Monograph 98-01

Development and Pilot Application of the California Urban and Biodiversity Analysis (CURBA) Model

John D. Landis, Juan Pablo Monzon,
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September 1998

University of California at Berkeley
$37.00

Monograph 98-01

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Development of the CURBA Model was funded by the National Biological Service of the USGS. We also wish to recognize the contributions of Bruce Goldstein, Ph.D. student in the Department of City and Regional Planning at UC Berkeley; and Peter Stine of the USGS.

University of California at Berkeley
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Chapter One: Introduction

Framing the Issue: Habitat and Species Loss

The U.S. has made tremendous progress during the last 25 years in improving its air and water quality. Between 1986 and 1995, for example, national average carbon monoxide emissions decreased 37 percent, even as total vehicle miles of travel (VMT) increased 31 percent (EPA 1996). Hundreds of rivers and water bodies classified as "unfishable" as recently as 1975 are now considered fishable.

Regrettably, far less progress has been made in the areas of land and habitat conservation. A 1995 study by the United States Geological Survey found significant *and continuing* declines in important habitat, with the greatest losses occurring in the South, Northeast, Midwest, and California.

Conversion to agriculture was the primary cause of habitat loss until 1920[1]. Today, most habitat loss occurs as a result of urban growth. U.S. metropolitan areas are currently consuming land at a much faster rate than they are adding population. Whereas the nation's metropolitan population increased 28 percent between 1970 and 1990, its metropolitan land area increased 82 percent (Bureau of the Census, 1990). Urban growth diminishes habitat quality in three ways. Foremost, it consumes habitat, replacing natural, presumably diverse habitats with less diverse and less natural urban habitats. Second, it reduces habitat integrity by promoting fragmentation. Third, it generates vegetation and species-damaging spillover effects such as runoff and air pollution.

There are few areas in the U.S. where these issues are of greater concern than California. Since European settlers first arrived, more than 17 million acres of land have been converted from natural habitat to urban or agricultural uses (Jenson, Torn, and Harte 1993). Although these processes began three hundred years ago, the pace of habitat loss appears to have increased in recent years. Nearly five million acres of pristine habitat were converted between 1950 and 1980, approximately 3.8 million to agricultural uses and 1 million to urban uses (California Department of Forestry 1988).

Five major habitat types have lost significant acreage in this 30-year period: grassland,

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[1] Even today, there are no accurate nationwide estimates of habitat loss.

coastal scrub, foothill oak woodland, closed-cone pine-cypress, and redwood forests (Table 1). Conversion of land to more intensive uses has not occurred evenly across habitat types. In general, habitats associated with water—wetlands, vernal pools, and riparian vegetation—have lost proportionately more acreage than other types. Any habitat-type found only along the central and south coast is also likely to be subject to significant habitat loss from urban development. For example, coastal sage scrub in San Diego and Orange counties has been reduced to only a fraction of its historical acreage (Westman 1987).

Table 1: Estimated Habitat Acreage Lost Through Conversion to Urban and Agricultural Land Uses: 1950-80

Major Vegetation Habitat	Acres Converted	Percent of Total Acreage Converted 1950-80
Redwood	62,000	4%
Douglas fir	2,000	less than 1%
Red fir	1,000	less than 1%
Ponderosa-Jeffrey pine	80,000	2%
Mixed conifer	42,000	less than 1%
Lodgepole pine	1,000	less than 1%
Juniper-pinyon	29,000	1%
Closed-cone pine-cypress	4,000	5%
Montane hardwood conifer	27,000	1%
Valley foothill hardwood	590,000	7%
Chaparral	203,000	2%
Sagebrush	217,000	3%
Coast scrub	294,000	11%
Grassland	295,000	26%
Desert	300,000	1%
Total	2,147,000	

SOURCES: Katibah 1984, California Dept. of Forestry, CDPR 1988, Airola 1989.

The issue of habitat loss is especially important in California because of the state's impressive biodiversity. There are an estimated 7,850 vascular plant species in California (Hickman 1989). California harbors the largest number of endemic plant species of any state except Hawaii. Over 1,600 full species, or 32 percent, of California native plants are found nowhere else in the world (Raven and Axelrod 1978, Shevock and Taylor 1987).

California is also home to one-quarter of the 2,300 vertebrate species found in the United States (The Nature Conservancy 1989). While only one full bird species is endemic to California (the yellow-billed magpie), altogether more than 583 separate bird species have been sighted in the state (Laudenslayer et al. 1991) California is home to 214 different species of mammals, 19 of which are found only in California. Seventeen reptile and amphibian species are endemic to California, and 40 percent of the 66 full species of freshwater fish are found only in California.

Altogether, 70 species of plants and animals are known to have been lost from California, including the grizzly bear, the gray wolf, the Tecopa pupfish, and the Santa Barbara song sparrow. Twenty-one animal species once found in California are now extinct (Jones and Stokes 1987). More than 30 plant species and subspecies are now extinct in California (Bittman 1992).

As of 1991, 150 plants and 106 animal species in California were listed as threatened or endangered by federal or state government;[2] an additional 66 plants are listed as rare (California Department of Fish and Game 1991a). Official lists of candidates for listing under the U.S. or California Endangered Species Acts indicate that more than 200 animal species and subspecies may be in trouble (CDFG 1991b). The number of plant and animal species whose populations face potential decimation is much larger. According to the California Department of Fish and Game, and the California Native Plant Society, 306 species and subspecies of animals and 599 plants are potentially at long-term risk of extinction in California.

Current Approaches to Habitat Protection

Habitat protection in California takes five general forms: (i) public land acquisition; (ii) private and non-profit land acquisition; (iii) federal and state protection under the U.S. and California Endangered Species Acts; (iv) land conservation through development agreements ; and (v) local land use and development regulation. According to Jenson, Tor,n and Harte (1993), approximately 12 percent of California's land area is under permanent public or private protection. As Table 2 shows, the extent of habitat protection varies widely by land cover type. Of the 25 habitat types evaluated under the FRRAP program, two—alpine dwarf scrub and subalpine conifer forests—have over 90 percent of their acreage in protected areas (CDF 1988). A third habitat type, conifer forests, covers 23 percent of California, but

[2] An endangered species is "in danger of extinction throughout all or a significant portion of its range." (16 U.S.C. sec 1532(6)). Threatened species are those "likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range" (16 U.S.C. sec 1532(20)).

