San Antonio River Restoration:
Benefits to Aquatic Communities

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Abstract

The Fort Worth District Corps of Engineers and the San Antonio River Authority (SARA) are formulating and evaluating plans for habitat restoration of the San Antonio River. Four alternatives (Design Conditions 1-3B) are being considered that include re-establishment of forested riparian zone, creation of meanders, channel excavation, and increasing complexity of substrate and flow patterns. Field data of fish and aquatic habitat were collected and used to determine baseline conditions and develop habitat models to predict benefits of restoration alternatives. Thirty-two species of fish were collected and the community was dominated taxonomically by minnows, sunfishes, cichlids and livebearers . Thirteen of the fish are not indigenous to the system. Biomass was dominated by suckermouth catfishes. Degraded habitat conditions prevailed in the study area primarily due to the lack of slackwater and instream/riparian strucuture except for large rubble. HEP analyses demonstrate that all four Design Conditions will result in substantial gains in HUs. Total HUs was greatest for DC3B. Smaller erosional sediments and littoral vegetation will increase enhancing spawning and rearing of most native fishes. Leaves, small woody debris, and detritus will be transported into the channel by wind from adjacent riparian zones. Overall, the restoration project will contribute to a sustainable ecosystem by providing physical habitat complexity and stability, food resources to invertebrates and fishes, and nursery resources to fishes.

Background

The San Antonio River is physically and faunistically distinctive from all other rivers of the western Gulf Slope (Conner and Suttkus, 1986). It has the third smallest drainage area (10, 619 km^2) and discharge is low (<<0.1 m^3/km^2), but ionic concentrations (silica, calcium, magnesium, sodium, sulphate, chloride), total dissolved solids, hardness, specific conductance, and pH are the highest. Only 42 native freshwater fishes are documented, but 7 of these are eastern lowland or Mississippi Valley fishes at the southwestern most limits of their distribution. Fish communities are dominated taxonomically by minnows and darters, including the state-endemic Texas shiner and Texas logperch. Environmentally sensitive ("intolerant") species, however, may constitute low percentages (< 6%) of the total biomass (Gonzales, 1988; Edwards, 2001). Aquatic communities of the San Antonio River are impacted by: urbanization; loss of riparian zone and floodplain habitats (pers. obs.); reduced complexity of instream physical habitat and availability of natural habitat (Gonzales, 1988);

elevated nutrient levels (TNRCC, 2002); and burgeoning populations of exotic fishes (Hubbs et al. 1978; Hubbs, 1982; Edwards, 2001).

Design Condition 1 (DC1): Aquatic ecosystem restoration which remains within the existing Federal Right-of-Way. Excavation is allowed for aquatic habitat creation and increased conveyance to accommodate tree plantings.

Design Condition 2 (DC2): Aquatic ecosystem restoration which remains within the existing Federal Right-of-Way. Excavation for aquatic habitat and riparian plantings, and implementation of the sediment transport channel design as recommended by Interfluve.

Design Condition 3 (DC3): Aquatic ecosystem restoration which is allowed to go outside the existing Federal Right-of-Way. Excavation for aquatic habitat and riparian plantings, and implementation of the sediment transport channel design/principles as recommended by Interfluve.

DC3A: A set of measures designed by CarterBurgess (for SARA) which adhere to the design conditions of DC3.
DC3B: A set of measures designed by USACE which adhere to the design conditions of DC3.

Determining which combination of restoration measures will provide the greatest cost-effective biological benefit requires quantitative relationships between biota and physical habitat. These relationships can be used in conjunction with measurements and projections of habitat area to model baseline conditions and benefits that will accrue from various restoration alternatives, respectively. Such relationships have not yet been described for San Antonio River fishes, and the unusual habitats that typically occur at the edge of a species' range obviates the use of extant models. Also, multiple restoration techniques have been proposed that require some level of precision and accuracy. To evaluate benefits, site-specific, multi-variable models are necessary which can address each class and combination of restoration techniques.

Principal restoration measures under consideration will address main-channel habitats and backwater wetlands. Main channel habitats have been degraded by loss of riparian zone and reduction of bathymetric and substrate diversity. Reforestation, construction of within channel meanders, excavation of within-channel pools, and creation of riffles would increase shading and cover, and provide a wider range of velocity and depth. Backwater habitats are isolated throughout most of the system due to channelization, sedimentation, and hydrologic changes, or are short-lived and of poor quality due to near-channel development or terracing. Wetland communities have not been documented for the San Antonio River, but forested wetlands of the southern United States provide critical habitat for distinctive assemblages of small, hypoxia-tolerant fishes and spawning habitat for many riverine fishes (Hoover and Killgore, 1998). Establishing passable connections with river cut-offs and excavating small, off-channel embayments would provide substantial benefits to flood-adapted fishes.

Numeric and taxonomic domination by invasive, generalist native species such as red shiner and mosquitofish (Gonzales, 1988) is problematic and indicative of low hydrologic variability. Re-configuring the channel to approximate natural hydrographs would provide temporal variation in stream hydraulics needed for expanded habitat area of lotic fishes (Schlosser, 1987) and reduced habitat of exotic fishes (Minckley and Meffe, 1987). Lastly, the proliferation of herbivorous species, exotic (e.g., loricariid catfishes, blue tilapia) and native (e.g., stoneroller), and the conspicuous occurrence of phytoplankton blooms and algal mats (pers. obs), indicates a problem with excess nutrients. Nitrogen and phosphorous levels are elevated and a source of concern in the San Antonio River (TNRCC, 2002). Reliance on recycled water for maintaining flow makes nutrient levels difficult to control. Macrophyte beds were once conspicuous features of the upper San Antonio River (Brown, 1953), and if reestablished, would help reduce waterborne nutrients and increase structural complexity of the river. Establishing riparian vegetation in selected areas (using native plant species) where it will flood would also facilitate reduction of nutrients and enhanced complexity of submersed cover.

Methods

Baseline Conditions

To establish baseline conditions and to develop fish-habitat relationships for the evaluation of restoration features, the San Antonio River and associated waters were sampled in Oct 2002, Jan 2003, and Mar 2003. Physical habitat (stream hydraulics, substrate, and water quality) and fish communities (species-abundance, size structure) were sampled concurrently. Thirty-two collections were made throughout the study area with localities sampled 1-3 times apiece. Collecting activities on National Park Service lands did not permit "standard effort" so data from those 5 collections were excluded from most analyses.

At each station, a cross-sectional transect was established at a representative point (usually mid-length of the reach sampled), at which stream width was measured. At 10 equidistant points, depth and water velocity were measured using a wading or stadia rod and Marsh-McBirney water velocity meter, respectively. Substrate was classified according to size (modified Wentworth classification) at each of those 10 points from direct observations or use of sounding rod. Turbidity was measured with a Hach 2100P turbidimeter. Temperature, conductivity, dissolved oxygen, and pH was measured with a Hydrolab multi-parameter water quality probe. Habitat data were summarized as mean values for separate reaches within the project area.

Stream fishes were sampled concurrently with physical habitat. Fishes were collected by seining. Standard effort was 10 hauls stratified among all apparent physical habitats and distributed equitably throughout a homogeneous reach. When water depths were > 6 ft., gillnets were set for 30 min to 1 hour. All fish were fixed in 10% formalin except for large specimens which were identified, measured, and released in the field. In the laboratory, preserved fishes were rinsed, sorted, identified, enumerated, and measured (total length to nearest mm). Specimens were preserved in isopropyl alcohol, cataloged, and deposited in the collections of the Museum of Zoology, University of Louisiana at Monroe (Catalog numbers available on request). Fish data were summarized as percent composition (by numbers) for separate reaches within the project area.

Fish-habitat association analyses

To assess degree of system-wide degradation, occurrence of the dominant introduced species was plotted in multivariate habitat space. Dominant species was determined based on fish biomass. Biomass was not measured directly in the field but was calculated from numbers and total lengths of each specimen. Length for each fish was converted to weight using extant length-weight regression models available in the published literature or from FISHBASE (Froese and Pauly, 2004). This value was multiplied times the number of fish of that size or in that size class.

