# APPENDIX D

## Methodology Used by the A-team to Collect Reference Data for the Development of the Santa Barbara HGM Guidebook

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### Hydrology and Coarse Wood Sampling

For each of the 60 reference sites sampled for this study, the A-team completed an examination of any available gauge data, published reports, plans, *etc.* prior to traveling to the field. Once in the field, the A-team completed a thorough reconnaissance of each candidate stream channel reach and riparian zone. The A-team also examined areas immediately upstream and downstream of the recommended location for the reference site. The A-team used current and historic air photos, U.S. Geological Survey and County maps at several scales, soil survey information, *etc.* to assist us in our reconnaissance. On completion of the site reconnaissance, the team conferred to review reconnaissance results and to either accept or reject the reference site for incorporation into the SCSBC Reference System. Grounds for rejection usually focused on access permission, safety, or toward the end of the field sampling, redundancy with reference sites already sampled. If a reference site was accepted, the A-team then worked to identify a "representative" and relatively homogeneous stream channel reach. On selection of the sample reach, the A-team established the main stream channel cross section.

Standard methods for locating a representative reach and stream cross section were used (Dunne and Leopold 1978, Harrelson *et al.* 1994). These methods caution investigators to avoid meanders or otherwise complex portions of the channel system (*e.g.* a cross section through a log jam) and to locate cross sections in relatively straight, homogeneous parts of the channel. For this study, and mainly for the purposes of establishing a standard reference level for measurements, the main channel cross section extended from the "Ordinary High Water" mark (OHW) on stream left (left bank, looking downstream) to OHW on stream right (right bank, looking downstream). Our definition of OHW was consistent with language offered in the Federal Regulations at 33 CFR 328.3 (e). In all three subclasses that were the main focus of this study, OHW stream left to OHW stream right delineations almost always represented the geographic extent of federal jurisdiction and our best judgment of the level of flood events that occur on an annual or near annual return frequency. The A-team used a standard non-stretch measuring tape, vice grips or clamps, and either bubble or laser levels to mark the main cross section and to ensure that our main cross section reference line was taught and level.

From the outset, the A-team recognized that use of OHW as a reference level in the main channel cross section may be problematic, because of the erratic and highly variable nature of stream hydrographs in the SCSBC region, and the degree of entrenchment or human alteration of many streams within the SCSBC domain. In an attempt to calibrate our field delineations of OHW to hydrograph data, the A-team cross-referenced several field determinations of OHW with stage and return frequency data, and with what would be standard determinations of the geographic extent of federal (Clean Water Act Section 404) jurisdiction at the cross section. Most of the stage data used for cross-reference efforts were applicable only to channel reaches that were highly altered, hardened, and entrenched (*e.g.* concrete trapezoids). Therefore, OHW determination by the A-team in many altered and in unaltered channel reaches represent our best professional judgment regarding the stage (OHW) of the approximately 1 to 1.5 year return flow event. The A-team recognize that this field measurement technique is somewhat contrived and that it does not capture the hydrologically active portions of the channel system at very high or catastrophic flow events. For the purposes of this *Draft Guidebook*, and consistent with the County Flood Control Agency approach, the A-team considered the area from "top of bank stream left" to "top of bank stream right" to be most likely flood-prone during very high to catastrophic flow events.

Following establishment of the main channel cross section, the A-team used a standard Robert White® laser level and rod system, and the cross section tape to complete horizontal and vertical measurements in the cross section. These included channel width and depth from OHW at several points in the cross section. From these measurements the A-team calculated cross-sectional area at the main cross section. The A-team also used the laser level system to complete measurement of the longitudinal profile of the channel for a distance 3.5 times the OHW width at the main cross section upstream and downstream from the main cross section. Thus, the longitudinal profile transect was a total length of 7 times the OHW channel width at the main cross section. To complete the series of measurements centered at the main cross section, the A-team developed sketches of both the main channel cross section and the longitudinal transect, and took representative photos.

Starting at the main cross section, the A-team measured the width of the area from the Santa Barbara County "top of bank" stream left to "top of bank" stream right. The "top of bank" width measurement is our best estimate of the geographic extent of the County Flood Control Agency easement along the stream. From the "top of bank" points, the A-team measured the County Buffer width, which is usually stipulated as 50 ft wide in urban zones, and 100 ft wide in rural zones.

Starting at the deepest point in the main cross section (thalweg), "Flood Prone Area Width" (FPAW) was measured using the assumption that it equals the width of a horizontal projection to channel or terrace banks on stream left and right from a level two times the thalweg depth (Leopold 1994; Rosgen 1994). The A-team also measured "wetted perimeter" at the main channel cross section by laying a cloth tape over the bottom of the channel from OHW stream left to OHW stream right. A summary of these basic channel geometry measurements, and derived channel geometry statistics (*e.g.* width:depth ratio; entrenchment ratio; hydraulic radius) are offered on the data sheets offered in Appendix B-17 through B-24.

Several measurements were completed along the main channel study reach for a distance of 3.5 times the OHW channel width upstream and 3.5 the OHW channel width downstream from the main channel cross section. For example, in the entire 7x study reach, the A-team used Rosgen's (1994) system to classify the stream channel type. The A-team also walked the study reach several times to:

1. Count and measure the distance between "residual pools." By definition, residual pools that are at least 10 $ft^2$ in area and 0.5 ft deep at the deepest point that would exist within the channel cross section at base flow conditions.
2. Complete a standard, 100 sample pebble count (Leopold 1970).
3. Use the pebble count estimates of larger size bed material (D-84) to identify and measure the degree of embeddedness of 20 samples of larger size channel bed material in smaller size channel bed materials.
4. Count the number and measure the length and diameter of each piece of "coarse woody debris" (wood > 3 inch diameter) in the channel below OHW.
5. Count and measure the length, width, area, and decomposition class of coarse and fine woody debris jams.
6 Count the number of coarse wood pieces from channel bank sources.

Measurements of immobile bed roughness were completed at OHW stream right to OHW stream left channel cross section transects located 25 ft upstream and downstream from the main channel cross section. Within these "immobile bed" transects, the area of each immobile bed feature (*e.g.* stones or boulders size class D-84 and larger, which are derived from pebble count data) intersecting the vertical plane of the cross section was measured. All area measurements were added, then divided by the cross sectional area at that point in the channel to derive an estimate of the proportion of the channel cross-section occupied by immobile bed features. Photos were then taken of the immobile bed cross sections from the main channel cross section (*i.e.* exactly 25 ft upstream or downstream) using a standard 35mm single lens reflex camera with standard focal length of 35 mm.