Table 2: Protected Habitat Acreage in California, 1988

Major Vegetation Habitat	Total Acreage (000)	% of State	Acres Reserved (000)	% Reserved
Subalpine conifer	228	0.2	207.5	91
Lodgepole pine	752	0.7	624.2	83
Red fir	1,906	1.9	933.9	49
Montane chaparral	1,039	1.0	249.4	24
Alkali scriub	1,299	1.3	298.0	23
Jeffrey pine	700	0.7	112.0	16
Sagebrush	6,549	6.5	982.4	15
Closed-cone pine cypress	78	0.1	10.1	13
Mixed conifer	9,268	9.2	1,112.2	12
Redwood	1,570	1.6	172.7	11
Juniper	1,469	1.5	161.6	11
Mixed chaparral	2,954	2.9	324.9	11
Douglas fir	1,772	1.8	177.2	10
Pinyon-Juniper	1,463	1.5	131.7	9
Chamise-red shank	4,808	4.8	432.7	9
Alpine dwarf scrub	206	0.2	185.4	9
Other desert	19,979	19.7	1,798.1	9
Ponderosa pine	2,651	2.6	212.1	8
Montane hardwood conifer	2,049	2.0	143.4	7
Montane hardwood	1,156	0.0	69.4	6
Coastal scrub	2,507	2.4	150.4	6
Valley-foothill hardwood	7,363	7.3	294.5	4
Valley riparian	49	0.1	1.0	2
Annual grassland	8,653	8.6	173.1	2
Perennial grassland	90	0.1	1.8	2
Montane riparian	86	0.1	0.0	0
Bitterbrush	581	0.6	0.0	0
Low sagebrush	507	0.5	0.0	0
Fresh emergent wetland	576	0.6	0.0	0
Wet meadow	238	0.2	0.0	0
Alpine barren and rock	2,120	2.1	0.0	0
Urban agriculture	15,211	15.0	0.0	0
Water	1,348	1.3	0.0	0
Unknown			1,500.0	
Total	101,225	100.0	10,460.3	

SOURCES: California Dept. of Forestry 1988.

comprises 38 percent of the protected land areas in the state. Other habitat types, including valley riparian forest and perennial grassland, are dramatically under-protected: less than two percent of their acreage is within protected areas.

In addition to the 10 million acres of various categories of protected areas in California, the federal government owns and manages 35 million acres under the Federal Land Management Planning Act of 1976 and the National Forest Management Act of 1976. Operated under a multiple-use mandate, these areas consist mostly of commercial range and timberlands and are largely unprotected.

California is also home to an active conservancy movement. Some conservancies—the Tahoe Conservancy, the Santa Monica Mountains Conservancy, the Coachella Valley Conservancy, and the Coastal Conservancy, for example—are statewide organizations established by the California Legislature. Other publicly chartered conservancies—the Marin County Land Trust, for example—are based in particularly counties or cities. Still other conservancies, notably the California Nature Conservancy and the Trust fro Public Lands, are private, non-profit organizations acting in concert with, but independently of government-sponsored organizations. Although sizeable (see Table 3), the total amount of land under conservancy control in California (and protected from development) is still relatively small compared to the amount still threatened by development.

Table 3: Acreage Protected by Selected Public Land Conservancies, 1997

	Protected Acreage
Tahoe Conservancy (1994)	7,000[1]
Santa Monica Mountains Conservancy	30,000
California Coastal Conservancy	unknown
Coachella Valley Conservancy	20,000
Natural Community Conservation Plans (NCCP)	
San Diego Multiple Species Conservation Plan	101,270
Orange County Central Coastal NCCP	37,380
Western Riverside County Multi-Species HCP	15,000

SOURCES: California Resource Agency.
NOTES: (1) Projected.

Outside of publicly protected and conservancy areas, the primary mechanism for habitat conservation is the administration of the federal and state Endangered Species Acts. These acts require, first, that private and public land developers determine whether their proposed projects will result in the loss of listed endangered species habitat; second, that they determine how (if at all) such losses may be mitigated; and third, that they implement such mitigations. Projects which result in unmitigatable habitat losses may not be approved. The California Department of Fish and Game applies a similar review-mitigation approach to projects developed on wetlands. Essentially regulatory in nature, these various approaches have been criticized by conservationists as being reactive and piecemeal, and by private property advocates as being overly draconian. Both sides agree, however, that there is often an insufficient factual basis upon which to make key determinations.

In an attempt to resolve conflicts between conservation and development interests, and to be both more proactive and more comprehensive, the California legislature in 1991 established a new program for Natural Communities Conservation Planning (NCCP) administered jointly by the California Resource Agency and the California Department of Fish and Game. The goal of the NCCP program is to "conserve long-term viable populations of the State's native animal and plant species, and their habitats, in landscape units large enough to ensure their continued existence (CDFG 1991c) To achieve this goal, the CRA and the CDFG are empowered to enter into cooperative agreements with private interests and other public agencies to protect large-scale biological areas from urban development. Three very large-scale NCCP areas in Southern California (the San Diego Multiple Species Conservation Program, the Orange County Central Coast NCCP Subregion Plan, and the Western Riverside County Multispecies Habitat Conservation Plan), which preserve more than 150,000 acres, have already been approved; and planning is underway for several more (California Resources Agency 1998). Nationwide, approximately 400 Habitat Conservation Plans (similar in design and implementation to NCCPs) have been adopted or are under development.

Local Approaches

When all is said and done, most of the responsibility for preserving critical natural habitat in California rests with the state's 500-plus local governments. Under the California Environmental Quality Act (CEQA), local governments must: (i) identify any and all adverse impacts associated with public and private "projects;" (ii) identify potential mitigations for those impacts; (iii) identify less harmful alternatives to the proposed projects; and (iv) certify that the appropriate analysis has been undertaken. Unlike NEPA, which applies just to federal projects, CEQA is not "action-forcing;" local governments in California are not required to approve the least-harmful project. CEQA does not impose statewide review standards. Each jurisdiction, or lead agency, is allowed to determine and identify its own impact thresholds and mitigation requirements. Indeed, most jurisdictions make such determinations on a case-by-case or project-by-project basis. Regarding habitat, few California municipalities go beyond consideration of species listed under the U.S. and California Endangered Species Acts.