Stations were plotted in multivariate space using Principal Components Analysis or PCA (Gaugh, 1982; SAS, 1985). This technique provided an ordination of samples based on multiple habitat variables: substrates, water velocity, water depth, channel width. PCA allowed data reduction by plotting observations (samples) in a high-dimensional space (i.e., equal to the number of habitat variables) into a space of lower-dimensions (i.e., two principal components), while preserving as much of the spatial configuration among points as possible.

Parameters associated with the first and second principal component, PCI and PCII, were identified by disparately higher "loadings" or eigenvectors , which describe the degree of correlation between the original habitat variable and the resulting component. Hydraulic data were $\log_{10}$ transformed and substrate data were square root-transformed because physical characteristics of streams are interrelated as power functions (Meffe and Sheldon, 1988). Transformed data provide homogeneity of variance and normal distributions of data [for individual variables] and improve linear relationships among variables. Such transformations also legitimize statistical tests of significance and reduce bias generated by outliers.

Occurrence of the dominant introduced/invasive species was projected on each point corresponding to each sample in which it occurred. PCA is frequently employed to describe physical habitats of fishes (Matthews, et al., 1985; Matthews et al., 1992). This technique assumes that introduced species are indicative of disturbed environments and that breadth of distribution in habitat space reflects breadth of habitat degradation.

Environmental benefits

Fish-habitat models were generated using three separate methodologies. Each model (or set of models) was evaluated by the HEP Team to select the most appropriate technique for describing habitat benefits of the restoration project. Models included: 1) fish-habitat correlations (based on empirical data); 2) categorical models (also based on empirical data); 3) traditional suitability index (SI) models (based on "best professional judgment"). The HEP Team was comprised of members from the following agencies: U.S. Army Engineer Research and Development Center (ERDC), San Antonio River Authority (SARA), United

States Fish and Wildlife Service (USFWS), and the Texas Commission on Environmental Quality (TCEQ).

Fish-habitat models were developed using stepwise multiple regression analysis in which some “collective property” of the fish community (sensu Sheldon and Meffe, 1995) was used as a dependent (response) variable and habitat parameters as independent (predictor) variables. Collective properties (e.g., diversity, total biomasss) are indicative of large-scale environmental characteristics (e.g., habitat complexity, carrying capacity) and are sensitive to environmental disturbance. Use of collective properties obviates the need to subjectively select individual evaluation species, represents habitat for the majority of species present, is associated with specific community functions, and provides analytical/statistical advantages (e.g., greater sample size, no zero observations). Diversity of individual collections of fish was quantified using the Shannon heterogeneity function (H’), a logarithmic function that incorporates species richness and equitability of abundances of individual species (evenness) into a single value quantifying complexity of_the collection (Magurran, 1988).

Categorical models were developed by delineating specific macrohabitats in the San Antonio river according to hydraulic and geomorphic classifications, and quantifying relative fish biomass (i.e., for either swift water or slack water species) or fish diversity in each category. The category with the highest value was assigned a SI score of 1.0 and other categories were scaled appropriately. Traditional SI models, which are univarate curves, were determined for individual variable (i.e., depth, velocity, substrate, dominant substrate, and vegetative cover) and specific guilds of fishes inhabiting each type of habitat (e.g., pools, riffles, embayments) based on consensus of all participating agencies.

Guild composition for each habitat category was determined by the HEP Team. ERDC provided preliminary guilds based on 2002-2003 samples. All fishes (native and non-native) collected during this study were listed in order of relative abundance for each of 9 habitats in the San Antonio River. Guilds were provided to stakeholder agencies for suggested revisions (i.e., exclusion of non-representative species obtained in sampling, addition of representative species not obtained in samples but known to occur in the river).

Output from hydraulic models (HEC-RAS), aerial photographs, and GIS of base flow conditions (20 cfs) in the San Antonio River were provided by CESWF to ERDC. For a series of 319 sites along the river (Park and Mission Reaches, combined), data were available on surface area (acres), velocity, depth, and percent vegetative cover. These data were delineated into habitat categories: chute, chute below pools (weirs), pools, riffle, scour pool, or vegetated channels. Classification into habitat categories was based on location of in-channel structures (e.g., weirs indicating upstream pools and downstream chutes below pools), proximity and amount of riparian vegetation (e.g., indicating vegetated channels), and combinations of width, water velocity, and depth (e.g., indicating pools, chutes, and riffles). Hydraulic models did not address off-channel habitats. Tributary (mouth of San Pedro Creek) and embayment (mouth of Noname Creek) were assessed based on estimated acreages of surface water and vegetation by CESWF and velocity, depth, and substrates recorded during ERDC field studies.

Output was modified and supplemented by field data from ERDC field surveys. Habitat categories within a few segments were reclassified based on direct ("ground-truth") observations. Substrates were classified according to a modified Wentworth-style system of classification: fines (silt and mud), sand, fine gravel, coarse gravel, cobble, rubble, and boulder. Dominant substrates were identified for all sites sampled based on maximum observed frequency of that substrate type in cross-sectional transects. Substrate data for sites not sampled were presumed based on prevalence of substrates in that habitat category at other locations and in proximate reaches. Estimates of vegetative cover were provided by CESWF based on aerial photography and GIS. Estimates of water velocity, depth, and width (water's edge to water's edge) were provided by CESWF based on results from hydraulic simulations.

For each site, water velocity, depth, substrate, and vegetation were each scored on a scale of 0.0 (unsuitable) to 1.0 (optimal) based on Suitability Index models developed for that habitat type (and its associated guild) by the HEP Team. For continuous variables (i.e., velocity, depth, vegetative cover), SI values intermediate between those specified in models were interpolated assuming a linear relationship between any two points (Example: A predicted water velocity of 28 cm/s would score an SI value of 0.88, if suitability index models indicated SIs of 0.8 for 20 cm/s and 1.0 for 40 cm/s).

A fifth habitat variable was developed to address riparian functions apart from providing vegetative cover (e.g., large woody debris, leaf litter, spawning substrates, velocity refugia at high stages). Formulating an SI model for this riparian value, or "organic input," was a two-step process. First, SIs were established for climax stages of all vegegative types, with minimum values assumed for non-vegetated areas (SI = 0), maximum value for greatest density of trees (SI = 1.0) and intermediate values for vegetation ranging from monospecific grasses to mixed native grasslands and woods. Second, SIs were established for each vegetative type for Years 0, 1, 5, 15, 25, and 50, assuming that herbaceous vegetation achieves maximum value in a single year, sparse woods by year 15 (due to rapid growth) and moderate and dense woods by Year 25 (due to slower growth). [Note – Riparian value for fishes does not correspond directly to tree size, since trees of moderate diameter provide full-habitat value to fishes as sources of cover, spawning substrates, grazing surfaces, etc.]. Models for the different time intervals were used iteratively to evaluate and annualize habitat benefits during the 50-year life of the restoration project.

Habitat Suitability Index (HSI) models for the riparian zone associated with each individual channel feature (e.g., pool, riffle, chute, etc.) were calculated as:

$$SI_{\text{Riparian}} = \frac{K[\,\Sigma\ (SI)(\%\text{Area})\,]_{\text{Tier 1}} + [\,\Sigma\ (SI)(\%\ \text{Area})\,]_{\text{Tier 2}}}{K + 1}$$

K is a constant (i.e., a ratio) expressing the relative frequency of inundation of Tier 1 (the elevated flat immediately adjacent to the baseflow channel) and Tier 2 (the landward slope adjacent to Tier 1). For example, if Tier 1 is inundated 100 days and Tier 2 only 20 of those days, this constant will equal 5. For each tier, the percentage area of each vegetative type is multiplied times the SI for that type, and all values are summed. All categories of vegetation therefore contribute to the HSI, but are weighted proportionately based on frequency of inundation and their respective relative areas.

