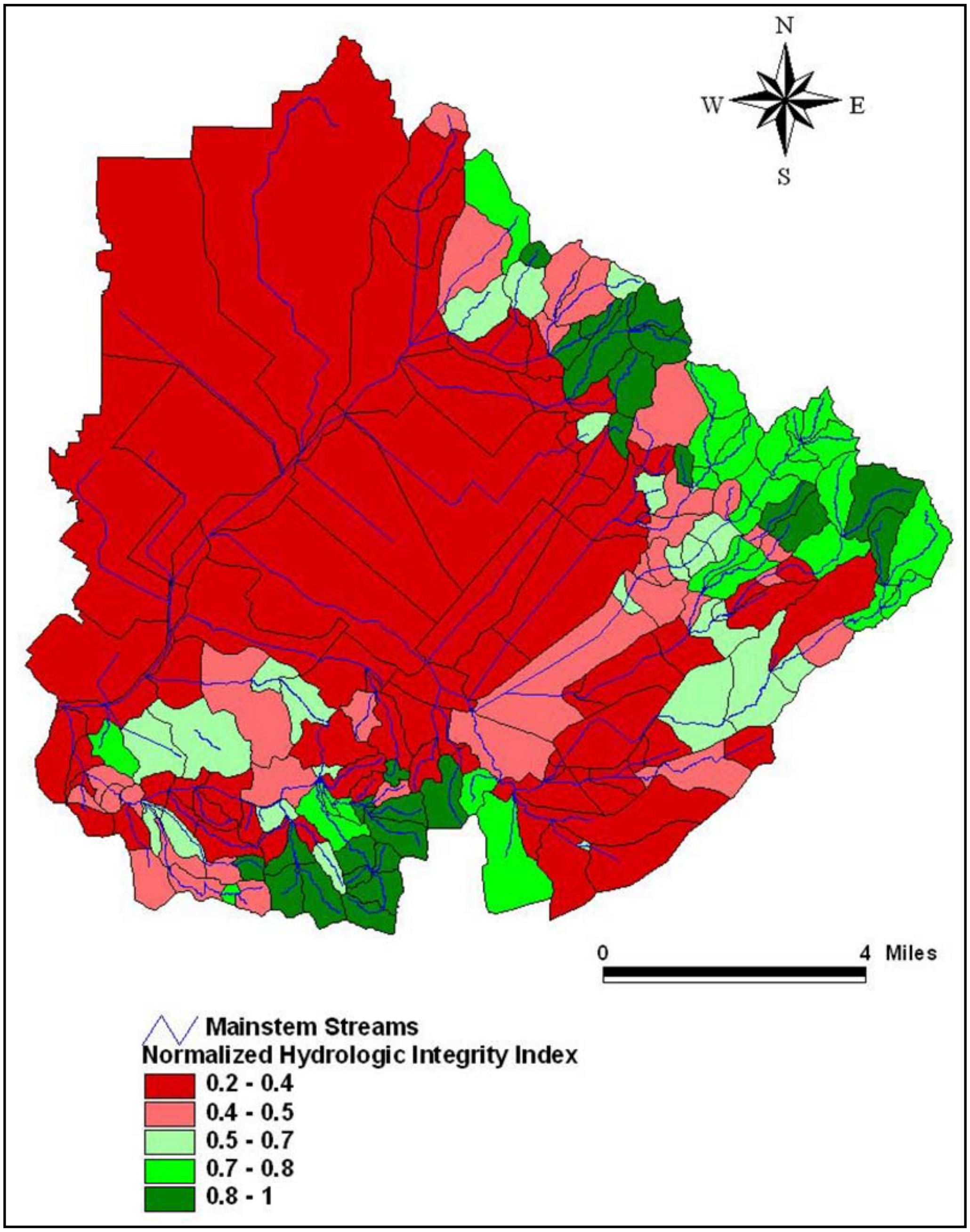


Figure 5. Hydrologic integrity indices (normalized) for riparian reaches in the San Diego Creek Watershed