The other arena in which local governments may consider habitat is in the production of their general plans. California planning law requires all California cities and counties to have adopted general plans consisting of seven elements: (i) land use; (ii) circulation; (iii) housing; (iv) conservation; (v) open space; (vi) noise; and (vii) safety. Except for the housing element, none of the required elements are subject to review. Issues of general plan adequacy are dealt with almost entirely through litigation. Regarding habitat, general plans are required only to address the presence of endangered species.

Even if more California jurisdictions were inclined to look more comprehensively at habitat loss and conservation, the task would be a daunting one. Planning institutions of all types—not just local government planning departments, and not just planning departments in California—often lack the analytical and resource capacity to undertake long-term strategic planning. In the case of habitat planning this involves understanding where, when, and under what circumstances future urban development is likely to occur; as well as understanding the effects of alternate urban development patterns on habitat quality and species viability.

Jurisdictional fragmentation is also a problem. Most local jurisdictions are simply too small for unilateral attempts at preservation to be successful. And while there is nothing to prevent neighboring local governments from jointly pursuing habitat protection, there is currently no real incentive to do so.

Even when jurisdictions are inclined to try to protect habitat, the types of development controls available to them—usually some form of zoning—are poorly suited to the task. When and where they exist, local environmental protection initiatives tend to be organized along functional lines (e.g., protecting farmlands, hillsides, or riparian areas) rather than along ecological lines.

Introducing the CURBA Model

This California Urban and Biodiversity Analysis (CURBA) Model was developed as a tool for constructively addressing these issues. The CURBA Model was designed to help bridge the gap between urban land use planners—who are principally concerned with directing urban growth—and conservationists and wildlife ecologists—who are concerned with promoting environmental and ecological quality. The CURBA Model integrates three sets of data sources and modeling approaches which have heretofore been separate:

1. A statistical model of urban growth incorporating spatial and non-spatial components.
2. Procedures for simulating the effects of alternative development and conservation policies on the amount and pattern of urban growth.
3. Detailed and spatially explicit map and data layers regarding habitat types, biodiversity, and other natural factors.

The CURBA Model was designed and developed at the University of California, Berkeley, by a team of planning and environmental researchers. So far, CURBA Model datasets and equations have been developed for nine California counties, including El Dorado, Monterey, Nevada, Placer, Sacramento, San Joaquin, Santa Cruz, Sonoma, and Stanislaus. Datasets (and models) for additional counties are under development.

This report explains the logic, calibration, and use of the CURBA Model. We begin in Chapter Two by looking at the structure of the model, how it measures and reports habitat quality, and how it integrates different spatial data sources. Next, in Chapter Three, we present the results of three pilot scenarios focusing on issues of urban expansion and habitat loss in three California counties: Santa Cruz, San Joaquin, and El Dorado. These three counties were chosen to demonstrate the use of the CURBA Model under different growth scenarios and in different ecological regions. Santa Cruz County is the Central West ecoregion; its population is projected by the California Department of Finance to increase by 50,000 between 1995 and 2010. San Joaquin County is in the Central Valley ecoregion and is projected to grow by 210,000 persons between 1995 and 2010. El Dorado County is in the Sierra Nevada ecoregion and is projected to add approximately 60,000 additional residents between 1995 and 2010. Chapter Four walks the reader through the use of the CURBA Model, outlining its interface and report formats. We conclude in Chapter Five by reviewing the model's features, strengths, and limitations.

Chapter Two: The Logic of the CURBA Model

The CURBA Model is a distant cousin of the second-generation California Urban Futures Model (see Landis and Zhang 1998). Like CUF II, the CURBA Model consists of two major components: (i) An *Urban Growth Model*, which includes procedures for calibrating countywide equations describing past urbanization patterns, and for using those equations to construct future development scores; and (ii) A *Policy Simulation and Evaluation Model*, consisting of procedures for simulating how alternative development policies might affect the future urbanization patterns and the impacts of those patterns on habitat integrity. The Urban Growth Model component uses spatial data but is calibrated outside of a GIS environment. The Policy Simulation Model is embedded in ArcView and makes use of ArcView Spatial Analyst as well as specially-written Avenue scripts. The CURBA Model's basic unit of analysis and minimum mapping unit is the one-hectare (100 meter by 100 meter) grid cell.

The CURBA Model Explained

Figure 1, below, outlines the relationship of the Urban Growth Model to the Policy Simulation and Evaluation Model.

Figure 1: The Logic of the CURBA Model

Urban Growth Model

1. Estimate county-based urbanization equations: Prob[grid-cell I urbanizing] = f{ proximity to highways proximity to city boundaries, site slope, site development constraints, other factors}
2. Use estimated equations to calculate future urbanization probabilities for all undeveloped sites.

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Policy Simulation and Evaluation Model

1. Read future urbanization probabilities.
2. Enter community-wide population growth increment and starting allocation density.
3. Construct a Policy Scenario (list and type of development constraint):
   * wetlands, floodplains, river/stream corridors
   * site slope
   * farmland
   * urban boundaries
4. Eliminate "undevelopable" sites.
5. Assign projected development increments to remaining sites in order of calculated urbanization probability.
6. Summarize land use change, and compute before-and-after measures of land cover and species habitat fragmentation.
7. Run additional scenarios.

The Urban Growth Model

The Urban Growth Model consists of one or more logit equations comparing observed changes in urbanized land to a variety of spatial and non-spatial factors[3]. These equations all take the following general form:

Prob [undeveloped grid-cell *i* is urbanized between 1986 and 1994]	=	*f* { grid-cell proximity to highway facilities, slope and other natural constraints to development, proximity to jurisdictional boundaries, local growth policies, recent population and job growth}

The observations consist of all undeveloped 1-hectare grid-cells in each county as of 1986. For calibration purposes, the dependent variable can take on one of two values: a 1, indicating that the grid-cell was urbanized between 1986 and 1994; or a 0, indicating that it was not. Separate equations are estimated for each county. All else being equal, we would expect:

- Sites (i.e., grid-cells) in faster-growing cities to be developed ahead of sites in slower-growing cities.
- Sites inside and/or closer to existing cities, spheres-of-influence, and/or place boundaries to be urbanized ahead of more distant sites.
- Flat and nearly flat sites to be developed before steeper sites.
- Sites near existing urban development, or surrounded by urban development, to be urbanized before more distant sites.
- Sites near highways to be developed prior to more distant sites.
- Sites located on wetlands or in floodplains to be urbanized after other sites.