Additional hydrology measurements included observations of hydrologic connections upstream and downstream, surface or subsurface water inputs and outputs, observations of sediment inputs and accumulations, and observations of any levees, dikes, or barriers to fish passage.

**Soils Sampling**

The A-team sampled soils using undisturbed channel cutbanks and soil pits to identify and describe soil characteristics. Soil characteristics also yielded important information on site hydrology (*e.g.* drainage class, presence or absence of redoximorphic features). When channel cutbanks were not present, soil pits were excavated. These pits were excavated to the depth of impenetrable debris (*e.g.* boulders, stones, cobbles) or excess water, or to a depth of approximately 3 ft, whichever was encountered first. The upper 3 ft were excavated with a "sharpshooter" shovel. A closed-bucket or Dutch auger often was used below approximately 2 ft. The A-team described the riparian soils on stream right and stream left, and estimated the texture and particle size class of the sediment within the stream channel.

Identification, nomenclature, and description of soil horizons were consistent with guidance provided by the USDA Natural Resources Conservation Service (Schoeneberger *et al.*, 1998). Field teams measured all depths from the top of the surface horizon, usually an A horizon. Live vascular and non-vascular plant materials were **not** included in these depths. Soil colors were determined using a standard Munsell Soil Color Chart (Munsell 1992).

**Vegetation Sampling**

Vegetation sampling allowed for the collection of multiple descriptive measures of the plant communities characteristic to the SCSBC riverine waters/wetlands. For example, the A-team collected data on tree, shrub, vine, herb, snag, and seedling/sapling and off-channel coarse woody debris percent cover, as well as tree and snag basal area. Other data included descriptions of dominant leaf type, dominant type of regeneration, average number of strata present, and width of riparian zone of influence. A species list was compiled, with cover class values assigned to each taxon. The vegetation sampling team also evaluated the continuity of the vegetation. Classes of waters/wetlands present, according the modified Cowardin classification developed by Ferren and colleagues (Ferren 1995, 1996 a, b, c) also were described.

*Point Center Quarter (PCQ) Plots*

The point-center quarter plot is a standard technique in vegetation sampling used to obtain a measure of stand composition and dominance (Mueller Dombois and Ellenberg 1974). The A-team chose a plot center that would allow the sampling team to obtain a set of measurements that best characterized the riparian vegetation within the variable assessment area. Where significant constraints were encountered such as extensive growth of Poison oak (*Toxicodendron diversiloba*) or a slope (> 70%) so steep that the A-team could not stand upright and take measures, the team estimated the requisite measurements (*i.e.*, inter tree distance and diameter at breast height) from outside the riparian zone, typically standing in the creek below OHW.

To use the point-centered quarter methodology, one member of the team stood at plot center, determined the four cardinal quarters of the plot using a standard compass, and held the zero end of the sampling tape for the second member of the team. This second person held the other end of the tape, and with the team recorder, determined the identity of and distance to the closest tree, shrub, vine, herb, and seedling/sapling in each of the four quarter plots. Additionally, distances to nearest snag and off-channel coarse woody debris also were obtained. For each tree and snag within each quarter, the diameter at breast height (DBH) using a forester's diameter tape.

*Number of Strata*

To obtain a measure of the average number of vegetation strata within the assessment area, the team recorder held one end of the 100 ft sampling tape while the other walked the length of the tape, parallel to the stream. Generally, but not always, the center of the PCQ plot was the (50 ft) center of vegetation strata transect. When it was not possible to stretch a tape for the entire 100 ft due to the density of the understory, ten measurements were obtained at sampling points spaced at minimum 10 ft apart, but not necessarily at exactly equivalent distances.

At every ten ft, one team member determined the number of strata that intersected the sampling point at the toe of their boot. For example, if a tree canopy overhung a continuous vine layer, with no additional vegetation present at the sampling point, two (2) vegetation strata (tree + vine) were recorded. The A-team obtained twenty (20) measurements total, ten (10) on each side of the assessment area within the riparian zone of influence.

*Width of Riparian Zone*

To obtain a measure of the extent of streamside vegetation from the ordinary high water mark to its upslope extent, the A-team measured the width of the riparian zone from OHW to the first break in vegetation. A break in vegetation was defined as any noticeable, measurable change in the continuity of vegetation, such as a foot trail or road, which had the potential to affect the movement of any terrestrial animal.

Typically, four measurements of riparian width were obtained from each side of the assessment area. One member of the team stood at OHW, while the other walked to the first break in continuity of vegetation. In most instances, it was possible to correct for the influence of slope by holding the tape plumb and from OWH to the break in vegetation. This sampling protocol was repeated up to four times to capture the range of variation in width. If the width of the riparian zone was unvarying, often the result of an immediately adjacent paved road or when the creek was highly disciplined (*e.g.*, concrete channel), then only one measurement was taken on each side of the assessment area.

*Tree Density and Basal Area*

To obtain a measure of tree density and basal area, the A-team used a basal area factor (BAF) 10 prism, which is a standard "plotless" technique used in forest measurement. The recorder stood at the center of the PCQ plot and using the prism, counted the number of trees that were large enough to be counted within the assessment area on one side (either left or right) of the stream. The second team member recorded the height of an individual representative of each species using a clinometer. This protocol was repeated on the other side of the assessment area.

*Species Composition and Indigenous Status*

After the above measurements had been taken, one member of the team walked the assessment area and recorded every plant species present. After the entire site had been thoroughly assessed, an ocular estimate of canopy cover was made for each species, and the cover class midpoint recorded. At the end of the sampling, the indigenous status (*i.e.*, whether the species was native, nonnative, ornamental, or cultivated [*e.g.*, avocado]) also was recorded.