Assuming that each habitat variable is equally important and that those variables with higher SIs will compensate for those variables with lower scores, we calculated the HSI for each reach as a geometric mean of the five SI scores and used that number to provided a weighted value of that habitat feature in Habitat Units (HUs)

$$HU = [(SI_{Velocity})(SI_{Depth})(SI_{Substrate})(SI_{Vegetation})(SI_{Organic\ Input})]^{1/5} * Area$$

Results and Discussion

Baseline Conditions

Physical conditions were variable among locations, although large substrates (gravel and larger) were common, and warm water (> 15 ^{o} C) and normoxia (D.O. > 5.5 mg/l) prevailed. Channel width ranged from 5.4-177 ft, mean depth (based on a single cross-sectional transect) from 0.5-4.6 ft, velocity from 0->3 ft/sec. Substrates were dominated by fine sediments (31%). Gravel (24%), boulders (20%), and cobble (17%) were less abundant, and sand comparatively uncommon (8%). Water temperature ranged from 15.3-29.1 ^{o} C, conductivity from 145-565 uS, and turbidity from 0.9-129.0 NTUs. Dissolved oxygen ranged from 5.8-13.0 mg/l. Acequias and old river bendways were narrower, shallower, and slower than main channel habitat (Table 1). In the main channel, there was a downstream trend for increased width, decreased water velocity, and higher turbidity.

Thirty-two species of fish were collected (Table 2). Community was dominated taxonomically by minnows (10 species), sunfishes (8 species), cichlids and livebearers (4 species each). Thirteen of the fish are not indigenous to the system: cichlids (4 spp.), suckermouth catfishes (2 genera, and at least 4 species), livebearers (3 species), centrarchids (2 species), common carp, and Mexican tetra. Exotic fishes represent a mix of tropical, sub-tropical, and temperate species from three continents. The two most abundant species, numerically, were the native red shiner (49.9 %) and western mosquitofish (13.6 %). The next most abundant species were exotic: sailfin molly (8.0 %), Mexican tetra (7.3 %), tilapias (6.1 %), and Rio Grande cichlid (3.5 %).

Analysis of Introduced Species

Fish biomass consisted primarily of introduced species (85%), secondarily of tolerant native species (10%) (Table 3). Sailfin catfishes were the dominant taxon (42%). Together with blue tilapia and Rio Grande cichlid these three species constituted 66% of total fish biomass. Native red shiners were fourth ranked in biomass (7%). Common carp and

Mexican tetra were 5th and 6th ranked (4-6%). Native channel catfish were 7th ranked (3%). Redbreast sunfish, sailfin molly, redbelly tilapia, and Nile tilapia were 8th through 11th ranked (2-3%). Native central stonerollers were 12th ranked (2%). All other native species comprised negligible components of fish biomass (<< 1%). Because of their disparate domination of fish biomass, sailfin catfishes were further evaluated. For comparative purposes, the taxonomically and ecologically similar, armadillo del rio were also used, although they comprised a very minor proportion of fish biomass (0.2 %).

Ordination of habitat data was performed using 8 habitat variables: mean water depth, mean water velocity, channel width, percentages of fine sediments, sand, gravel, cobble, and boulder. Water quality variables were used initially in PCA but because they showed negligible or un-interpretable variation, were not useful in identifying meaningful axes for detecting pattern. PCI and PCII accounted for 33 and 22 % of dataset variance respectively. Three variables were associated with (i.e., had high loadings on) on PCI: fine sediments (-0.56), water velocity (0.52), and gravel (0.40). Two variables were associated with PCII: channel width (0.61) and mean water depth (0.60). Most stations were characterized by swift water and gravel substrates, and water of moderate depth and velocity, but several stations were characterized by slack water and fine substrates, shallow water in narrow channels, deep water in wide channels (Figure 1).

Suckermouth catfishes occurred in 11 of the 27 samples (41%) but were broadly distributed along both habitat axes. Sailfin catfishes were habitat generalists occurring in all habitats with the exception of shallow, narrow channels. These sites (i.e., those in or near Brackenridge Park) were occupied by the armadillo del rio. Data reflected pervasive, widespread dominance of invasive species in a degraded river system.

Comparison of Habitat Models

Inclusive of all species collected, diversity ranged from H' = 0.13 (2 species, domination by a single species) to H' = 1.83 (10 species, none numerically dominant). Most values for H' were less than 1.60. Total fish biomass ranged from 38 g to 6109 g, but only 4/28 values were greater than 3000 g. Biomass was high > 2000 g when width ranged from 32-50 ft, depths > 3 ft, and velocity ranged from 0.2-1.8 ft/s.

Fish-habitat correlations - Diversity was positively correlated with water temperature ($r = 0.54$, $p = 0.003$), minimum depth ($r = 0.38$, $p < 0.05$), amount of cobble ($r = 0.36$, $p = 0.06$), and negatively with amount of boulder ($r = -0.47$, $p = 0.01$). Stepwise multiple regression using diversity as a dependent (response) variable, and hydraulic parameters as independent (predictor) variables resulted in the following model:

$$H' = 0.749 + 0.530[\text{Minimum Depth}]$$

Model is significant ($p = 0.05$), but accounted for < 15 % of variance ($r^2 = 0.14$). It can be standardized on 0-1 scale by dividing by a theoretical maximum diversity value (e.g., H' = 2.0-2.5) based on frequency of observed values in this system and values known from other undisturbed systems. Resulting model may be used as an SI to quantify benefits derived from any restoration feature that results in deepened water: pooling behind structures, excavating channels, creating scour pools, etc..

Biomass was positively correlated with minimum, mean, and maximum depth ($r > 0.52$, $p \leq 0.01$), amount of fine substrates and sand ($r > 0.51$, $p \leq 0.01$), and water temperature 0.35, $p = 0.10$). Stepwise multiple regression using diversity as a dependent (response) variable, and hydraulic parameters as independent (predictor) variables resulted in the following model:

$$\text{Biomass} = -529.4 + 945.4[\text{Mean Depth}]$$

Model was significant ($p = 0.01$) and accounted for > 25 % of variance ($r^2 = 0.28$). It can be standardized on 0-1 scale by dividing by the maximum value desired for fish communities in this system (i.e., biomass = 3500 g) based on frequency of observed values. This model may also be used as an SI to quantify benefits derived from any restoration feature that results in deepened water.

Regression-based models are easy to justify statistically and are convenient to use because they employ “continuous” variables (e.g., hydraulic parameters) readily predicted for post-project conditions. A principal shortcoming of such models is that they may not accommodate “discontinuous” or “qualitative” variables (e.g., discrete habitat features) and that they cannot address variables for which there is insufficient variation in baseline conditions (e.g., vegetative cover). Because fish-habitat analysis (see above) and consensus of team members suggest system-wide degradation, no reference condition exists within the study area. The range of observed values for some (or all) variables, therefore, is insufficient to represent optimal (SI=1.0) conditions.

Categorical Models - Alternative models were developed based on a combination of fish diversity and fish biomass for discrete habitat features using all species collected. Fishes were classified into two broad habitat categories: swift water (lentic) species and slack water (lotic) species. Species accounts were reviewed for each fish using regional fish atlases (primarily) or the Internet source, FishBase (secondarily). Swift- or slack-water classifications were based on the habitats listed as characteristic or preferred for each species (Table 4). Species richness, numbers, and biomass of fish in each of the two velocity-based guilds were sufficient to create robust measures for evaluating each of the habitat features.

Sites were each classified as one of nine possible habitats/restoration features: 1) vegetated channel; 2) old river bendways; 3) embayments; 4) pool; 5) scour pool; 6) tributary mouth; 7) chute (run); 8) chute below pool; 9) riffle (Table 5). Vegetated channels, bendways, and embayments are comparatively small features, ≤ 35 ft wide (Table 6). Other habitats are larger (37.5-67.0 ft wide). Pools, scour pools, and tributaries are characterized by lower velocities (0.2-0.9 ft/s) than chutes, chutes below pools, and riffles (1.1-2.1 ft/s).