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

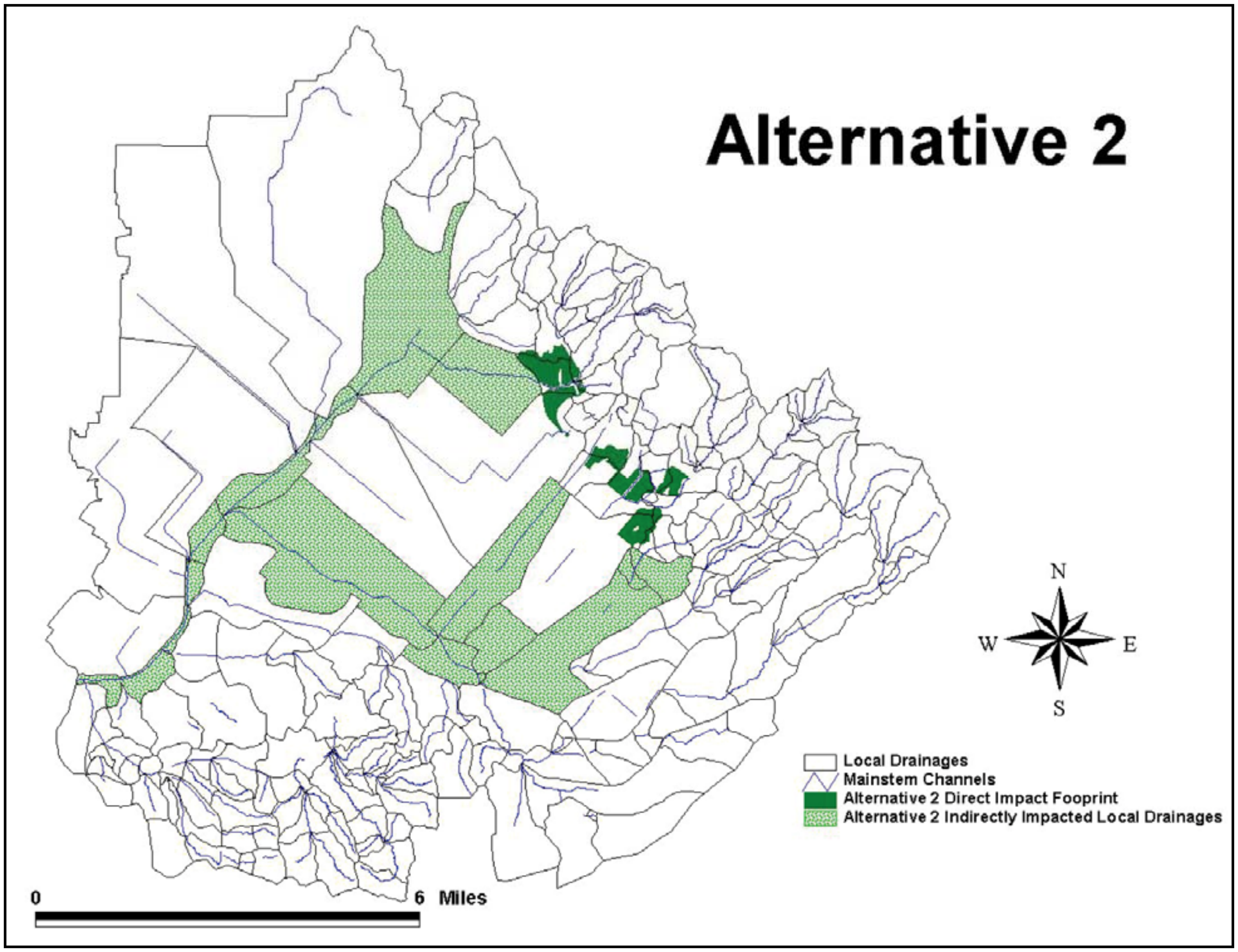


Figure 6. Alternative development scenario direct impact footprint and indirectly impacted local drainages

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.