*Additional Descriptive Information*

Various other data were obtained at the end of the sampling effort. The team member responsible for the species list recorded the (1) leaf type of the dominant stratum, (2) dominant type of regeneration, and (3) type of waters/wetland(s) present within the assessment area, using the Ferren *et al.* classification for each stratum (Ferren *et al.* 1995, 1996 a, b, c). For leaf type, the possible states for trees, which most often were the dominant vegetation, were broadleaf evergreen, broadleaf deciduous, needle leaf [evergreen], mixed broadleaf deciduous and evergreen. When trees were not the dominant vegetation, then the dominant life form (*e.g.,* herbs) was recorded. For dominant type of regeneration by strata, the A-team recorded either sexual exclusively, vegetative exclusively, or both the dominant taxa exhibited sexual and vegetation modes of regeneration.

The listing of waters/wetland types from the Ferren, Fiedler, Leidy classification (1995) was more problematic. This classification technique requires considerable knowledge of the classification structure as well as the vegetation. Classification of waters/wetland types at each sampling site typically was time-intensive. Therefore, the A-team recorded only one riverine wetland type and one palustrine wetland type at each site. Very often, there were several additional waters/wetland types, primarily described at the class/subclass and dominance type subclass levels (*i.e.*, multiple substrates and multiple dominants often were present).

**Habitat/Faunal Support Sampling**

At each of the 60 reference sites sampled for this study, the A-team completed a systematic look for either direct or indirect signs of animal use of the waters/wetlands or the associated riparian zone/buffer area. The area sampled extended laterally from buffer boundaries on stream left to buffer boundaries on stream right. Upstream and downstream boundaries extended at minimum 3.5 times the OHW channel width at the main cross section. Direct observations required that the team member would actually see or hear the call of an animal within the assessment area. Indirect observations included several types of sign (*e.g.* tracks, browse, nests, scrapes or rubs, *etc.*). A complete list of animal signs is included in the data sheet, provided in Appendix A.

**Land Use, Buffers, and GIS Location Input**

Observations were noted on the data sheet (Appendix A) regarding the dominant land use within the assessment area and the adjacent buffer. Buffers were identified using the Santa Barbara County definitions for wetland and riparian buffers. Land use was classified as either (1) undisturbed, (2) logged within last 5 years, (3) logged more than 5 years ago, (4) agriculture, (5) low density housing, (6) urban, (7) cleared, or (8) other.

HGM reference site locations were identified in the field using three handheld non-differential GPS (Global Positioning System) units programmed to read UTM (Universal Transverse Mercator) coordinates. The three measurements were averaged to locate the position of the reference site channel cross-section. The reference site locations were stored in the GPS units and then converted to GIS (Geographic Information System) point features in Arc/Info for all 60 HGM reference sites (Figure 3.2). The reference site locations were converted to a map projection useful for area calculations and consistent with the other public and SB County data in the GIS database (*i.e.*, Albers California map projection). Data points were attributed with the appropriate reference site identification numbers and HGM subclasses. In some instances, due to steep topography and tree canopy cover in the riparian zone, a positional error of as much as 50 meters occurred. Therefore, several of the GPS captured points did not overlay onto the existing digital streams data layer (*i.e.*, U.S.G.S. Hydrography 1:100,00 Digital Line Graph [DLG]). In these instances, the points were manually moved to coincide with the DLG stream data layer.

**Remote Sensing and GIS Methodology and Applications**

*Generation of Variable Assessment Scales*

A digital elevation model (DEM) mosaic was assembled for the entire reference domain using a publicly available U.S.G.S. 7.5 minute DEMs (http://www.usgs.gov). The DEM mosaic was converted to a Albers California map projection, re-sampled to a 30 meter resolution and smoothed with an Arc/Info high-pass filter. The high pass filter minimized errors resulting from the production of the DEM mosaic for the entire reference domain (*e.g.*, edge matching errors) (ESRI 1998). Remaining errors in the DEM mosaic (*i.e.*, “sinks" or points of internal drainage in the filtered DEM) were “filled” by the GIS. Flow direction and flow accumulation grids were derived using standard ARC/INFO methodology (ESRI, 1998). A stream network grid was then derived using a minimum contributing area threshold of 100 pixels.

Watershed boundaries within the reference domain were derived in two ways. First, the stream network grid generated from the DEM was converted from a raster data format to a vector data format and all of the watersheds in the western portion of the reference domain (*i.e.*, Point Conception to Eagle Canyon) were derived from this vectorized stream network. In the eastern portion of the reference domain (*i.e.*, Eagle Canyon to Rincon Point), an existing Santa Barbara County Water Agency GIS watershed layer was used to define the watersheds (Santa Barbara County Water Agency, 2000). These two data sets were combined to form a complete watershed data layer for the entire reference domain, from Point Conception to Rincon Point.

In some instances, the DEM-derived streams were incorrect with respect to position in low-gradient portions of the reference domain (*i.e.*, the coastal plain). These positional errors result from either 1) insufficient topographic relief in the DEM that prevents accurate automated generation of the stream network/watershed boundaries by the GIS or, 2) areas where the natural stream channel courses have been altered through civil engineering activities. Thus, in the low-gradient portions of the reference domain, it was necessary to augment the DEM-derived watershed boundaries with the Santa Barbara Water Agency GIS watershed data. In some cases, sub-watershed boundaries used by the Santa Barbara Water Agency were deleted, leaving a single watershed boundary for the main stream channel.

In order to assess the characteristics of the landscape contributing runoff to a particular HGM reference site, sub-watershed boundaries were derived from the point on the channel that was sampled in the field. These reference site sub-watershed boundaries were derived individually for each of the 60 HGM reference sites. The sub-watershed boundaries were derived from the DEM using similar ARC/INFO hydrologic modeling methods described above for the entire watershed boundaries (ESRI 1998). For reference sites occurring in low-gradient portions of the reference domain, where the DEM inaccurately defined the watershed boundary (see discussion above), the sub-watershed boundaries were digitized on screen using the existing SB County Water Agency watershed information and any available topographic contour information.

A 1000 ft radius variable assessment area (VAA) ring was generated around each of the 60 reference site locations. These 1000 ft VAA rings were generated in order to evaluate landscape characteristics in the immediate vicinity of the reference site.