Construction and testing of the various logit models is undertaken using a statistical package such as SPSS or SAS. For each county, we tested multiple models involving dozens of variable combinations. Table 4 reports on the results of the "best parsimonious model" for each of the eight case-study counties. This is the specification that includes the fewest independent variables yet produces the highest overall goodness-of-fit. More extensive model results are included in Appendix A.

Two relationships stand out for all or almost all counties. First, all else being equal, sites

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[3] The assumptions behind the use of the logit estimator to model changes in land use are explained in greater detail in Landis and Zhang, 1998.

Table 4: Urban Growth Model: Selected Results for El Dorado, Monterey, Nevada, Placer, Sacramento, San Joaquin, Santa Cruz, and Stanislaus Counties

(**Dependent Variable:** Likelihood of Urbanization between 1986 and 1994)

Independent Variable	Expected Coefficient Sign	El Dorado County	Monterey County	Nevada County	Placer County	Sacramento County	San Joaquin County	Santa Cruz County	Stanislaus County
City 5-year growth rate	+		0.0291						
Distance to city limits (meters)	-						3.9937	-0.032	
Distance to existing urban development (meters)	-	-0.3543	-0.0724	-0.1193	-0.1379	-0.1325	-0.0277		
Distance to major highway (meters)	-			-0.0363		-0.0183		-0.0049	
Distance to Roseville (meters)	-				-0.0036				
Locally-important farmland	-								
Pct. of neighboring cells in urban use	+		-0.2829						-0.5155
Percent slope	-	-0.0965		-0.1028			-0.2709	-0.1559	-0.2037
Within census-designated place (0/1)	+								
Within city limtis (0/1)	+					0.892			
Within FEMA floodzone	-					-1.7361	-1.7462		
Within Rocklin city limits (0/1)	+				1.9249				
Within Roseville city limits (0/1)	+				1.7861				
Within Salinas city limits (0/1)	+		2.4147						-0.0689
Within sphere-of-influence (0/1)	+						1.6686		1.2718
Within wetland area (0/1)	-	-2.7748							
Intercept		0.0833	-1.5191	1.53	-0.7986	-1.0325	-5.4298	-2.9046	0.883
Goodness of fit measures									
Log-likelihood ratio		9,539.0	13,271.0	4,315.5	19,520.0	34,578.0	13,494.0	5,982.0	19,145.0
Chi-squared		6,540.0	8,499.0	1,778.0	13,617.0	15,336.0	6,421.0	1,334.0	14,062.0
Pct. concordant predictions		95.7%	94.0%	90.8%	94.4%	90.8%	84.4%	84.7%	94.1%

near existing urban development (or, in the case of Santa Cruz, near city limits) tend to be developed before more distant sites. Second, flat and nearly flat sites tend to be developed before steeper sites.

The roles of other factors varied between counties. Highway proximity served to encourage development in Nevada, Santa Cruz, and Sacramento counties. In Sacramento and San Joaquin counties, sites inside city boundaries were developed ahead of sites outside city boundaries. Likewise, cites outside floodzones were developed ahead of sites inside floodzones. In Monterey and Stanislaus counties, free-standing vacant sites were more likely to have been developed than sites surrounded by other urban uses. In Placer County, sites in the cities of Rocklin and Roseville were developed ahead of sites in other cities. In Monterey County, sites in fast-growing cities and within Salinas city limits were developed ahead of other sites.

Their parsimonious structure notwithstanding, all eight models do a surprisingly good job explaining 1986-94 urbanization trends. The El Dorado County model, for example, explains fully 96 percent of observed site-level urbanization. Even the worst model, for San Joaquin County, explains more than 86 percent of observed urbanization.

Once the various logit models have been checked and compared, the estimated coefficients are used to calculate future urbanization probabilities for all remaining undeveloped grid-cells. These probabilities range from a high of 1 (indicating development is certain) to 0 (indicating the impossibility of future development). The calculated urbanization probability grid is then exported to the Policy Simulation and Evaluation Model in Arc/Info export format.

The Policy Simulation and Evaluation Model

The Policy Simulation and Evaluation Model consists of a series of ArcView commands and scripts designed to help users construct and simulate alternative growth policy scenarios. Policy scenarios are constructed at the county level. Each policy scenario consists of an urbanization probability grid, a set of population and density projections, a series of development constraints, and appropriate habitat or species layers.

The first step in specifying a scenario is to import and display a projected urbanization probability grid. An output of the Urban Growth Model (see above), the urbanization probability grid is a site-by-site listing of the likelihood that every undeveloped grid-cell in the county will be urbanized.

The second step in running a scenario is to enter the increment of population growth to be allocated to suitable grid-cells, as well as the minimum allocation density, in persons per hectare.[4] Population projections may be obtained from a variety of sources, including the California Department of Finance, local councils of government, or independent projections. Gross allocation densities may be estimated by dividing current county population levels by the number of one-hectare grid-cells identified as urbanized, or may be obtained from external sources. Unless otherwise specified, projected population growth may be allocated to suitable grid-cells anywhere within a subject county.

The third step in constructing a scenario is to identify constraints which would prohibit or limit the urbanization of particular grid-cells based on their location, physical characteristics, environmental character, or current land use. Using a digital "check sheet" (Figure 2), model users can identify whether particular grid-cells are to be precluded from development (regardless of their development probability scores) on the basis of their slope; whether they are in a designated wetland or floodzone; their agricultural class; their proximity to a river, stream, highway or road; and their proximity to particular jurisdictional boundaries, including city limits and sphere-of-influence lines. The effect of precluding a grid-cell from being urbanized is to shift the population growth it might otherwise have been allocated to another, lower-scoring grid-cell. (Policy scenarios can also be constructed by specifying alternative allocation densities.) Once a particular policy scenario has been fully specified, the CURBA Model displays a summary map of developable and undevelopable grid-cells.

The next step is for the CURBA Model to allocate projected population growth to the remaining developable sites. Development is allocated to sites in order of their calculated development probability, subject to specified policy constraints. The allocation process proceeds until all required sites have been developed, or until no more sites are available, or until some user-specified minimum development probability threshold has been reached. Once the allocation process has been completed, the CURBA Model reports the average

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4 The CURBA Model allocates urban development based on projected population growth and average population density. The model does not differentiate between different land use types. Commercial, industrial, and other urban land uses are all subsumed in the average population density estimate.