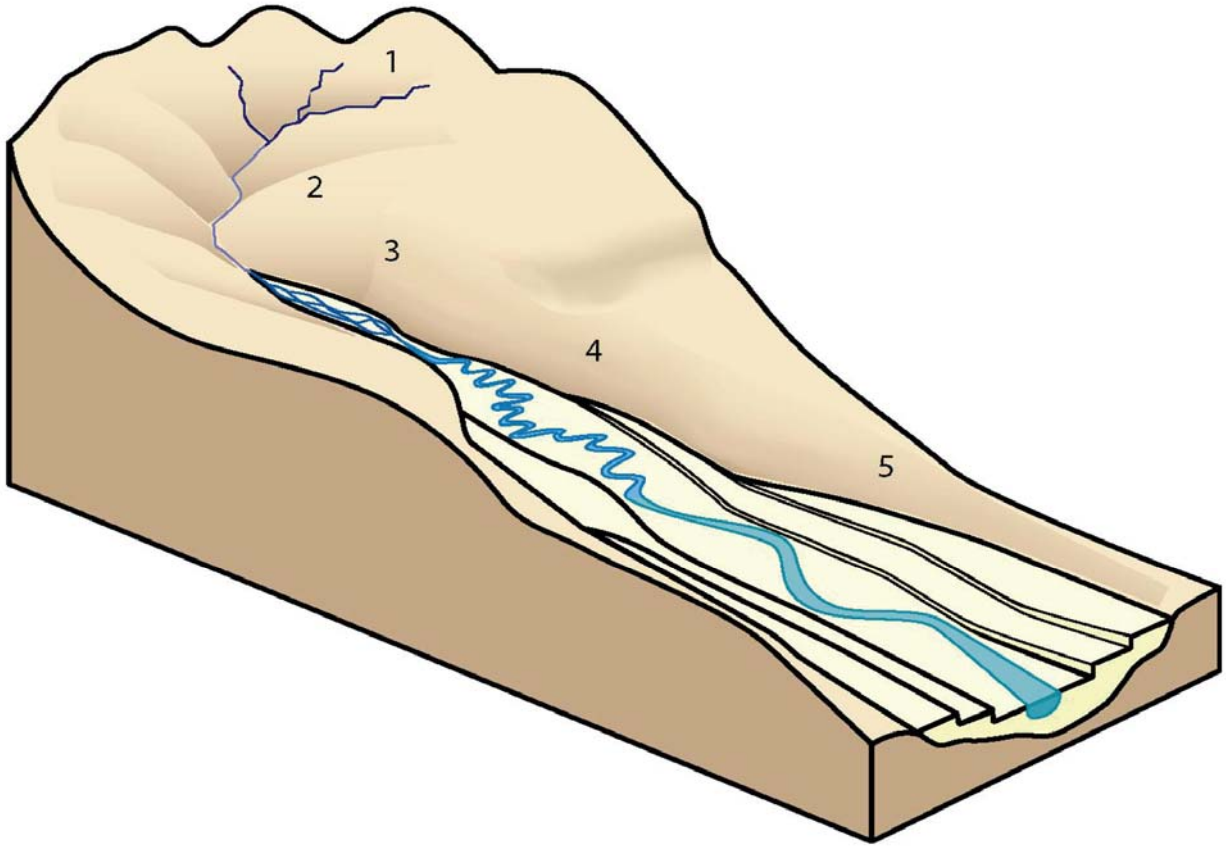


Figure 7. Generalized representation of landscape settings associated with geomorphic zones