Smaller habitats, sometimes off-channel, provide refugia for smaller fishes (< 100 mm TL) from high or flashy stream flows and from large, mobile predators. They also offer greater shoreline perimeter (relative to stream area) enhancing surface feeding on allochthonous foods (riparian detritus, terrestrial insects). Value of these smaller features is mainly as habitat for young-of-year and smaller species – groups which numerically dominate fish communities of the San Antonio River. Consequently evaluations of these features were based on diversity measures. Larger, slack water habitats support greater numbers of older, larger fish and were evaluated for biomass of slack water species. Larger, swift water features were evaluated similarly for biomass of swift water fishes. To derive SIs, mean diversity and biomass measures were compiled for each of the habitats. They were then standardized to a 0-1 scale, by dividing by the maximum observed value, among habitats, for each measure.

SIs for all measures were calculated for each habitat (Table 7). They provide objective quantification for the intuitive appeal of the various restoration features that are being discussed as project alternatives. Also, these values can be justified using biological rationale. They suggest that habitat suitability of certain homogenous reaches of the San Antonio and its tributaries (HSI < 0.20) could increase 2- to 10-fold by incorporating certain of the restoration features under consideration.

Habitat Units based on categorical models may be calculated from pre- and post-project acreages. Their principal short-comings are that they do not address variation in assemblages adapted to specific habitats independent of gross differences in water velocity (e.g., pool fishes vs. embayment fishes, riffle fishes vs. chute fishes) and that they do not account for variation in individual habitat parameters among specific habitat categories (e.g., shallow embayments vs. deep embayments, open pools vs. vegetated pools). Therefore, it was the decision of the HEP Team to develop traditional SI models using the fish-habitat correlations and categorical models as a basis for assigning SI values.

Traditional Suitability Index Models - This was the methodology selected for benefit analysis based on team consensus. It allowed habitat suitability of different habitat features (e.g., pools, chutes, riffles) to be quantified for specific fish assemblages (guilds) based on individual habitat parameters: depth (Table 9), velocity (Table 10), substrate (Table 11), vegetative cover (Table 12), and organic input (Figure 2). These parameters represent channel and riparian cues to which fish exhibit short-term behavioral responses (e.g., feeding, hiding) and long-term population responses (e.g., recruitment, growth). All five parameters could be forecast from GIS, hydraulic simulations, and plans for re-vegetation.

The initial step was to agree upon species comprising each cell of the guild. A draft guild was sent to the HEP Team. Participating agencies suggested the addition of several species characteristic of the San Antonio River, including tadpole madtom and Texas logperch. SARA suggested the addition of several species documented from its monitoring program, including spotted gar, gizzard shad, gray redhorse, spotted bass, and smallmouth bass. TCEQ suggested the addition of speckled chub and Guadalupe bass. USFWS and TCEQ advocated the elimination of non-native species, including all tropical livebearers and Mexican tetra, cichlids, and armored catfishes. TCEQ also advocated elimination of sailfin molly contending that it too is non-native. Sailfin molly, a North American species, is native to western Gulf drainages and is listed in some sources as a native of the upper San Antonio River, but some older literature suggests that it is an introduced species. The final guild included all native fishes collected by ERDC and all species identified for inclusion by any other participating agency. Species known to be non-native, or suspected to be non-native were excluded. Several iterations of recommended SI values for each guild were compiled and final scores used to calculate Habitat Units for each alternative.

<u>Environmental Benefits</u>

HEP analyses demonstrate that all four Design Conditions will result in substantial gains in HUs and in similar temporal pattern of total habitat gains (See Appendix I). Substantial gains (54-80%) in habitat take place during the first year, principally from increased acreages of total habitat. Suitability of several habitat features, especially swiftwater features (riffles, chutes, tributary mouths) decreases from elimination of coarse substrates, resulting in temporary, uncharacteristically fine substrates. Pools, however, increase in acreage and in suitability, due to the removal of unnatural coarse substrates and replacement with characteristic fine, depositional sediments. Habitat gains are still high through Year 05 (an additional 58-73%) due to rapid recruitment of natural substrates (sand, fine gravel) and establishment of saplings (having higher habitat value than grasses and forbs). Habitat gains continue, to a somewhat lesser extent, through Year15 (an additional 33-48%) with the development of trees (having 2-3 times the habitat value of grasses and forbs). At Year15, 90% of the final total HUs for each Design Condition have been obtained. Subsequent gains are moderate through Year25 (an additional 7-12%) and minor through Year50 (1-8%).

Differences exist among the Design Conditions at Year 50 and from which habitat features the HUs are accrued (Tables 13-16). Total HUs was greatest for DC3B. Pools (46-52 HUs) and embayments were (8-11 HUs) were comparable among all Design Conditions. Riffles were low (< 3 HUs) in DC1 and DC3A, high (> 9 HUs) in DC2 and DC3B. Likewise, chutes were low (< 7.5 HUs) in DC2 and DC3B, high (> 9 HUs) in DC1 and DC3A. Overall DC3B had the greatest number of habitat features representing significant acreages and higher SIs. This Design Condition offers the greatest benefits to aquatic communities.

	DC1	DC2	DC3A	DC3B
Total HUs at Year50	71.2	73.2	77.7	**83.3**
Habitat Features > 0.5 HU at Year50	5	5	5	**6**
Habitat Features ≥ 1.5 acres	4	4	4	**6**
Habitat Features with Maximum HUs at Year50	0	1	2	**5**
Habitat Features with Maximum HSI at Year50	0	2	0	**6**

Benefits of the restoration alternatives occur for several reasons. Substrates and vegetation are now "limiting" in the main channel of the river but HSI model and calculations assume compensatory effects of other habitat parameters (i.e., depth, velocity). Many of the native fishes present (or historically present) inhabit a broad range of hydraulic conditions, but require a narrow range of substrate sizes (e.g., sand and fine gravel) and/or submersed vegetation in which to spawn and rear. Smaller erosional sediments and littoral vegetation are essentially absent throughout much of the pre-project channel. Recruitment and transport of natural sediments and establishment of natural vegetation will greatly enhance spawning and rearing of most native fishes.

Benefits of vegetation as organic input are delineated based on type, proximity to shore, and flood frequency. Allochthonous inputs, however, will take place during periods other than high water. Leaves, small woody debris, and detritus will be transported into the channel by wind from adjacent riparian zones. These and larger materials will be transported downstream by water movement. Organic input from aeolian forces during low water, and cumulative effects of input downstream during all river stages, but especially during spates, will provide important benefits to aquatic communities. These include coarse particulate organic matter (CPOM) as food for invertebrate shredders, litter as refugia for benthic fishes like madtoms, and large woody debris (LWD) as egg-laying sites for crevice-spawning shiners.

Certain microhabitats, such as undercut banks and root wads, are conspicuously rare in the San Antonio River. These features are vital habitat as resting and hiding areas for fishes moving in swift water. Increasing hydraulic diversity, and recruitment and transport of LWD from reforested land will facilitate natural development of these habitats by embedding limbs and stumps in river banks and creating natural eddies that will scour small cavities and expose roots of shoreline vegetation.

Habitat outputs (i.e., gains in HUs) determined in this study are, therefore, conservative measures of the benefits that will result from restoration of the San Antonio River. Replacement of large artificial substrates with natural sediments and re-vegetation of nearshore areas alone will provide substantial benefits to aquatic communities in excess of those calculated. Although the interactive effects among habitat parameters cannot be easily quantified, they can be readily identified as "value added" gains from proposed restoration measures and will contribute to a sustainable ecosystem by providing physical habitat complexity and stability, food resources to invertebrates and fishes, and nursery resources to fishes.

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Table 1. Physical characteristics of the San Antonio River system. Values are means with standard deviations in parenthesis.