*Data Sources for Analysis of Site Landscape and Watershed Characteristics*

Several data layers were used to assess the landscape and watershed characteristics of the HGM reference sites. These thematic layers included:

1. Landsat 7 - Enhanced Thematic Mapper based land use classification (http://www.usgs.gov)
2. California Gap Analysis Program (GAP) based vegetation and land cover (http://www.biogeog.ucsb.edu/projects/gap/gap_home.html)
3. National Wetlands Inventory (NWI) data (http://www.nwi.fws.gov)
4. National Resource Conservation Service Soil Survey Geographic (SSURGO) soils data (http://www.ftw.nrcs.usda.gov/ssur_data.html) - file ca673
5. Federal Emergency Management Agency (FEMA) flood zones (http://www.fema.gov)
6. United States Geological Survey 1:100,000 Digital Line Graph (DLG) roads data
7. SB County Water Agency groundwater basins data (Santa Barbara County Water Agency 2000)
8. SB County Environmental Health Services septic tank data (Santa Barbara County Environmental Health Services 2000)
9. SB County Assessors parcel land use data (Santa Barbara County Assessors Mapping Division 2000)

These thematic layers were assessed at one or more spatial scales: 1000 ft radius VAA rings, the reference site sub-watersheds, and the entire watershed that the reference site occurs. For a given thematic layer and variable assessment scale, the within which were summarized using ArcView/Xtools (http://www.odf.state.or.us/sfgis/). These Arcview Xtool commands included 'Tabulate Area' 'Identity', 'Intersect', and 'Table Frequency'. These tools generated summary tables that were placed into Microsoft Excel and processed into an interpretable format (see Appendix B-77 through B-112). In addition, a series of hydrologic and geomorphic analyses (*i.e.*, stream gradients, bifurcation ratios, drainage densities) based on the USGS DEM mosaic created for the project were performed.

<u>California Gap Analysis Program Data</u>
In 1993 the California Gap Analysis Program (GAP) mapped vegetation and land use at a statewide scale. This extensive spatial scale required a coarse resolution of 100 hectares (25 acres) as the minimum mapping unit. Despite this coarse resolution, the GAP data set was analyzed in order to compare it to other available land use data sets, and to identify its utility within the reference domain.
GAP vegetation cover and land use within the reference site sub-watersheds and entire watersheds were both analyzed. The Wildlife Habitat Relations (WHR) use/cover descriptions in the GAP data set were used for the analysis. Examples of these land use description/attributes include "urban", "coastal sage scrub", "annual grasslands", "coastal oak woodlands" *etc.* Each map unit (polygon) in the GAP dataset is attributed for its primary, secondary and tertiary land cover type. It also is attributed to indicate what proportion of the polygon each land cover type occupies. The primary, secondary, and tertiary cover types were accounted for in calculating areas of each cover type for the reference site sub-watersheds and entire watersheds. Results of these analyses are included in Appendix B-101 through B-103.

<u>US Fish & Wildlife Service National Wetlands Inventory Data</u>
The US Fish and Wildlife Service National Wetlands Inventory (NWI) is charged with creating and updating maps of the waters/wetlands of the entire United States. Due to the continental scale of the mapping effort, the data set is insufficient for projects requiring detailed waters/wetland and riparian maps at a local scale. Although NWI maps are distributed at a scale of 1:24,000, generally they are drafted from aerial photographs at a scale of 1:58,000 or coarser. As a consequence, riparian wetlands are often completely absent in the NWI, which is especially true in the case of the NWI data for the South Coast of Santa Barbara County. Nevertheless, the NWI dataset was utilized to compare to other available

datasets and to identify its utility in the reference domain. NWI data were assessed for the 1000 ft variable assessment area rings, the reference site sub-watersheds, and the entire watersheds. The number and total area of waters/wetlands for each waters/wetlands class (estuarine, lacustrine, marine, palustrine and riverine) were calculated for each scale. Results of these analyses are included in Appendix B-98 through B-100.

National Resource and Conservation Service Soil Survey Geographic (SSURGO) Data

The National Resource and Conservation Service (NRCS) mapped the soils of the South Coast of Santa Barbara County at a scale of 1:24,000. Hundreds of attributes are attributed to the soil map units. However, these attributes often are incomplete. The SSURGO dataset was utilized to identify its utility as the best available digital soils map for the reference domain. This data set was used to identify and summarize hydric soils, soil drainage characteristic, soil hydrologic groups, and suborder names for the reference site sub-watersheds and the entire watersheds. Results of these analyses are documented in Appendix B-105 through B-109.

Federal Emergency Management Agency Flood Zone Data

Based on Federal Emergency Management Agency (FEMA) data, the percent of each reference site sub-watershed and entire watershed occurring within a mapped state flood hazard area was calculated. Results of these analyses are documented in Appendix B-104.

United States Geological Survey 1:100,000 Digital Line Graph (DLG) Roads Data

The presence of roads in the reference domain was assessed by measuring road density based on the USGS 1:100,000 DLG roads theme. Hiking trails were queried out of the data set so that only roads were evaluated. Road density was calculated for 1000 ft VAA rings, reference site sub-watersheds and entire watersheds, by measuring the total length of roads within the evaluation area. Road density was measured as miles of road per square mile. Results of these analyses are documented in Appendix B-110 through B-112.

Santa Barbara County Water Agency Ground Water Basin Data

Based on Santa Barbara County Water Agency data, the percent of each reference site sub-watershed and entire watershed occurring within a mapped ground water basin was calculated. Results of these analyses are documented in Appendix B-95.

Santa Barbara County Water Agency Septic Tank Data

Based on Santa Barbara County Water Agency data, the number of parcels using septic tanks within each 1000 ft assessment area ring, reference site sub-watershed, and entire watershed were calculated. The results of these analyses are documented in Appendix B-96 through B-97.

Santa Barbara County Assessors Parcel Land Use Data

The Use Codes from the Santa Barbara County Assessor's Parcel data were reclassified from 93 land use classes to 20 classes (see Appendix B-86). Land use classes were aggregated by relating the described land use to its affect on water quality. Analyses were conducted for three HGM reference sites; #29, #32, and #47 (Figure 3.2; Appendix B86) to compare the differences between the two land use classification schemes (*i.e.*, Assessors parcel land use data *vs.* ETM Land use classification). Total area within each of the 20 land use classes was calculated for the reference site sub-watersheds. These land use areas were converted to relative percentages of the total sub-watershed area. Because the assessors parcel layer does not map roadways as a class, the total area of the parcels is slightly less than the total area of the sub-watersheds. This difference was calculated and described as 'roads' (*i.e.*, DIF in Appendix B). Finally, the 20 aggregated land use classes were aggregated once again, as closely as possible, to reflect the ETM land use classification analysis. This allowed for a comparison of the two land-use classification schemes for the three HGM reference sites (Figure 4.29).