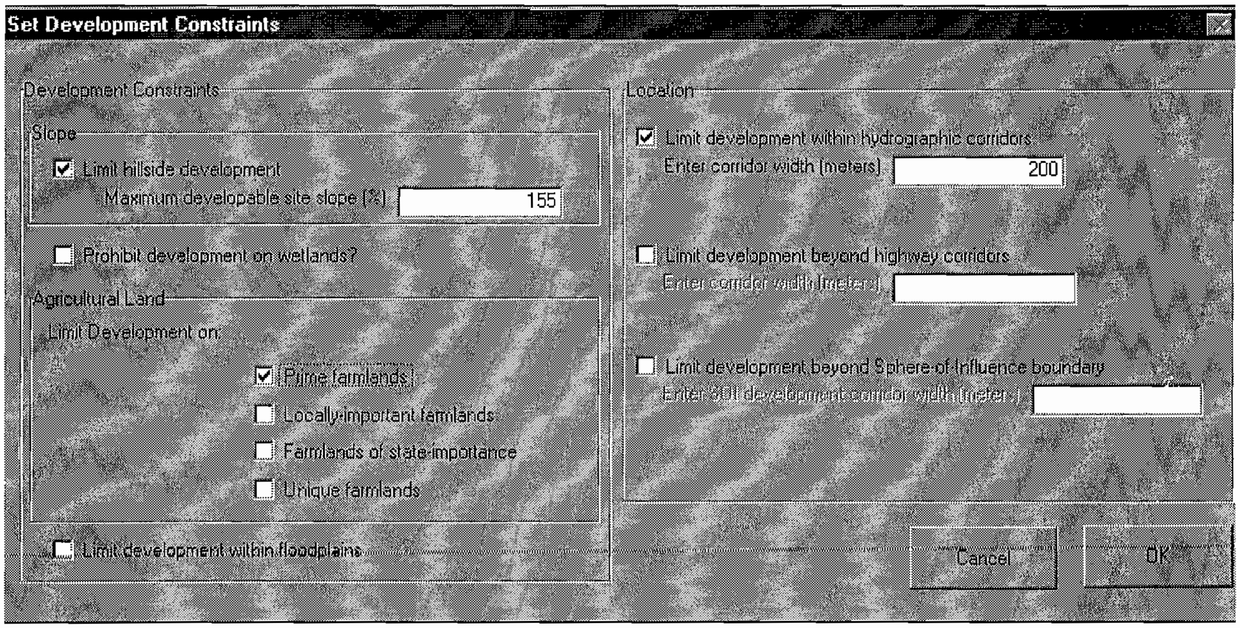

Figure 2: CURBA Model Constraint "Checklist"

allocation density and displays a map showing the resulting growth allocation.

The resulting countywide growth allocation is then compared with vegetative land use cover classifications and cross-listed habitat designations, as present in the Gap Analysis database (see below). Users can investigate the effects of urban growth on:

- Loss of vegetative land cover by type.
- Loss of mammal, reptile, and bird habitat for multiple or individual species.
- Loss of lands associated with varying eco-regional value.
- Changes in the level of vegetative land cover fragmentation.
- Changes in habitat fragmentation for multiple and individual species.

Data Sources

The CURBA Model makes use of a wide variety of spatial and non-spatial data sources (Table 5). Foremost among them are the California Farmland Mapping and Monitoring Project (FMMP), and the Gap Analysis Project.

FMMP Data

Information on the location and type of urban development and farmland in California is collected and distributed on an ongoing basis through the work of the California Farmland Mapping and Monitoring Project (FMMP). Begun in 1986, the FMMP database covers all or parts of most California counties and is updated every two years. Areas (polygons) are classified into eight categories (urban, prime agricultural lands, agricultural lands of importance to the state economy, agricultural lands of importance to a local economy, unique agricultural lands, grazing lands, wetlands, unique agricultural areas, and other areas) according to current land use and land cover, soil quality, and cultivation potential.

FMMP data are used in both components of the CURBA Model. They are used as the dependent variable in the Urban Growth Model to identify multi-year changes in the location and extent of urbanization. They are used in the Policy Simulation and Evaluation Model as potential constraints to future urbanization. Prior to their use in the CURBA Model, FMMP data are converted from their native polygon form into one-hectare (100 meter by 100 meter) grid cells.

Gap Analysis Data

The CURBA Model also makes extensive use of GAP Analysis data. Initially developed by Scott (1993) and others at the University of Idaho, GAP Analysis is a GIS-based procedure for identifying "gaps" in biodiversity protection. First-generation Gap Analysis data consisted of three primary GIS layers: (i) the distribution of actual vegetation types, as delineated from satellite imagery; (ii) the distribution of public vs. private land ownership, as assembled from various land information systems; and (iii) the distribution of terrestrial vertebrate species, as predicted from the distribution of vegetation.

The CURBA Model makes use of second-generation GAP Analysis data, as prepared at the University of California, Santa Barbara (UCSB). Because of California's size and complexity, the UCSB GAP Analysis classification system incorporates both Jepson eco-regions (Hickman 1993) and Holland vegetation classification zones. Image interpretation is guided by vector overlays of existing vegetation maps, land use maps, and forest inventory data. Upland areas are mapped with a minimum mapping unit of 100 hectares. Major wetland areas are mapped using a 40-hectare- minimum mapping unit. Vegetation polygons are

Table 5: CURBA Model: Summary of Key Data Items and Sources

Data Item	Source	Resolution
Extent of Urban Development	California Farmland Mapping & Monitoring Project	100m x 100m grid cell
Farmland Type (prime, of state importance, of local importance, unique, or grazing)	California Farmland Mapping & Monitoring Project	100m x 100m grid cell
Vegetative Land Cover (Holland classification	GAP Analysis data	100m x 100m grid cell
Vertebrate Species Habitat	Wildlife Habitat Relationships (WHR) as applied to GAP Vegetation Layers	100m x 100m grid cell
Slope	USGS Digital Elevation Model (DEM)	100m x 100m grid cell
Highway, road, and street locations	Census Bureau TIGER Files	center lines
Hydrographic line features (streams and rivers)	Census Bureau TIGER Files	center lines
Major water bodies	Census Bureau TIGER Files	100m x 100m grid cell
Wetlands and vernal pools	National Wetlands Inventory	100m x 100m grid cell
FEMA Q3 Floodzones	FEMA	100m x 100m grid cell
Jurisdiction boundaries	Census Bureau TIGER Files	100m x 100m grid cell
Designated sphere-of-influence boundaries	Digitized from LAFCO maps	100m x 100m grid cell

identified according to their primary, secondary, and tertiary vegetative covers.