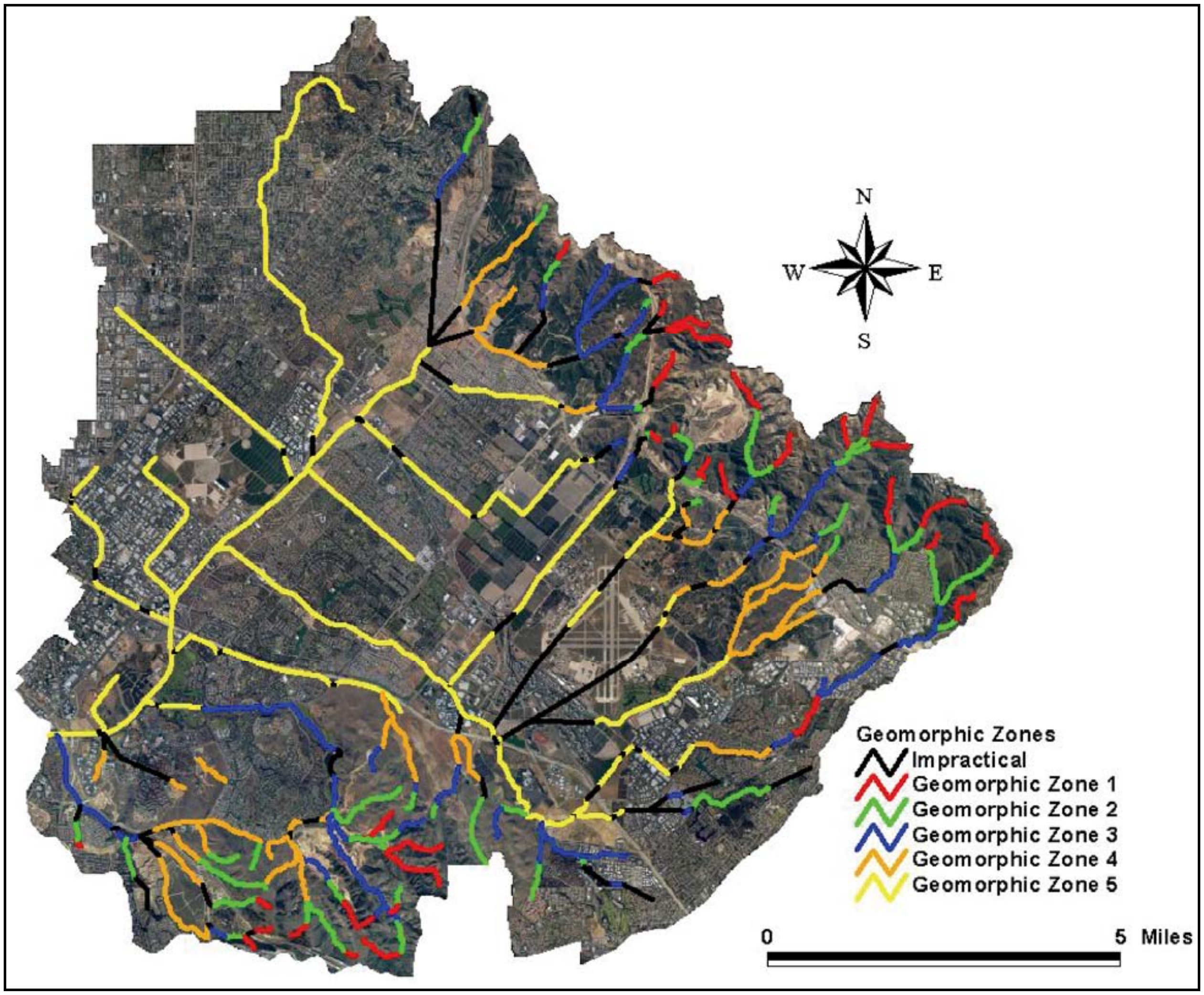


Figure 8. Geomorphic zones for riparian reaches in San Diego Creek watershed

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.

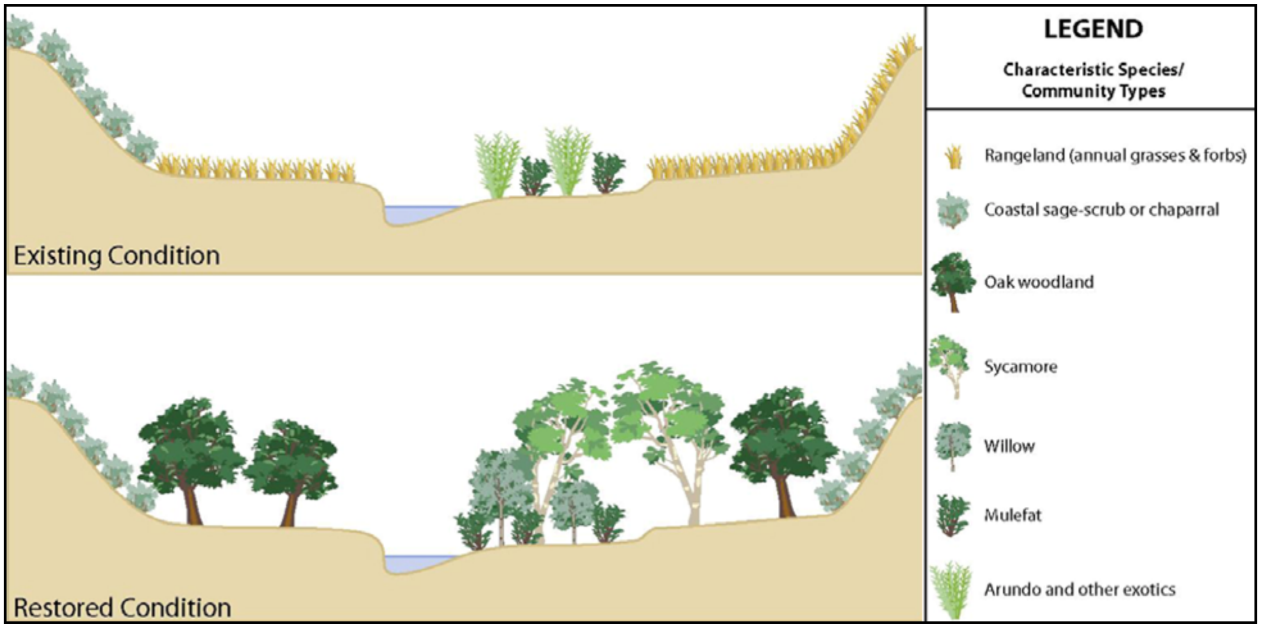


Figure 9. Typical pre- and post-restoration conditions of riparian reaches assigned to the natural template