Hydrologic & Geomorphic Analyses - Bifurcation Ratios/Stream Gradients/Drainage Densities

- *Drainage Densities*

Drainage density was calculated for the reference site sub-watersheds and for the entire watersheds. Drainage densities were calculated separately from both 1:100,000 USGS DLG streams and derived streams from the DEM mosaic of the reference domain. Drainage density was calculated as miles of stream per square mile of watershed area. Results of these analyses are documented in Appendix B-91 through B-92.

- *Stream Gradients*

Stream gradients were calculated for the all watersheds in the reference domain. DEM-derived streams served as the basis for this analysis. The DEM derived streams were assigned to Strahler based stream orders and stream gradients were then calculated in percent (Strahler 1957). Stream order designations were derived directly from the DEM using Arc/Info hydrologic modeling and slope derivation techniques respectively (ESRI 1998). The minimum, maximum, mean, and standard deviation stream gradients were calculated for each entire watershed using Arcview Spatial Analyst (ESRI 1998). The results of these analyses are documented in Appendix B-87 through B-90.

- *Bifurcation Ratios*

An average bifurcation ratio was calculated for each entire watershed using streams derived from the DEM mosaic. As above, these streams were assigned to Strahler stream order, then vectorized as lines in Arc/Info. A list of the number of stream segments of each stream order was created for each entire watershed. Individual bifurcation ratios were calculated by dividing the number of segments of a given order by the number of segments of the next highest order. Thus, watersheds with only first order streams would have no bifurcation ratio calculated for them. Results of these analyses are documented in Appendix B-93 through B-94.

*Landsat 7 - Enhanced Thematic Mapper (ETM) Land Use Classification and Analysis*

Rationale for ETM Based Land Use Analysis

Landsat 7 - ETM imagery collected on 9/11/99 was used to generate a land use thematic layer that 1) was at a resolution finer than previously existing data for the reference domain, and 2) that was more temporally up to date than existing land use data sets for the reference domain. For example, vegetation and land cover data from the California GAP Analysis are mapped at a minimum mapping unit of 100 hectares (25 acres), a resolution too coarse to be of use for this land use classification. Likewise, Santa Barbara County Assessor's Parcel land use data are very descriptive of uses within parcels; however, these use descriptions often describe the zoned use and not the actual land use. Furthermore, the descriptions often do not apply to the entire parcel and do not necessarily relate to natural processes affecting riparian areas and waters/wetlands. In contrast, the Landsat 7 ETM imagery was collected on 9/11/99 and has a minimum mapping unit of 30 by 30 meters (100 by 100 ft, or ± ¼ acre).

Classification Approach & Methodology

The Landsat 7 ETM imagery was classified in order to differentiate and map types of land cover and land use that would affect the high, medium, and low gradient subclasses of riverine waters/wetlands within the reference domain. Various types of remote sensing classifications can be performed, each with their respective benefits and drawbacks depending on the requirements of the project. For instance, a remote sensing classification technique that works well for urban landscapes (*i.e.*, that can differentiate between high density and low density residential/commercial) will be less useful in vegetated areas and likely will misclassify vegetation types. Conversely, a remote sensing classification technique that works well in vegetated landscapes (*i.e.*, can differentiate between multiple vegetation types) will likely falter in urban areas. Furthermore, the various classification techniques can range from very simple to very complicated, with the time, data, and computational resources required increasing with the complexity of the classification technique. As a result, the choice of a classification approach represents a balance between the requirements of the output, the type of remote sensing data being classified, the availability of ancillary data sources, and the time and resources available for the project.

Unsupervised Classification - Cluster Analysis

For this effort, an unsupervised classification (*i.e.*, cluster analysis) was selected for the ETM land use analysis. This technique requires limited additional input data other than the raw Landsat 7 imagery and the number and specificity of the output land use/land cover classes can be controlled easily. Control of the number of output land use classes was crucial because the reference domain contains a diversity of land use/land cover types from urban/impervious surfaces to native chaparral and forest; therefore, a generalized approach was required. Furthermore, the complexity of the technique and the number of land use classes had to be balanced with the requirements of the HGM functional assessment protocol. The intent was to utilize an approach that was relatively simple and straightforward, easily reproducible, and that provided data that could be directly incorporated into the HGM functional assessment profiles and models.

Unsupervised classification of remote sensing imagery is a technique whereby digital information within the raw image is extracted by the computer and the resulting map pixels are assigned categories with no instructions from the operator. This technique is computationally efficient and allows for no *a priori* biases or knowledge on the part of the operator. In essence, the computer groups pixels in the raw image data that have similar spectral signatures. These initial groups, or clusters, are rarely the final classifications, as they often are large and/or contain diverse classes of spectral data. Additional subdivision and/or grouping of data clusters based upon ancillary data sources (*e.g.*, aerial photography) and local knowledge often is necessary and desirable for the final classification scheme (Sabins 1997).

Processing and Classification Steps

The final ETM land use classification went through several processing steps. First, a cluster analysis (ESRI 1998) on the ETM image bands 1 (blue), 2 (green), 3 (red), 4 (near infrared), 5 (mid infrared) and 7 (mid infrared) was performed with a selection of ten initial land use classes specified. Band 6 was eliminated during image processing as it is the thermal wavelength band and provides less useful information for this type of classification. In consultation with aerial photography and local knowledge of the reference domain by the authors, these ten classes were initially identified as urban/impervious, barren/exposed soil, open water bodies, irrigated agriculture/golf courses, riparian forest, grasslands, and four additional vegetation classes representing chaparral, scrub shrub, forest (closed canopy), and woodlands (open canopy). These last four vegetation classes were the least differentiable and thus required additional processing before final classification was possible.