Species habitats are identified by applying the California Wildlife-Habitat Relationships system (WHR), to Holland vegetative land use classes. The WHR system assigns specific vertebrate species to particular vegetation types. Since most species occupy multiple vegetation areas, WHR list tables are quite complex. UCSB Gap Analysis data includes vegetation-species relationships for 570 vertebrate species, including mammals, reptiles, birds, and freshwater and sea life. Appendix B includes a complete list of vegetative land covers and vertebrate species present in California, as well as the format of the GAP database. *Unless otherwise specified, GAP Analysis data does not incorporate primary information regarding species locations or population sizes.*

GAP Analysis data was obtained from UCSB in polygon form, and then gridded into one-hectare cells. Note that this "gridding" process suggests a level of classification accuracy that is not present in the original data. GAP Analysis data is used only in the Policy Simulation and Evaluation Model.

Other Data Sources

In addition to FMMP and GAP Analysis data, the CURBA Model draws on a variety of other digital data sources:

1. Slope and elevation data: USGS 30-meter Digital Elevation Model (DEM) data are used to generate one-hectare slope and elevation grid cells. These data are used in both the Urban Growth and Policy Simulation Models.

2. Locations and types of roads, hydrographic features, and jurisdictional boundaries. U.S. Census TIGER files are used to identify major roads, hydrographic features, and city and place boundaries. Arc/Info was used to generate one-hectare distance grids to major highways, rivers and streams, and to city and sphere-of-influence boundaries. These grids, as well as the original line features, are used in both the Urban Growth and Policy Simulation Models.

3. Wetlands and floodzones: Digital maps of wetland areas and floodzones were obtained from the National Wetlands Inventory and the Federal Emergency Management Agency, respectively, and then gridded. The floodzone data is used in both the Urban Growth and Policy Simulation Models; the wetlands data is used solely in the Policy Simulation Model.

4. Jurisdictional spheres-of-influence (S-O-I). Sphere-of-influence boundaries[5] were obtained in paper and/or digital form from Local Agency Formation Commissions, and then digitized or imported. Arc/Info was used to generate one-hectare S-O-I distance grids, which are used in both the Urban Growth and Policy Simulation Models.

5. Various socio-economic data. Population and employment counts by jurisdiction were obtained from the California Department of Finance and the California Employment Development Department, respectively. Historical population and employment estimates are used in the Urban Growth Model; population projections are used in the Policy Simulation and Evaluation Model.

CURBA Model datasets are organized and accessed by county(Appendix C). Future versions of the CURBA Model will allow for city or jurisdictional-level analysis.

Habitat Fragmentation Analysis

After generating alternative development scenarios, the CURBA Model allows users to analyze the impacts of projected development on vegetative cover, habitat loss, habitat

[5] Spheres-of-influence demarcate local area planning boundaries. Set at the county level by Local Agency Formation Commissions, or LAFCOs, they are intended to indicate planned "build-out" boundaries

fragmentation, and thus, indirectly, on habitat quality and biodiversity. In addition to Total Land Cover and Habitat Area, the CURBA Model automatically calculates the following before-and-after-habitat fragmentation measures:

1. Percent of Landscape: This is a specific habitat or land cover's share of the total undeveloped (or landscape) area. It is obtained by dividing total land cover or habitat area by total landscape area. Higher values mean that the landscape is composed of fewer distinct habitat types, and, all else being equal, suggest a lower level of biodiversity.
2. Number of Patches: This measure is a count of the number of distinct (non-adjacent) areas, or *patches*, of a particular habitat type. For a given habitat area, a larger patch count indicates greater habitat fragmentation, and thus reduced habitat quality.
3. Maximum Patch Size (in hectares): This measure is the area of the largest patch of a specific habitat type. All else being equal, larger patches are preferable to smaller ones.
4. Minimum Patch Size (in hectares): This measure is the area of the smallest patch of a specific habitat type. Patches that are too small may lack sufficient food sources to support particular species populations.
5. Mean Patch Size (in hectares): This is the typical, or average, patch size for a particular habitat type. It is obtained by dividing total habitat area by the number of patches. Larger mean patch sizes are almost always preferable to smaller ones.
6. Patch Size Variance and Standard Deviation (in hectares): These measure the distribution of habitat patch size. A small variance and standard deviation indicates that distribution of patch sizes clusters around the mean. A large variance and standard deviation indicates a wide variety of patch sizes.
7. Patch Density: This is the number of habitat patches of a particular type per 100 hectares of landscape. As an indicator of habitat quality, lower patch densities are preferable to higher ones.
8. Largest Patch Index: This is the area of the largest patch of a particular type divided by the total landscape area. An index value close to 1 (or 100 percent) indicates that most of the landscape is composed of a single habitat patch. Depending on the type of habitat, this may be a positive indicator of habitat quality, but a negative indictor of biodiversity.
9. Total Edge: This is the total (outside) perimeter of patches of a particular habitat type. Greater amounts of edge permit easier movement across habitat types.
10. Average Edge-Area Ratio: This measure is the ratio of total patch edge (or perimeter) to total patch area. Higher edge-area ratios are typically associated with greater patch fragmentation, or with long-and-narrow patch shapes.

11. Edge Density: This measure is the ratio of total patch edge to landscape area. Higher edge densities are associated with greater patch fragmentation

The extent to which particular habitat fragmentation values are associated with habitat quality varies by area, habitat type, and species. Some species—deer and racoons—for example, can thrive in multiple, fragmented habitats. Other species (e.g., many bat species) require unfragmented habitats to thrive. Given the difficulties of associating particular levels of habitat loss and fragmentation with species viability, users should exercise extreme care in interpreting the results of the CURBA Model.