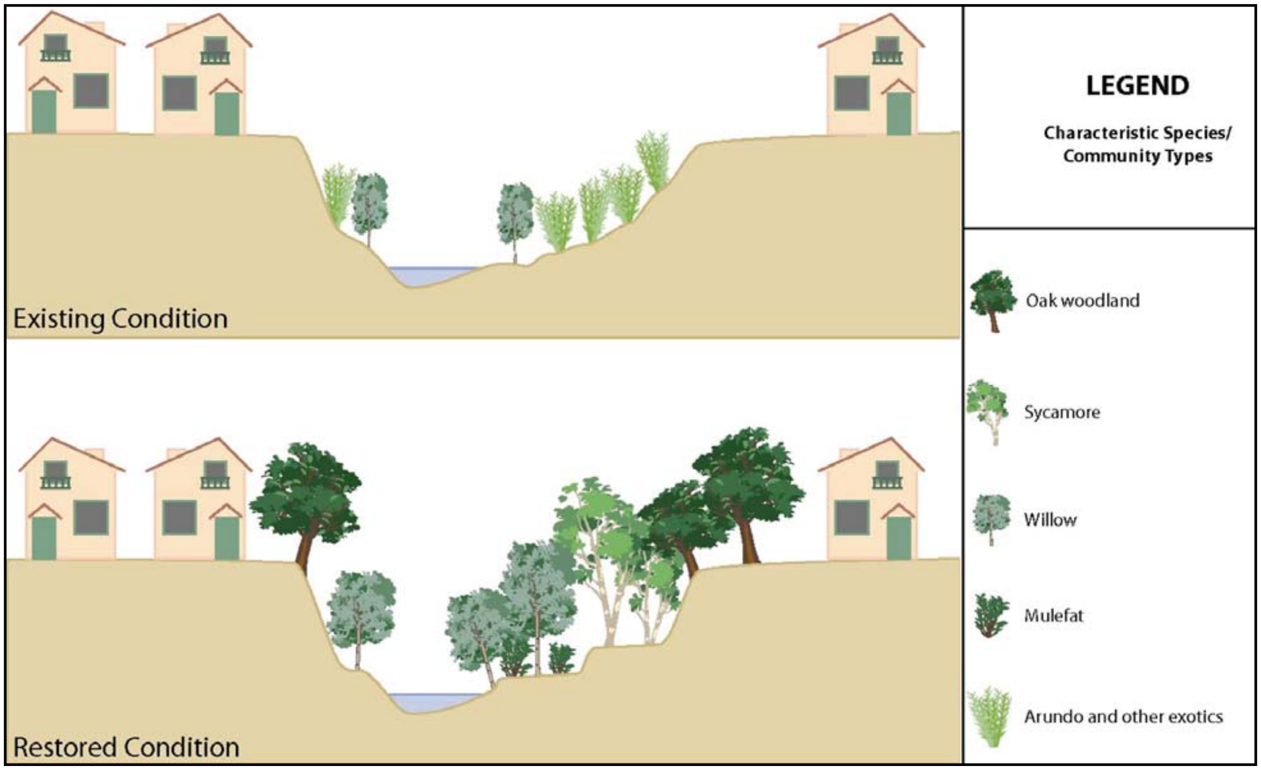


Figure 10. Typical pre- and post-restoration conditions of riparian reaches assigned to the constrained template

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.