	Acequia N=2	Old River Bendway N=5	Park Reach N=4	Upper Mission Reach N=15	Lower Mission Reach N = 6
Channel Width, ft.	8.4 ---	34.8 (23.7)	43.5 (18.1)	46.9 (13.2)	61.5 (59.8)
Depth, ft.	1.0 ---	1.4 (0.7)	2.3 (1.6)	2.3 (0.9)	1.9 (0.7)
Velocity, ft/s	0.4 ---	0.7 (0.5)	1.7 (1.2)	1.0 (0.7)	1.0 (1.1)
Fine substrate, %	95 ---	47 (44)	37 (43)	8 (14)	49 (42)
Sand, %	5 ---	6 (9)	4 (5)	8 (8)	13 (19)
Gravel, %	0 ---	37 (38)	34 (28)	23 (19)	17 (27)
Cobble, %	0 ---	7 (16)	25 (20)	23 (23)	9 (12)
Boulder, %	0 ---	2 (4)	0 (0)	37 (28)	13 (21)
Temperature, ^{o} C	21.7 ---	23.5 (1.1)	23.0 (1.2)	23.2 (4.3)	20.5 (3.2)
Conductivity, uS	521 ---	526 (172)	503 (10)	543 (42)	475 (181)
D.O., mg/l	6.23 ---	7.53 (0.93)	8.4 (0.7)	9.7 (2.0)	9.7 (2.0)
Turbidity, NTUs	19.5 ---	27.9 (30.8)	5.2 (3.0)	5.6 (0.9)	39.3 (50.3)

Table 2. Fishes of the San Antonio River collected 2002-2003 from acequias (ACEQ), old river bendways (BEND), Park Reach (PARK), upper Mission Reach (UPPR MISSN), and lower Mission Reach (LOW MISSN). Values are percentage of total fish collected (in **boldface**). N = sample size and I=Introduced species.

	ACEQ N=2	BEND N=5	PARK N=4	UPPR MISSN N=15	LOW MISSN N=6	TOTAL FISH N=32
Characidae, characins						
Astyanax mexicanus, Mexican tetra [I]	31.6	12.5	23.6	4.6	1.9	**323**
Cyprinidae, carps and minnows						
Campostoma anomalum, central stoneroller		2.6		2.6	3.1	**108**
Cyprinella lutrensis, red shiner	15.8	34.3	30.1	52.9	60.7	**2194**
Cyprinella venusta, blacktail shiner		0.1				**1**
Cyprinus carpio, common carp [I]					0.1	**2**
Notemigonus crysoleucas, golden shiner					2.1	**36**
Notropis amabilis, Texas shiner		1.2			0.1	**13**
N. ludibundus, sand shiner		0.4				**3**
N. texanus, weed shiner				0.2		**3**
Pimephales notatus, bluntnose minnow		1.2				**8**
Pimephales vigilax, bullhead minnow					0.1	**1**
Ictaluridae, bullhead catfishes						
Ameiurus melas, black bullhead				0.1		**1**
Ameiurus natalis, yellow bullhead	2.6	0.3			0.2	**6**
Ictalurus punctatus, channel catfish	2.6	0.1		0.5	0.5	**18**
Loricariidae, suckermouth catfishes						
Hypostomus sp., Armadillo del rio [I] [1]			5.7			**31**
Pterygoplichthys spp., sailfin catfishes [I] [2]				1.0	0.3	**20**
Poeciliidae, livebearers						
Gambusia affinis, western mosquitofish	5.3	14.0	33.4	13.3	7.4	**597**
Poecilia formosa, Amazon molly [I]				0.2	0.7	**15**
Poecilia latipinna, sailfin molly [I?]		20.7	2.8	10.7	2.4	**354**
Poecilia reticulata, guppy [I]					0.1	**2**

Table continued on following page

[1] Individuals of armadillo del rio, although frequently assigned to the species *Hypostomus plecostomus*, cannot be identified with certainty. Three forms are known from North American waters and at least 6 species are commonly imported

[2] Sailfin catfishes have only recently been documented in the San Antonio River. A single species was reported by Bob Edwards: *Pterygoplichthys multiradiatus*, the vermiculated sailfin catfish. Our collections consist of three forms: *P. multiradiatus, P. disjunctivus*, and the well-known snow king, *Pterygoplichthys anisitsi*.

Table 2. (continued)						
	ACEQ N=2	BEND N=5	PARK N=4	UPPR MISSN N=15	LOW MISSN N=6	TOTAL N=32
Centrarchidae, sunfishes						
Lepomis auritus, redbreast sunfish [I]	5.3	4.6	1.7	1.0	0.9	**72**
Lepomis cyanellus, green sunfish				0.3	0.4	**10**
Lepomis gulosus, warmouth				0.3		**4**
Lepomis macrochirus, bluegill		0.9	0.4	0.7	1.5	**45**
Lepomis megalotis, longear	31.6	1.0			0.1	**20**
Lepomis miniatus, redspotted sunfish				0.1		**1**
Micropterus punctulatus, spotted bass [I ?]				0.1		**2**
Micropterus salmoides, largemouth bass		1.2	0.7	4.2		**74**
Cichlidae, cichlids						
Cichlasoma cyanoguttatum, Rio Grande cichlid [I]	5.3	1.6	0.7	5.1	3.7	**153**
Tilapia aurea, blue tilapia [I]		0.3	0.6	1.6	0.5	**38**
Tilapia nilotica, Nile tilapia [I]			0.4			**2**
Tilapia zilli, red belly tilapia [I]		0.3		0.2	0.1	**7**
Tilapia sp., young-of-year tilapia [I]		1.8			12.9	**228**
Total Number of Species	8	20	11	20	22	**32**
Total Number of Individuals	38	679	539	1463	1678	**4397**

Table 3. Biomass of fishes of the San Antonio River. Numbers represent percentage of cumulative weight collected during all standard sampling efforts (10 seine hauls + 2 gillnets, depth permitting). T = percentages less than 0.1. N/c = "not collected" in a using standard sampling effort.

	%		%
Characidae, characins		**Centrarchidae, sunfishes**	
Astyanax mexicanus, Mexican tetra [I]	4.4	*Lepomis auritus*, redbreast sunfish [I]	2.7
Cyprinidae, carps and minnows		*Lepomis cyanellus*, green sunfish	0.1
Campostoma anomalum, central stoneroller	1.8	*Lepomis gulosus*, warmouth	0.2
Cyprinella lutrensis, red shiner	7.0	*Lepomis macrochirus*, bluegill	0.6
Cyprinella venusta, blacktail shiner	T	*Lepomis megalotis*, longear	N/c
Cyprinus carpio, common carp [I]	5.8	*Lepomis miniatus*, redspotted sunfish	0.1
Notemigonus crysoleucas, golden shiner	0.3	*Micropterus punctulatus*, spotted bass [I?]	0.2
Notropis amabilis, Texas shiner	T	*Micropterus salmoides*, largemouth bass	0.3
N. ludibundus, sand shiner	N/c	**Cichlidae, cichlids**	
N. texanus, weed shiner	T	*Cichlasoma cyanoguttatum*, Rio Grande cichlid [I]	8.6
Pimephales notatus, bluntnose minnow	N/c	*Tilapia aurea*, blue tilapia [I]	15.1
Pimephales vigilax, bullhead minnow	T	*Tilapia nilotica*, Nile tilapia [I]	2.0
Ictaluridae, bullhead catfishes		*Tilapia zilli*, red belly tilapia [I]	2.1
Ameiurus melas, black bullhead	0.1	*Tilapia* sp., young-of-year tilapia [I]	0.3
Ameiurus natalis, yellow bullhead	T		
Ictalurus punctatus, channel catfish	3.0		
Loricariidae, suckermouth catfishes			
Hypostomus sp., Armadillo del rio [I]	0.2		
Pterygoplichthys spp., sailfin catfishes [I]	42.4		
Poeciliidae, livebearers			
Gambusia affinis, western mosquitofish	0.2		
Poecilia formosa, Amazon molly [I]	0.1		
Poecilia latipinna, sailfin molly [I?]	2.3		
Poecilia reticulata, guppy [I]	N/c		