Chapter Three: CURBA Model Pilot Studies

This chapter puts the CURBA Model to work to test and evaluate various alternative growth policy scenarios in Santa Cruz, San Joaquin, and El Dorado counties for the year 2010. The tested scenarios include:

* *No Constraints*: tested in all three counties, this scenario allows development to occur anywhere in a county except on sites identified as wetlands.
* *Farmland Protection*: tested in Santa Cruz and San Joaquin counties, this scenario prohibits the development of sites classified by California Farmland Mapping and Monitoring Project as being either "prime" or "unique" farmland. The Santa Cruz farmland protection scenario also protects state-important and locally-important farmlands; the San Joaquin farmland protection scenario prohibits development inside floodplains.
* *Environmental Protection:* tested in Santa Cruz and El Dorado counties, this scenario prohibits development on hillsides and in riparian zones.
* *Compact Growth*: tested in San Joaquin and El Dorado counties, this scenario requires that new development be limited to areas within or immediately adjacent to current sphere-of-influence boundaries. It also assumes new development occurs at higher-than-current densities.

Table 6 summarizes the various scenarios in greater detail. Note that none of the tested scenarios explicitly protect particular types of vegetative land cover or habitat.

Santa Cruz County Development Scenarios

The California Department of Finance projects that the population of Santa Cruz County will increase by approximately 50,000 persons between 1995 and 2010. At the county's current average density of 20 persons per hectare, an additional 2,500 hectares (or approximately 6,250 acres) will be required to accommodate this level of population growth. Where this growth goes and how it impacts Santa Cruz habitats will depend, first, on the attractiveness of particular sites and areas to development; and, second, on how local governments in Santa Cruz County choose to regulate development.

Table 6: Summary of Test Scenarios for Santa Cruz, San Joaquin, and El Dorado Counties

	Santa Cruz Scenarios			San Joaquin Scenarios			El Dorado Scenarios		
Assumptions	**SC1: No Constraints**	**SC2: Farmland Protection**	**SC3: Environmental Protection**	**SJ1: No Constraints**	**SJ2: Prime Farmland Protection**	**SJ3: Compact Growth**	**ED1: No Constraints**	**ED2: Environmental Protection**	**ED3: Compact Growth**
Projected Population Growth: 1995-2010	50,000	50,000	50,000	210,000	210,000	210,000	55,000	55,000	55,000
Initial Allocation Density	20 persons per hectare	20 persons per hectare	25 persons per hectare	20 persons per hectare	20 persons per hectare	25 persons per hectare	12 persons per hectare	12 persons per hectare	20 persons per hectare
Farmland Restrictions	None	Prohibited on Prime, State, Local & Unique Farmlands	Prohibited on Prime & Unique Farmlands	None	Prohibited on Prime & Unique Farmlands	Prohibited on Prime & Unique Farmlands	None	None	None
Slope Restrictions	None	None	Prohibited on Slopes > 10%	None	None	Prohibited on Slopes > 10%	None	Prohibited on Slopes > 10%	Prohibited on Slopes > 10%
Wetland Development	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited
Floodplain Restrictions	None	None	Prohibited in Q3 Floodplains	None	Prohibited in Q3 Floodplains	Prohibited in Q3 Floodplains	None	Prohibited in Q3 Floodplains	Prohibited in Q3 Floodplains
Hydrological Restrictions	None	None	Prohibited within 100m of a major river or stream	None	None	None	None	Prohibited within 300m of a major river or stream	None
Sphere Restrictions	None	None	Prohibited 500m beyond current SOI Boundaries	None	None	Prohibited 500m beyond current SOI Boundaries	None	None	Prohibited 3000m beyond Highway 50
Final Allocation Density	20 persons per hectare	21 persons per hectare	25 persons per hectare	20 persons per hectare	21 persons per hectare	28 persons per hectare	15 persons per hectare	13 persons per hectare	36 persons per hectare

We used the CURBA Model to test three distinct Year 2010 scenarios. We assumed that local governments in Santa Cruz County would act in concert to implement all policies on a county-wide basis:

1. ***Scenario SC1***, entitled *No Constraints*, permits urban development to occur just about anywhere in Santa Cruz County, except on wetlands. Urban development is permitted on all types of farmlands, within floodzones, adjacent to rivers and streams, on hillsides of any slope, and outside existing sphere-of-influence boundaries.

2. ***Scenario SC2***, entitled *Farmland Protection*, assumes the adoption of zoning and other regulatory policies that would preclude the development of prime and unique agricultural lands, as well as farmlands classified as being of importance to the state and local economy. Approximately __ hectares of undeveloped land currently falls within these four categories. Scenario SC2 would also prohibit development on wetlands. Other hazard areas and environmental resources such as floodzones, riparian zones, and hillsides would be unprotected.

3. ***Scenario SC3***, entitled *Environmental Protection*, would impose numerous limits on new development throughout Santa Cruz County. Development would be prohibited from occurring on wetlands, within FEMA-designated floodzones, on sites with slopes greater than 10 percent, and within 100 meters of a river stream. Development would also be limited to sites within 500 meters of existing sphere-of-influence boundaries. To further reduce land consumption, Scenario SC3 assumes the adoption of a development density floor of 25 persons per hectare—a level 20 percent higher than the current countywide average density.

Simulation Results

Map 1 presents baseline information for all three scenarios. The top panel, which is based on the results of the Urban Growth Model, shows the calculated probability that each undeveloped site will be urbanized: dark red sites are the most likely to be urbanized; light blue sites the least likely. The bottom panel of Map 1 shows Santa Cruz County's major habitat zones, according to the Holland classification system. A comparison of the top and bottom panels of Map 1 reveals that the sites most attractive to development are in habitat areas classified as Agricultural or Upland Redwood Forest.

Maps 2 through 4 present the results of the various scenarios. The top panel of each map shows which sites are to be considered developable and undevelopable given the constraints imposed under each scenario (development is allowed in the yellow areas, but precluded from the red ones). The bottom panel presents the growth allocation results for each scenario: existing development is in dark grey; projected new development is in red.

Under *Scenario SC1: No Constraints*, almost every undeveloped site in Santa Cruz County is considered developable (Map 2, top panel). As the bottom panel shows, however, projected new development will tend to favor sites at the edges of existing cities, particularly Watsonville. These locations are flat, and are well-served by existing infrastructure, especially regional highways. They are also less likely than more distant sites to arouse political opposition to sprawl.

The effect of adopting policies designed to protect farmland (Map 3: *Scenario SC2: Farmland Protection*) is to place most of the county's coastal and southern areas off-limits to development. The areas east of Watsonville, in particular, which comprise some of California's best farmland, would be protected from development. The effect of these constraints (compared to Scenario SC1) would be to shift more new development northward to the outskirts of Santa Cruz and Scotts Valley, and to the unincorporated areas of Felton and Ben Lomand.