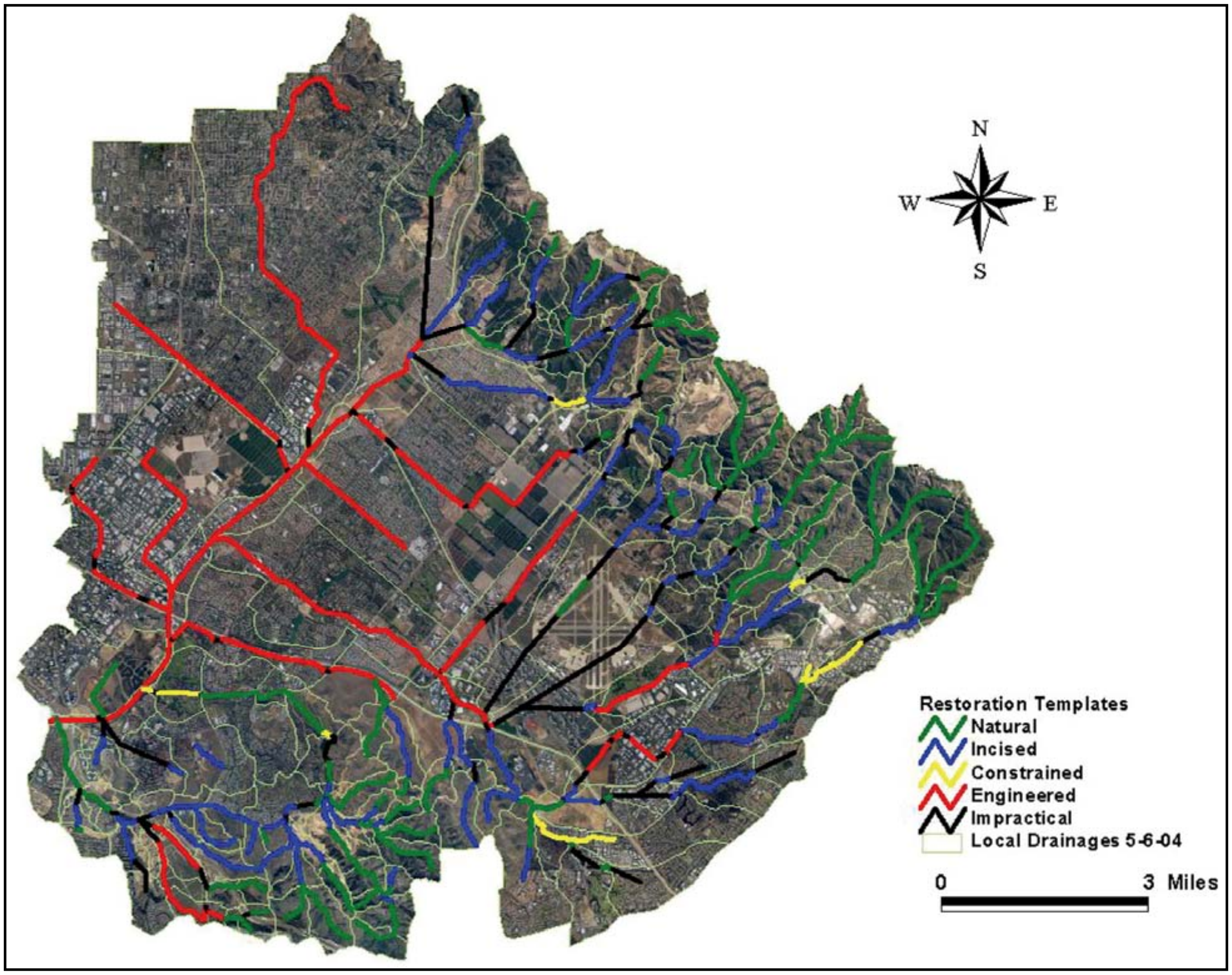


Figure 11. Restoration template assignments for riparian reaches in San Diego Creek watershed

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.