Table 4. San Antonio River fishes classified according to preferences for water velocity (including those species reported in previous studies). I = Introduced species.			
Slack Water		**Swift Water**	
Spotted gar	Sheepshead minnow	Longnose gar	Orangethroat darter
Alligator gar	Blackstripe topminnow	American eel	Texas logperch
Gizzard shad	Western mosquitofish	Rainbow trout [I]	Bigscale logperch
Threadfin shad	Amazon molly [I]	Mexican tetra [I]	Dusky darter
Goldfish [I]	Sailfin molly [I?]	Central stoneroller	River darter
Common carp [I]	Guppy [I]	Red shiner	
Roundnose minnow	Green swordtail [I]	Blacktail shiner	
Pallid shiner	Inland silverside	Texas shiner	
Ghost shiner	Green sunfish	Sand shiner	
Weed shiner	Warmouth	Mimic shiner	
Golden shiner	Bluegill	Blue sucker	
Pugnose minnow	Redear sunfish	Blue catfish	
Bluntnose minnow	Redspotted sunfish	Headwater catfish	
Fathead minnow [I]	Largemouth bass	Freckled madtom	
Bullhead minnow	White crappie	Flathead catfish	
River carpsucker	Black crappie [I]	Armadillo del rio [I]	
Lake chubsucker	Bluntnose darter	Sailfin catfishes [I]	
Smallmouth buffalo	Slough darter	White bass	
Gray redhorse	Freshwater drum	Redbreast sunfish	
Blacktail redhorse	Rio Grande cichlid [I]	Longear	
Black bullhead [I?]	Blue tilapia [I]	Smallmouth bass	
Yellow bullhead	Mozambique tilapia [I]	Spotted bass [I]	
Channel catfish	Red belly tilapia [I]	Guadalupe bass	
Tadpole madtom		Greenthroat darter	

Table 5. Stations sampled on the San Antonio River and their classification as habitat restoration features.

Station	Habitat Category
San Antonio River Below Zoo	Vegetated Channel
San Antonio River Below Mulberry Ave.	Vegetated Channel
Old San Antonio River Padres Drive – Head	Bendway
Old San Antonio River Padres Drive – Midreach	Bendway
Old San Antonio River Padres Drive – Mouth	Bendway
Noname Creek Mouth – upstream from Ashley Avenue	Embayment
San Antonio River Lone Star Blvd. - Upstream from Weir	Pool
San Antonio River Upstream from Brackenridge Park Dam	Pool
San Antonio River Upstream from Espada Dam	Pool
San Antonio River Upstream from sill at Concepcion	Pool
San Antonio River Downstream from sill at Concepcion	Scour Pool
San Pedro Creek Mouth at Concepcion	Tributary
San Antonio River VFW Blvd. Near Riverside	Chute
San Antonio River Ashley Road	Chute
San Antonio River Lone Star Blvd. – below weirs	Chute below pool
San Antonio River Riffle at Concepcion	Riffle

Table 6. Hydraulic characteristics of habitats and proposed restoration measures for the San Antonio River. Values are means.

	Vegetated Channel	Bendway	Embayment	Pool	Scour Pool	Tributary	Chute	Chute Below Pool	Riffle
Width (ft)	35.0	20.0	22.5	63.3	67.0	49.0	61.5	37.5	42.0
Depth (ft)	1.5	1.1	2.2	3.1	2.7	1.4	1.4	2.6	1.3
Velocity (ft/s)	2.1	0.4	0.0	0.9	0.7	0.2	1.5	1.1	2.1

Table 7. Habitat Suitability Indices (SIs) for the San Antonio River of categorical models. Values in **boldface** were those proposed for calculating baseline conditions or benefits for that habitat category.									
Parameter Used to Determine HSI	Vegetated Channel	Bendway	Embayment	Pool	Scour Pool	Tributary	Chute	Chute Below Pool	Riffle
Fish Diversity, H' (Shannon Function)	**0.81**	**0.87**	**0.87**	0.75	0.44	0.37	0.25	1.00	0.56
Biomass of Slackwater Species	0.62	0.21	0.27	**1.00**	**0.52**	**0.10**	0.03	0.40	0.04
Biomass of Swiftwater Species	0.14	0.40	0.04	0.41	0.07	0.24	**0.19**	**1.00**	**0.01**

Table 8. Habitat-based guilds of fishes in the San Antonio River excluding introduced species. Lists developed by agency consensus.

Old River Bendway	Chute	Chute Below Pool
Central stoneroller Red shiner Blacktail shiner Texas shiner Yellow bullhead Western mosquitofish Longear sunfish Largemouth bass Spotted bass Smallmouth bass	Spotted gar Central stoneroller Red shiner Speckled chub Texas shiner Ghost shiner Weed shiner Mimic shiner Gray redhorse Yellow bullhead Channel catfish Tadpole madtom Spotted bass Smallmouth bass Texas logperch	Red shiner Blacktail shiner Speckled chub Texas shiner Ghost shiner Weed shiner Mimic shiner Gray redhorse Yellow bullhead Tadpole madtom Western mosquitofish Largemouth bass Guadalupe bass Green sunfish Texas logperch
Embayment	**Vegetated Channel**	**Pool**
Central stoneroller Red shiner Mimic shiner Bullhead minnow Fathead minnow Yellow bullhead Black bullhead Tadpole madtom Sailfin molly Western mosquitofish Green sunfish Bluegill Longear sunfish Redspotted sunfish	Spotted gar Red shiner Texas shiner Weed shiner Mimic shiner Tadpole madtom Sailfin molly Western mosquitofish Largemouth bass Spotted bass Smallmouth bass Longear sunfish Bluegill	Spotted gar Gizzard shad Central stoneroller Red shiner Texas shiner Ghost shiner Weed shiner Mimic shiner Fathead minnow Yellow bullhead Black bullhead Channel catfish Tadpole madtom Sailfin molly Western mosquitofish Largemouth bass Guadalupe bass Spotted bass Smallmouth bass Green sunfish Bluegill Longear sunfish Redspotted sunfish
Riffle	**Scour Pool**	**Tributary**
Central stoneroller Red shiner Speckled chub Channel catfish Orangethroat darter Texas logperch	Gizzard shad Central stoneroller Red shiner Texas shiner Weed shiner Gray redhorse Sailfin molly Western mosquitofish Largemouth bass Guadalupe bass Spotted bass Smallmouth bass Warmouth Bluegill Longear sunfish	Spotted gar Gizzard shad Central stoneroller Red shiner Ghost shiner Weed shiner Gray redhorse Western mosquitofish Largemouth bass Spotted bass Smallmouth bass Warmouth Bluegill

Table 9. Habitat suitability models for water velocities (cm/s) in the San Antonio River.							
Habitat Feature	**0**	**20**	**40**	**60**	**80**	**100**	**120**
Old River Bendway	1.0	1.0	0.8	0.8	0.4	0.2	0.1
Chute	0.5	0.8	1.0	1.0	0.8	0.5	0.3
Chute Below Pool	1.0	1.0	0.8	0.8	0.6	0.4	0.2
Embayment	1.0	0.5	0.3	0.1	0	0	0
Vegetated Channel	0.8	1.0	1.0	0.8	0.4	0.2	0.1
Pool	1.0	0.8	0.6	0.4	0.2	0.1	0
Riffle	0.5	0.8	1.0	1.0	0.8	0.5	0.3
Scour Pool	1.0	0.8	0.6	0.4	0.2	0.1	0
Tributary	0.8	1.0	0.8	0.6	0.4	0.2	0

Table 10. Habitat suitability models for water depths (cm) in the San Antonio River.								
Habitat Feature	**10**	**20**	**40**	**60**	**80**	**100**	**150**	**200**
Old River Bendway	0.3	0.6	1.0	0.8	0.6	0.4	0.2	0.2
Chute	0.3	0.6	0.8	1.0	0.8	0.6	0.4	0.2
Chute Below Pool	0.2	0.4	0.6	0.8	1.0	0.8	0.6	0.5
Embayment	0.3	0.5	0.7	1.0	0.7	0.5	0.3	0.3
Vegetated Channel	0.5	0.8	1.0	0.7	0.5	0.3	0.1	0
Pool	0.2	0.3	0.5	0.8	1.0	1.0	0.8	0.6
Riffle	0.5	1.0	0.5	0.3	0.1	0	0	0
Scour Pool	0.1	0.3	0.5	0.8	1.0	0.9	0.8	0.7
Tributary	0.5	0.8	1.0	0.8	0.6	0.4	0.2	0.2