The remaining four vegetation classes were removed and replaced with new classes derived from a Normalized Difference Vegetation Index (NDVI) (Figure 4.27). NDVI is a technique by which multiple bands of image data are reduced down to a single number per pixel that predicts or assess such canopy characteristics such as biomass, productivity (phytomass), leaf area index (LAI), amount of photosynthetically active radiation (PAR) consumed, and/or percent vegetative ground cover (Jensen 1996). The NDVI was calculated as follows:

$$\frac{\text{ETM Band 4} - \text{ETM Band 3}}{\text{ETM Band 4} + \text{ETM Band 3}}$$

Once the NDVI was calculated for the image, the index range occupied by each of the four vegetation classes was identified. Based on the NDVI analyses, three equal-interval classes for the index were identified and assigned to the four vegetation classes. This stratification process reduced the four vegetation classes down to three based upon similarities in their relative NDVI values. These three vegetation classes subsequently were identified and classified as scrub shrub/coastal chaparral, native chaparral/woodlands, and native chaparral/forested. The second iteration of the land use classification thus resulted in the following nine land use classes: urban/impervious, barren/exposed soil, open water bodies, irrigated agriculture/golf courses, riparian forest, grasslands, scrub shrub/coastal chaparral, native chaparral/woodlands, and native chaparral/forest.

Final Image Processing and Land Use Classification

The nine category ETM land use classification was stratified further by collapsing the original riparian forest class with the native chaparral/forest class based upon comparisons with aerial photography and local knowledge of the authors. In addition, some of the high gradient portions of the watersheds, proximate to stream channels were being miss-classified as 'irrigated agriculture' due to the presence of water and/or moist soil conditions. Comparisons with aerial photography and local knowledge confirmed that these areas were in fact dominated by native chaparral and/or riparian forest. As a result, a slope threshold of 25 degrees was used to filter out and reclassify these areas to the native chaparral/forested land use class (*i.e.*, areas with slopes > 25% are generally too steep for commercial agriculture/irrigation operations, so they were reclassified if they exceeded the slope threshold). In general, this reduced the amount of area being mis-classified as irrigated agriculture, though some areas remain in the valley bottoms where moist conditions exist and slopes are less than 25%. Ultimately these techniques and processing steps produced a land use/land cover classification with eight classes (Appendix F.1, Figure 4.28) and the following descriptions).

- *Class 1 Ocean & Open Water*

  ETM class 1 represents the ocean and other open water bodies such as lakes, ponds, and reservoirs.

- *Class 2 Urban (Residential/Commercial) & Impervious Surfaces*

  ETM class 2 represents urbanized areas (high and low-density residential and commercial) and other impervious surfaces such as roads and highways. In addition, beach sand shares a similar spectral signature to urban/impervious areas due to its smooth texture and high reflectivity in the visible wavelengths. It is included in this land use class, although it represents a very small proportion (<1%) of the Class 2 land use within reference domain.

- Class 3 Irrigated Agriculture, Golf Courses, and Residential Lawns

  ETM class 3 represents irrigated areas (*e.g.*, commercial agriculture, irrigated golf courses) within the reference domain. Within the high and medium gradient subclasses, avocado groves and citrus orchards are the most prevalent type of irrigated agriculture associated with this ETM land use class. Some ETM class 3 appears in the riparian zones within the high gradient subclass due to the presence of water and/or moist soil conditions.

In portions of the medium gradient and throughout the low gradient subclass, irrigated golf courses and large (*i.e.*, bigger than a 30 meter square pixel in the Landsat 7 image) residential estate lawns/landscaping (*e.g.*, Hope Ranch and Montecito) are the primary form of irrigated land use. One exception to this pattern of land use within the low gradient subclass is the extensive irrigated agriculture (*i.e.*, avocados and citrus) occurring to the east and northwest of downtown Carpinteria.

- *Class 4 Shrub/Scrub and Coastal Chaparral*

  ETM Class 4 consists of a vegetation mosaic dominated by scrub/shrub and coastal chaparral characteristic to the south coast of Santa Barbara County. These vegetation communities often contain an interspersion of exotic grasses and forbs as well. The scrub/shrub and coastal chaparral community is dominated by a small number of native shrubs, including *Baccharis pilularis, Eriogonum fasciculatum*, and *Artemisia californica*. The exotic grass/forb complement commonly found within this mosaic includes *Avena* spp.*, Brassica nigra, Bromus diandrus, Bromus hordaceus, Hordeum murinum* ssp. *leporinum, Picris echioides,* and *Raphanus sativa* with the grass *Leymus condensatus.* The distribution of the scrub/shrub and coastal chaparral species is discontinuous to scattered due to anthropogenic disturbance (land clearing, light to moderate grazing, *etc.*).

- *Class 5 Native Chaparral and/or Woodlands (open canopy)*

  ETM Class 5 consists predominantly of a homogeneous cover of 1) native chaparral communities (*Adenostema fasciculatum, Arctostaphylos* spp., *Ceonothus* spp., *Quercus dumosa, Q. berberidifolia*, *etc.*, within the high gradient subclass and 2) native/non-native woodlands (*i.e.*, open canopy structures) in the medium and low gradient subclasses (*e.g.*, *Quercus agrifolia, Eucalyptus globulus*, and *Phoenix canariensis*). Within the high gradient subclass, ETM classes 5 and 6 (see below) are similar with respect to their community composition and structure. The distinction between ETM classes 5 and 6 is the result of two factors, 1) shadows in the imagery, due to steep topography, which result in differing spectral signatures and thus separation into two ETM classes, and 2) variation in hillslope aspect that affect the structure/physiology of the vegetation cover.

  Within the medium gradient subclass, ETM class 5 represents some native chaparral (*i.e.*, in the steeper and undisturbed portions of the medium gradient subclass) as well as native/non-native woodland communities with open canopy structures. The heterogeneity of ETM class 5 is often a result of ornamental plantings/landscaping (*e.g.*, eucalyptus, palms, *etc.*) within the urban areas of the reference domain and/or 2) remnant patches of native woodlands in the non-urbanized portions of the reference domain (*e.g.*, riparian zones in Hollister Ranch).

  Within the low gradient subclass, ETM class 5 represents native/non-native woodland communities with open canopy structures. Similar to the medium gradient subclass described above, the heterogeneity of ETM class 5 often is a result of ornamental plantings/landscaping within the urban areas of the reference domain, and/or remnant patches of native/non-native woodlands in the non-urbanized portions of the reference domain. Contiguous areas/patches of ETM class 5 often are located proximate to riparian zones in the medium to low gradient subclass and these native/non-native woodlands often are maintained as a result of Santa Barbara County setbacks/buffers.