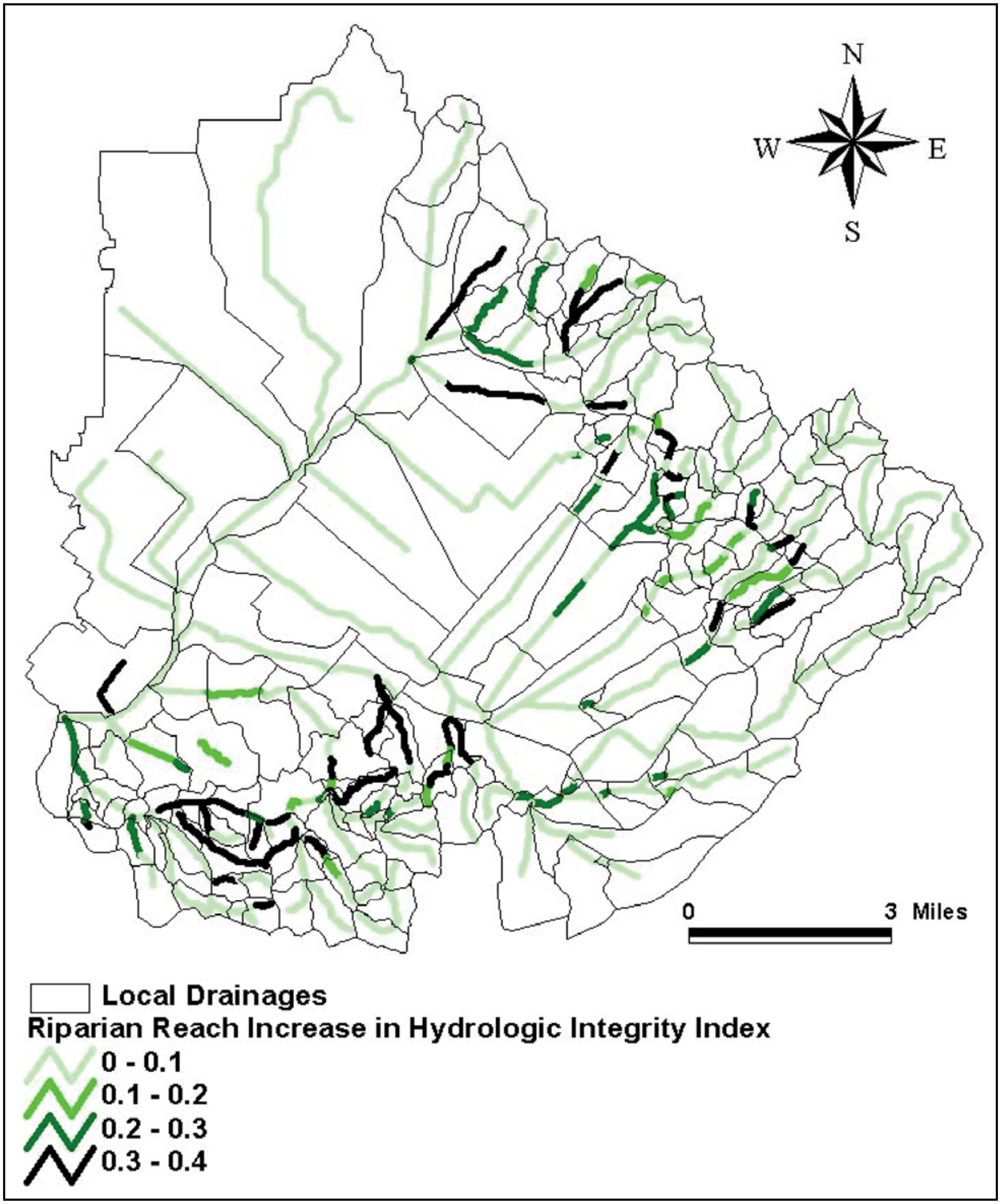


Figure 12. Hydrology index increase following restoration for riparian reaches

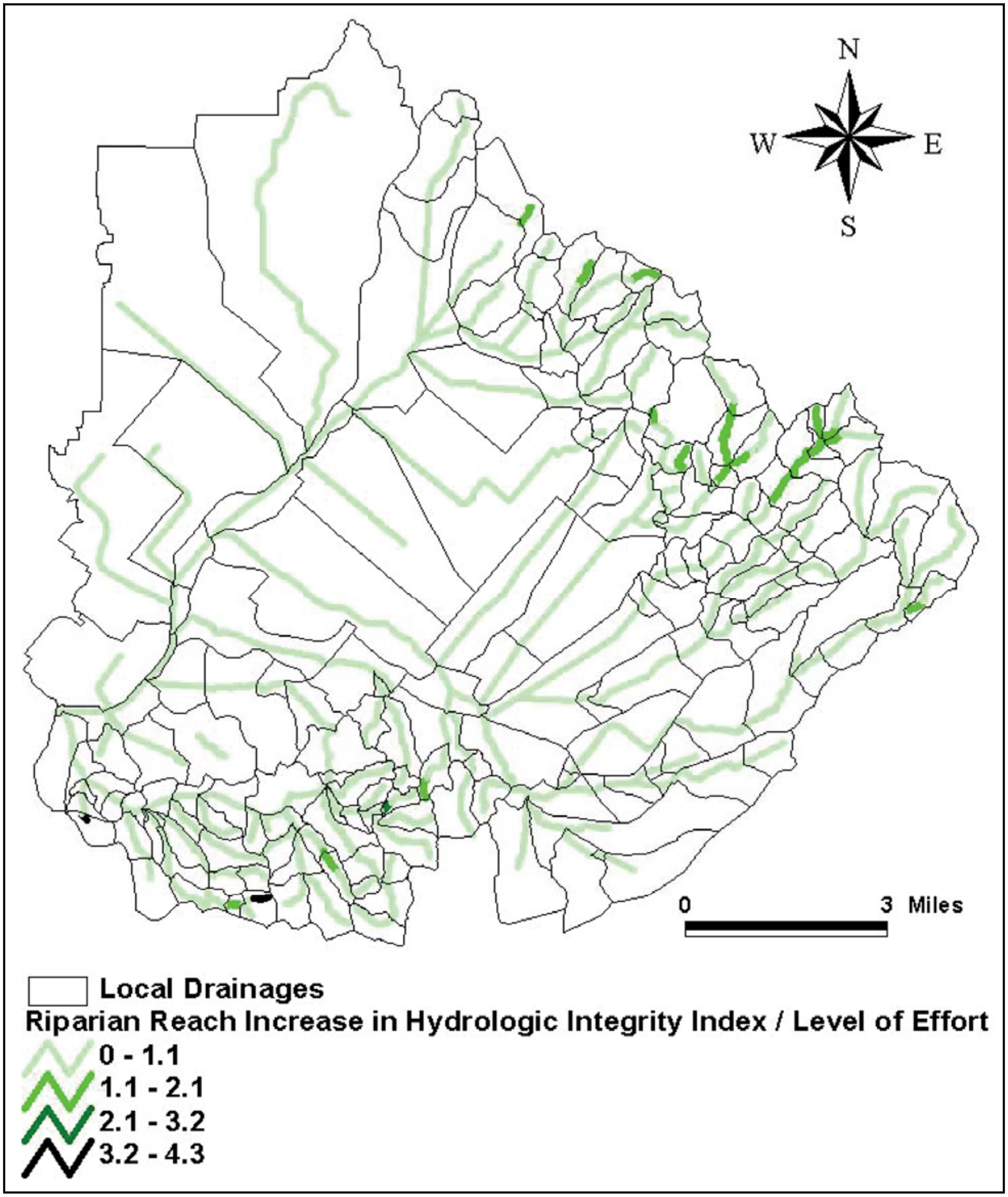


Figure 13. Hydrology index increase divided by level of effort following restoration for riparian reaches

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.

POINTS OF CONTACT: For additional information, please contact Mr. R. Daniel Smith (601-634-2718, *Ronald.D.Smith@erdc.usace.army.mil*) or the manager of the System-wide Water Resources Program (SWWRP), Dr. Steven L. Ashby (601-634-2387, *Steven.L.Ashby@erdc.usace.army.mil*).

This technical note should be cited as follows:

> Smith, R. D., Klimas, C. V., and Kleiss, B. A. (2005). "A watershed assessment tool for evaluating ecological condition, proposed impacts, and restoration potential at multiple scales," *SWWRP Technical Notes Collection,* ERDC TN-SWWRP-05-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS. *https://swwrp.usace.army.mil/*

REFERENCES

Bailey, R. G. (1995). "Description of the ecoregions of the United States," Misc. Publ. No. 1391, 2nd ed., U.S. Forest Service, Washington, DC.

Dinius, S. H. (1987). "Design of an index of water quality," *Water Resources Bulletin* 23, 833-843.

Heathcote, I. W. (1998). *Integrated watershed management: Principles and practices*. John Wiley and Sons, New York.

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

Lee, L. C., Rains, M. C., Mason, J. A., and Kleindle, W. J. (1997). "Peer Review Draft Guidebook to Hydrogeomorphic Functional Assessment of Riverine Waters/Wetlands in the Santa Margarita Watershed," L. C. Lee & Associates, Inc., Seattle, WA.

Morton, P. K., and Miller, R. V. (1981). "Geology map of Orange County, showing mines and mineral deposits," California Division of Mines and Geology, Sacramento, CA.