Table 11. Habitat suitability models for dominant substrates in the San Antonio River.							
Habitat Feature	**Mud**	**Sand**	**Fine Gravel**	**Coarse Gravel**	**Cobble**	**Rubble**	**Boulder**
Old River Bendway	0.6	1.0	1.0	0.6	0.3	0.2	0.1
Chute	0.2	1.0	1.0	0.8	0.5	0.3	0.1
Chute Below Pool	0.2	1.0	1.0	0.8	0.5	0.3	0.1
Embayment	0.8	1.0	0.5	0.3	0.1	0.1	0.1
Vegetated Channel	0.6	1.0	1.0	0.5	0.2	0.1	0.1
Pool	0.7	1.0	0.5	0.3	0.1	0.1	0.1
Riffle	0.2	0.8	1.0	0.8	0.6	0.4	0.2
Scour Pool	0.4	1.0	0.8	0.4	0.2	0.1	0.1
Tributary	0.5	1.0	1.0	0.6	0.3	0.1	0.1

Table 12. Habitat suitability models for vegetation (percent area covered by submersed aquatic plants or shaded by emergent/marginal plants) in the San Antonio River.							
Habitat Feature	**0**	**10**	**30**	**50**	**70**	**90**	**100**
Old River Bendway	0.1	0.5	1.0	1.0	0.5	0.3	0.1
Chute	0.7	1.0	0.7	0.4	0.2	0.1	0
Chute Below Pool	0.7	1.0	0.7	0.4	0.2	0.1	0
Embayment	0.3	0.6	1.0	1.0	0.6	0.3	0.1
Vegetated Channel	0.3	0.6	1.0	1.0	0.6	0.3	0.1
Pool	0.5	1.0	0.7	0.5	0.2	0.1	0
Riffle	0.7	1.0	0.5	0.2	0.1	0	0
Scour Pool	0.5	1.0	0.5	0.3	0.1	0	0
Tributary	0.7	1.0	0.5	0.2	0.1	0	0

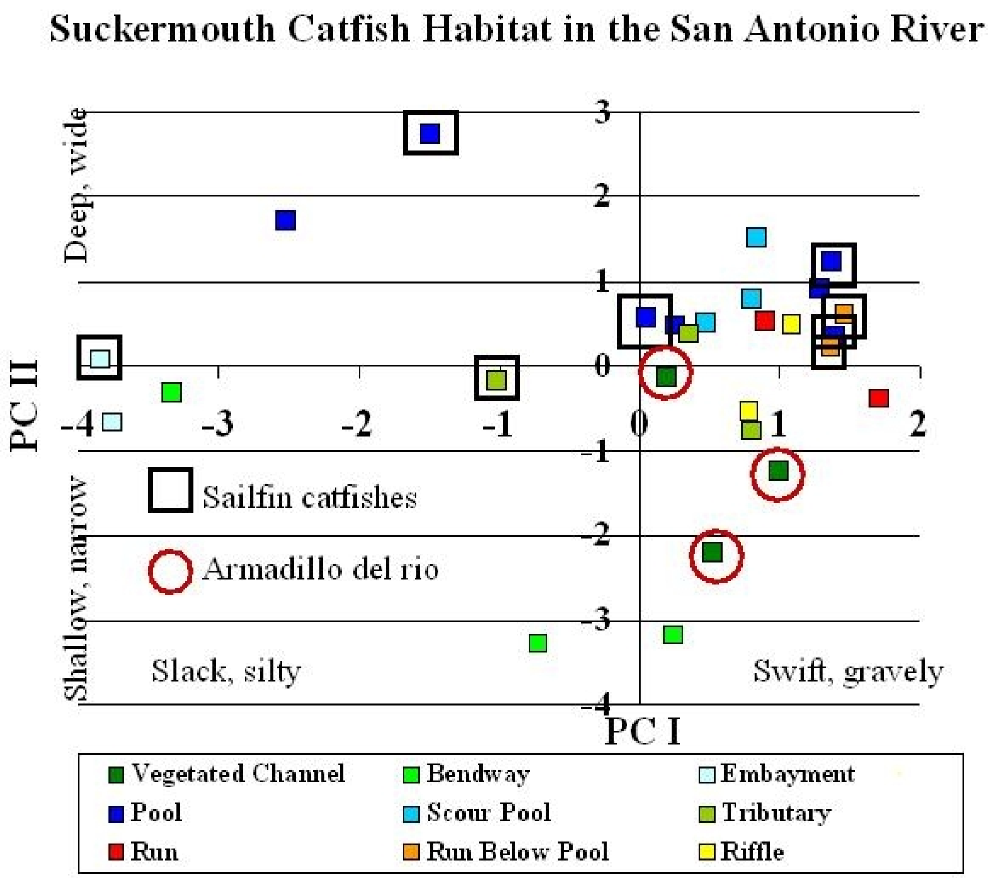

Figure 1 Habitat of suckermouth catfishes in the San Antonio River based on principal components analysis of hydraulic and substrate data.

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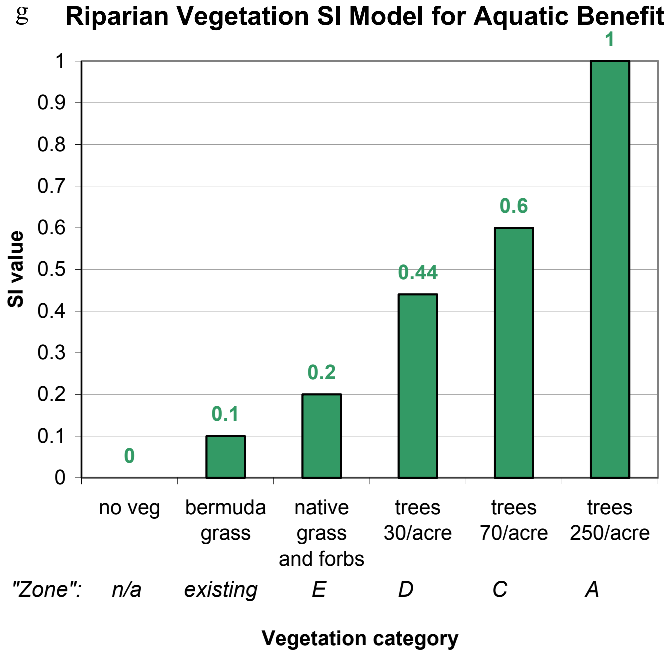

Example:

	Bermuda Grass	Native Grass	30Tr/ acre	70Tr/ acre	250Tr/ acre
Tier 1	--	100%	--	--	--
Tier 2	--	20%	40%	40%	--

HSI Calculation

Tier 1 HSI = 0.2 x 1.0 = **0.2**

Tier 1 inundated 5x

Tier 2 HSI = (0.2 x 0.2) + (0.44 x 0.4) + (0.6 x 0.4)