- *Class 6 Native Chaparral & Riparian Forest (closed canopy)*

  ETM Class 6 consists of 1) homogeneous native chaparral communities within the high gradient subclasses (*i.e.*, see ETM high gradient class 5 above) and 2) native/non-native riparian forest (closed canopy) in the medium and low gradient subclasses. Within the high gradient subclass, ETM classes 5 and 6 (see above) are similar with respect to their community composition and structure. The distinction between ETM classes 5 and 6 is the result of two factors, as before, 1) shadows in the imagery due to steep topography, and 2) differences in hillslope aspect that affect the structure/physiology of the vegetation cover.

  Within the medium and low gradient subclasses, ETM class 6 represents closed canopy forest communities. Contiguous areas/patches of ETM class 6 are often located in riparian zones in the medium to low gradient subclass and are maintained through SB County setbacks/buffers. Typical species found in this ETM class include *Alnus rhombifolia, Populus balsamifera* subsp. *trichocarpa*, *Platanus racemosa,* and *Quercus agrifolia*, among others.

- *Class 7 Grasslands*

  ETM class 7 represents grassland communities dominated by non-native species such as *Avena* spp*., Brassica nigra, Bromus diandrus, B. hordaceus,* and *Hordeum murianum* subsp. *Leporinum*. In the low and medium gradient subclasses, this land use class results from anthropogenic disturbance typically in the form of land clearing activities, or from light to moderate grazing of domestic livestock (*e.g.*, cattle grazing on San Marcos foothills East of Highway 154). Ground cover of grasses and forbs is continuous with little to no exposed soils. As the level of disturbance increases (*e.g.*, moderate to heavy grazing, removal of the grass/forb cover due to mowing/grading, *etc.*), a transition to ETM class 8 occurs (see below). The presence of ETM class 7 in the high gradient subclass is a generally associated with the margins of exposed bedrock outcroppings where trees and shrubs are absent.

- *Class 8 Heavily Grazed Grasslands, Exposed/Graded Soils, Bedrock*

  ETM class 8 represents several land use classes. Within the high gradient subclass, ETM class 8 represents un-vegetated bedrock outcroppings on the Santa Ynez Mountain front. In the medium and low gradient subclasses, ETM class 8 reflects heavily grazed grasslands where the vegetative cover has been reduced and/or eliminated sufficiently to expose the underlying soils (*e.g.*, portions of Hollister Ranch), areas where grasslands are being actively mowed (*e.g.*, taxiways at the airport), or soils that are graded/exposed (*e.g.*, southern slope of Ellings Park, Tajiguas landfill *etc.*).

*Use of the ETM Land Use Classification for HGM Functional Assessment Variables*

The ETM land use classification was used as the basis to scale four variables in the HGM functional assessment protocol; $V_{LANDUSE,}$ $V_{PATCHNUMBER}$, $V_{PATCHAREA}$ and $V_{PATCHCONTIG}$. These variables were created in order to assess the effect land use and land cover have on the high, medium, and low gradient HGM riverine subclasses in the reference domain. The type and distribution of land use, within that portion of the watershed (*i.e.*, sub-watershed) that contributes runoff to the reference site, affects the timing and volume of runoff, sediment loads, and the volume and concentration of nutrients, organic matter, and contaminants that are transported to the site. Land use has a direct influence on the type and structure of vegetation communities and faunal habitats in the reference site sub-watershed

$V_{LANDUSE:}$ was classified in the ETM Land use analysis, within the reference site sub-watershed. The $V_{LANDUSE}$ variable was scaled directly from the ETM land use classification with no transformations of the data. The relative areas of each ETM land use class were calculated for the reference site sub-watersheds and used to scale the variable (Appendix B-77 through B-82) (Figure D.1).

$V_{PATCHNUMBER}$ was defined as the number of habitat patches, generated from the ETM Habitat Patch analysis, within a 1000 ft radius VAA surrounding the reference site. In order to quantify differences in habitat among the reference sites, a measure of habitat patchiness was derived from the ETM land-use classification. The eight land use classes were reclassified into 3 habitat classes: "good", "fair" and "poor" based upon local knowledge of the authors. ETM land use classes 5 and 6 were reclassified as "good" habitat, ETM land use classes 4 and 7 were reclassified as "fair" habitat, and ETM land use classes 1, 2, 3, and 8 were reclassified to "poor" habitat (Appendix F.2)

The re-classified "good" and "fair" habitat pixels in the image were vectorized into polygon themes. The minimum patch size for the analysis was set at 3600 $m^2$ (*i.e.*, four 30$m^2$ pixels). This minimum value was chosen based upon the 1) relative spatial error of the Landsat 7 imagery and 2) the professional judgment of the authors that patches smaller than this minimum value would not perform habitat ecosystem functions. All polygons smaller than this value were thus removed from the analysis.

For each reference site, the 1000 ft VAA ring was used as the scale of analysis for habitat patchiness. The "good" and "fair" polygons that were encompassed or intersected by the 1000 ft VAA ring were selected in the GIS. The number of "good" and "fair" habitat polygons were calculated and summarized (see Appendix B-83 through B-84). The $V_{PATCHNUMBER}$ variable was scaled based upon the data from this analysis (Appendix B-1 through B-112)(Figure D.2).

$V_{PATCHAREA}$ was defined as the relative area of habitat patches, as generated from the ETM Habitat Patch analysis, within the 1000 ft radius VAA surrounding the reference site. Using the "good" and "fair" habitat classes derived in $V_{PATCHNUMBER}$ above, the relative area of the habitat patches within the 1000 ft VAA ring was calculated in the GIS for each of the reference sites (see Appendix B-83 through B-84). The $V_{PATCHAREA}$ variable was scaled based upon the data from this analysis (See Appendix B- through B-112).

$V_{PATCHCONTIG}$ is a measure of habitat patch contiguity, as generated from the ETM Habitat Patch Contiguity analysis, within the reference site sub-watershed. In order to quantify the contiguity of a HGM reference site to the "core" wilderness areas of the Santa Ynez Mountains/Los Padres National Forest, a measure of habitat patch contiguity was derived. Based upon the ETM Habitat Patch analysis classification discussed above, a large "core" patch of "good" habitat currently exists throughout the high gradient portions of watersheds along the Santa Ynez Mountains and the Los Padres National Forest. To identify contiguity to this "core" habitat area, the reference site sub-watersheds were used as the scale of analysis for $V_{PATCHCONTIG}$. The contiguity of habitat patches from each HGM reference site to this "core" habitat patch was assessed and the data used to scale $V_{PATCHCONTIG}$.