National Research Council. (1999). "New strategies for America's watersheds," Committee on Watershed Management, National Academy Press, Washington, DC.

Newbold, S. C. (2002). "Integrated modeling for watershed management: Multiple objectives and spatial effects," *Journal of the American Water Resources Association* 38(2), 341-353.

Ogg, C. W., and Keith, G. A. (2002). "New Federal support for priority watershed management needs," *Journal of the American Water Resources Association* 38(2), 577-586.

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

Smith, R. D. (2000). "Assessment of riparian ecosystem integrity in the San Diego Creek Watershed, Orange County, California," Final Report to the U.S. Army Engineer District, Los Angeles.

Smith, R. D. (2004). "Alternatives analysis for San Diego Creek Watershed, Orange County, California: Potential impacts to waters of the United States and riparian ecosystems," U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Vicksburg, MS. Final Report to the U.S. Army Engineer District, Los Angeles.

Smith, R. D., and Klimas, C. V. (2002). "San Diego Creek Watershed Riparian Ecosystem Restoration Plan: General Design Criteria," U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Vicksburg, MS. Final Report to the U.S. Army Corps of Engineers, Los Angeles District.

Trewartha, G. T. (1968). *An introduction to climate*. McGraw-Hill, New York.

U.S. Army Corps of Engineers (USACE). (2004). "Aquatic Resources Conservation Program for the San Diego Creek Watershed Joint Special Area Management Plan (SAMP) / Master Streambed Alteration Agreement Fish and Wildlife Service (MSAA)," draft version 5, USACE District, Los Angeles, CA.

Wachtell, J. K. (1978). "Soil survey of Orange County and western part of Riverside County, California," U.S. Department of Agriculture Soil Conservation Service and Forest Service in cooperation with University of California Agricultural Experiment Station.