= 0.04 + 0.176 + 0.24 = **0.456**

Tier 2 inundated 1x

Riparian HSI = $\frac{5(0.2) + 1(0.456)}{6}$

= $\frac{1.456}{6}$

= **0.242**

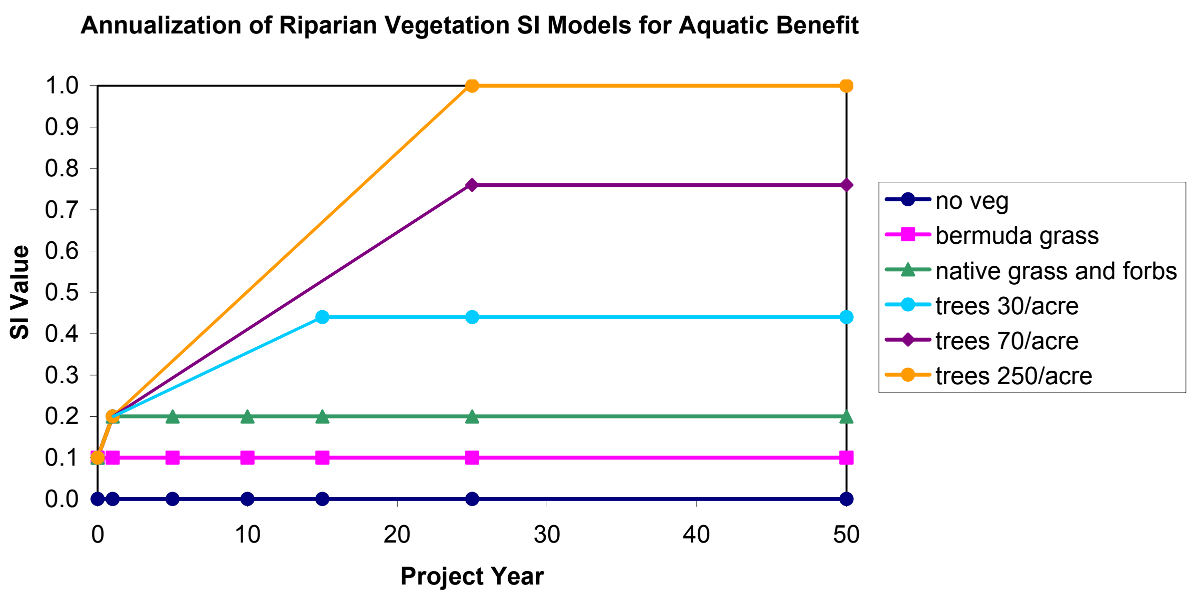

Figure 2. Method for calculating Suitability Indices for riparian "organic inputs."

Appendix I

DC1_HU_Table

	Pre-Project			Post-Project										
	Year 0				Year 1		Year 5		Year 15		Year 25		Year 50	
Habitat Category	Acres	HSI	HU	Acres	HSI	HU	HSI	HU	HSI	HU	HSI	HU	HSI	HU
Old River Bendway	0.0	0.00	0.0	0.6	0.36	0.2	0.46	0.3	0.71	0.4	0.87	0.5	0.89	0.5
Chute	18.9	0.47	9.6	16.9	0.37	6.2	0.59	10.0	0.67	11.4	0.68	11.6	0.68	11.6
Chute Below Pool	0.4	0.32	0.1	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Embayment	0.0	0.51	0.0	11.9	0.41	3.7	0.60	8.7	0.72	9.5	0.78	9.9	0.80	10.0
Vegetated Channel	0.0	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Pool	39.4	0.37	15.8	71.9	0.47	34.3	0.56	42.7	0.65	48.8	0.68	50.2	0.71	52.0
Riffle	1.3	0.42	0.5	4.7	0.31	1.4	0.52	2.3	0.55	2.6	0.56	2.6	0.56	2.6
Scour Pool	0.0	0.44	0.0	1.2	0.48	0.6	0.72	0.8	0.72	0.8	0.72	0.8	0.72	0.8
Tributary	0.2	0.56	0.1	0.5	0.30	0.1	0.39	0.1	0.43	0.2	0.44	0.2	0.44	0.2
Total	60.1		26.1	107.6		46.6		65.0		73.7		75.8		77.7

DC2_HU_Table

	Pre-Project			Post-Project										
	Year 0				Year 1		Year 5		Year 10		Year 25		Year 50	
Habitat Category	Acres	HSI	HU	Acres	HSI	HU	HSI	HU	HSI	HU	HSI	HU	HSI	HU
Old River Bendway	0.0	0.00	0.0	0.9	0.19	0.2	0.26	0.2	0.40	0.4	0.47	0.4	0.49	0.5
Chute	18.9	0.47	9.6	7.7	0.38	3.0	0.63	5.0	0.72	5.7	0.74	5.9	0.74	5.9
Chute Below Pool	0.4	0.32	0.1	0.1	0.29	0.0	0.46	0.1	0.47	0.1	0.47	0.1	0.47	0.1
Embayment	0.0	0.51	0.0	10.0	0.30	2.3	0.48	7.6	0.59	8.0	0.64	8.2	0.65	8.2
Vegetated Channel	0.0	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Pool	39.4	0.37	15.8	70.3	0.49	33.5	0.59	40.4	0.68	46.9	0.71	48.0	0.71	48.2
Riffle	1.3	0.42	0.5	14.5	0.32	4.7	0.51	7.5	0.59	8.7	0.61	8.9	0.61	9.0
Scour Pool	0.0	0.44	0.0	1.5	0.44	0.7	0.62	0.9	0.73	1.1	0.77	1.2	0.77	1.2
Tributary	0.2	0.56	0.1	0.5	0.30	0.1	0.41	0.2	0.48	0.2	0.50	0.2	0.48	0.2
Total	60.1		26.1	105.6		44.5		62.0		71.1		72.9		73.2

DC3A_HU_Table

	Pre-Project			Post-Project											
	Year 0				Year 1		Year 5		Year 10		Year 25		Year 50		
Habitat Category	Acres	HSI	HU	Acres	HSI	HU	HSI	HU	HSI	HU	HSI	HU	HSI	HU	
Old River Bendway	0.0	0.00	0.0	1.4	0.27	0.4	0.37	0.5	0.51	0.7	0.57	0.8	0.59	0.8	
Chute	18.9	0.47	9.6	15.8	0.37	5.9	0.58	9.3	0.71	11.4	0.72	11.5	0.72	11.5	
Chute Below Pool	0.4	0.32	0.1	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	
Embayment	0.0	0.51	0.0	12.6	0.45	3.9	0.60	9.6	0.75	10.5	0.81	10.8	0.87	11.2	
Vegetated Channel	0.0	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	
Pool	39.4	0.37	15.8	67.8	0.46	29.2	0.55	34.8	0.69	43.8	0.72	45.5	0.72	46.3	
Riffle	1.3	0.42	0.5	0.3	0.29	0.1	0.44	0.1	0.56	0.2	0.58	0.2	0.57	0.2	
Scour Pool	0.0	0.44	0.0	1.5	0.42	0.6	0.50	0.8	0.62	0.9	0.63	1.0	0.63	1.0	
Tributary	0.2	0.56	0.1	0.5	0.42	0.2	0.49	0.2	0.61	0.2	0.62	0.2	0.63	0.3	
Total	60.1		26.1	99.8		40.3		55.3		67.7		69.9		71.2	

DC3B_HU_Table

	Pre-Project			Post-Project										
	Year 0				Year 1		Year 5		Year 10		Year 25		Year 50	
Habitat Category	Acres	HSI	HU	Acres	HSI	HU	HSI	HU	HSI	HU	HSI	HU	HSI	HU
Old River Bendway	0.0	0.00	0.0	1.5	0.31	0.5	0.51	0.8	0.79	1.2	0.90	1.4	0.99	1.5
Chute	18.9	0.47	9.6	9.4	0.38	3.6	0.62	5.9	0.72	6.9	0.75	7.1	0.75	7.1
Chute Below Pool	0.4	0.32	0.1	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Embayment	0.0	0.51	0.0	12.9	0.45	4.0	0.61	10.0	0.76	11.0	0.83	11.4	0.88	11.6
Vegetated Channel	0.0	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Pool	39.4	0.37	15.8	68.9	0.48	32.1	0.57	38.6	0.69	46.6	0.72	48.5	0.73	49.7
Riffle	1.3	0.42	0.5	18.4	0.32	6.0	0.51	9.6	0.61	11.3	0.63	11.7	0.63	11.8
Scour Pool	0.0	0.44	0.0	1.5	0.42	0.6	0.59	0.9	0.72	1.1	0.74	1.1	0.75	1.2
Tributary	0.2	0.56	0.1	0.6	0.48	0.3	0.62	0.3	0.79	0.4	0.80	0.4	0.77	0.4
Total	60.1		26.1	113.2		47.1		66.1		78.5		81.7		83.3