First, the "good" and "fair" habitat classes derived in the ETM Habitat Patch Analysis (described above) were re-classified and merged into a single "suitable" habitat class, with the remaining areas of the reference domain re-classified as "unsuitable" habitat. This resulted in a binary classification cover with regions of "suitable" and "unsuitable" habitat covering the entirety of the reference domain. This cover was then converted into a polygon coverage in order to facilitate further analyses.

Next, the USGS 1:100,000 DLG stream cover was overlaid onto the new "suitable/unsuitable" habitat classification cover and then "erased" with the regions classified as "suitable" habitat (ESRI, 1998). This process effectively removed all DLG stream arcs (*i.e.*, riparian areas) coinciding with the "suitable" habitat class from the analysis, thus leaving a map of DLG stream arcs that represented stream reaches only in "unsuitable" habitat conditions (or "gaps" in habitat) within the reference domain. Finally, the shortest route from each HGM reference site to the "core" habitat patch was identified along the DLG stream network, and the number of DLG stream arcs classified as "unsuitable" habitat was counted (See Appendix F.3). A stream arc was counted as being "unsuitable" habitat only if it was bordered by "unsuitable" habitat on both sides of the arc (*i.e.*, in instances where a stream arc split "suitable" and "unsuitable" habitat polygons the arc was considered in "suitable" habitat because one side of the arc/channel was accessible through "suitable" habitat). The variable $V_{PATCHCONTIG}$ was scaled based upon the data from this analysis (Appendix B-85).

**Figure D.1 Calculation of ETM Land Use Class for the Reference Site Sub-watersheds**

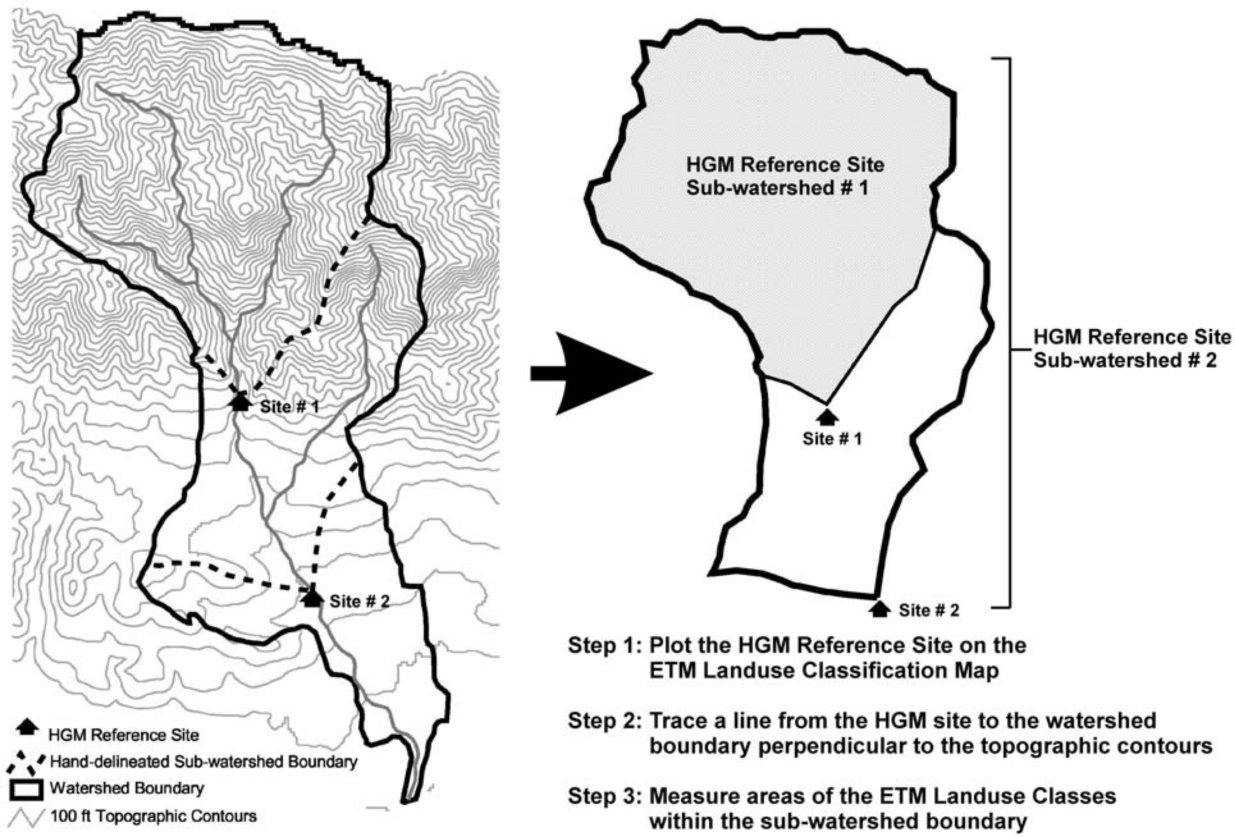

**Figure D.2 ETM Habitat Patch Analysis $V_{PATCHNUMBER}$ and $V_{PATCHAREA}$ Mearsurement Protocol**

**Step 1: Plot the HGM Reference Site on the ETM Habitat Patch Analysis Map.**

**Step 2: Draw a 1000 ft Radius Assessment Area Ring centered on the site.**

**Step 3: Count the number of Good and Fair Habitat Patches within the 1000 ft AA Ring. Include patches that intersect, but also extend beyond the AA Ring in the Vpatchnumber count. Count patches as separately if they do not share a common edge, or are connected only diagonally on the map.**

**Step 4: Measure the area of the Good and Fair Habitat patches within the AA Ring. Only include areas within the AA Ring in the Vpatcharea measurement.**

**Example Below: 6 Good habitat patches and 5 Fair habitat patches with < 25% of the 1000 ft AA ring area classified as Good and Fair habitat.**