Because Santa Cruz County is so hilly, and contains hundreds of miles of stream bed, the effects of limiting development on hillsides and in riparian areas (as well as in prime and unique agricultural areas) is to place most of the county off-limits to development. This is the result shown in the top panel of Map 4, which summarizes the results for *Scenario SC3: Environmental Protection*. The effect of these constraints is to shift projected new development to the areas judged to be the least environmentally sensitive. This includes areas surrounding Scotts Valley, areas to the northwest of Santa Cruz, and a few "infill" sites north of Watsonville. Thus, one of the primary effects of adopting policies designed to protect the environment would be to shift much of the county's prospective growth to Scotts Valley, a city known for its small-town, environmentally friendly character.

We note that these are scenarios, not forecasts. The extent to which the development patterns we have identified under the various scenarios might ultimately occur would depend not on which conservation programs and regulations are adopted, but on how those regulations are administered.

Vegetative Cover Loss and Fragmentation

Regardless of which of the three scenarios are pursued, the vegetation types likely to be most affected by projected urban growth are Agriculture and Upland Redwood Forest (Table 7). Under *Scenario SC1: No Constraints*, projected urban growth would consume 902 hectares of Agricultural land cover and 405 hectares of Upland Redwood Forest land cover. Under *Scenario SC2: Farmland Protection*, Agricultural land cover losses would decline to 447 hectares, while Upland Redwood Forest losses would rise to 620 hectares. Agricultural land cover losses would decline somewhat further under *Scenario SC3: Environmental Protection*, while the loss of Upland Redwood Forest would increase to 1,232 hectares. On a percentage basis, the loss of Agricultural land cover would range from a high of 4.4 percent under Scenario SC1 to a low of 1.8 percent under Scenario SC3. The maximum percentage loss of Upland Redwood Forest, 2.5 percent, would occur under Scenario SC3.

Two other land cover types, Non-native Grassland and Mixed Evergreen Forest, would be substantially diminished under *Scenario SC3: Environmental Protection.* Non-native Grasslands would decline by 145 hectares, or 21.6 percent, while Mixed Evergreen Forest land cover would decline by 282 hectares, or 3.7 percent.

More significant than the issue of loss is the issue of fragmentation. Table 8 presents multiple measures of fragmentation change for two types of land cover—Agricultural and Upland Redwood Forest—for each of the three scenarios.

With respect to Agricultural land cover, it is *Scenario SC2: Farmland Protection* which, surprisingly, results in the most additional fragmentation: compared to their initial 1994 level, the number of vegetation patches increases the most, while average patch size declines the most. Scenario SC2 also produces the highest patch density. Across the board, *Scenario SC3: Environmental Protection* results in a somewhat lower level of Agricultural land cover fragmentation than Scenario SC2. The reason for this surprising result is that Agricultural land cover is more extensive than are cultivated agricultural lands. Thus, the preservation of agricultural lands under Scenario SC2 does not result in a comparable conservation of Agricultural habitat quality.[6]

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[6] This result may also be the result of discrepancies between the GAP and FMMP layers.

Table 7: Santa Cruz County Alternative Year 2010 Development Scenarios: Habitat Loss

	Initial 1994 Land Area	Scenario SC1: No Constraints		Scenario SC2: Farmland Protection		Scenario SC3: Environmental Protection	
Vegetative Land Cover Type	hectares	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change
Upland Redwood Forest	48,353	-405	0.8%	-620	-1.3%	-1,232	-2.5%
Agriculture	20,296	-902	4.4%	-447	-2.2%	-367	-1.8%
Mixed Evergreen Forest	7,723	-41	0.5%	-81	-1.0%	-282	-3.7%
Coastal Prairie	5,282	-4	0.1%	-12	-0.2%	-1	0.0%
Central Maritime Chaparral	4,079	0	0.0%	0	0.0%	0	0.0%
Upper Sonoran Manzanita Chaparral	3,318	0	0.0%	0	0.0%	0	0.0%
Urban or Built-up	3,313	-1070	32.3%	-1,251	-37.8%	-850	-25.7%
Chamise Chaparral	2,517	0	0.0%	0	0.0%	0	0.0%
Tan Oak Forest	2,041	0	0.0%	0	0.0%	0	0.0%
Blue Brush Chaparral	1,955	0	0.0%	0	0.0%	0	0.0%
Coast Live Oak Fores	949	0	0.0%	0	0.0%	0	0.0%
Non-native Grassland	670	-2	0.3%	-4	-0.6%	-145	-21.6%
Knobcone Pine Forest	633	0	0.0%	0	0.0%	0	0.0%
Central Coastal Scrub	607	0	0.0%	0	0.0%	0	0.0%
Mesic North Slope Chaparral	426	0	0.0%	0	0.0%	0	0.0%
Monterey Pine Forest	409	0	0.0%	0	0.0%	0	0.0%
Northern Coastal Scrub	399	0	0.0%	0	0.0%	0	0.0%
Orchard or Vineyard	356	0	0.0%	0	0.0%	0	0.0%
Coast Range Ponderosa Pine Forest	224	0	0.0%	0	0.0%	0	0.0%
Strip Mine	168	0	0.0%	0	0.0%	0	0.0%
Central Coast Arroyo Riparian	158	-14	8.9%	-19	-12.0%	0	0.0%
Central Coast Cottonwood Sycamore	96	0	0.0%	0	0.0%	0	0.0%

Table 8: Santa Cruz County Alternative Year 2010 Development Scenarios: Agricultural Land and Upland Redwood Forest Habitat Fragmentation

	Land Cover: Agricultural Land				Land Cover: Upland Redwood Forest			
Patch Measure	Initial (1994)	Scenario SC1	Scenario SC2	Scenario SC3	Initial (1994)	Scenario SC1	Scenario SC2	Scenario SC3
Total Area (hectares)	20,296	19,394	19,849	19,929	48,353	47,948	47,732	47,121
Percent of Landcape (%)	17.6	16.8	17.2	17.3	41.9	41.5	41.3	40.8
Largest Patch Index (%)	13.5	12.8	13.2	13.3	38.7	36.5	36.4	36.2
Number of Patches	31	44	46	34	54	61	64	72
Mean Patch Size (hectares)	654.7	440.7	431.5	586.2	895.4	786.0	745.8	654.5
Maximum Patch Size (hectares)	15,583.0	14,779.0	15,267.0	15,319.0	44,676.0	42,218.0	42,100.1	41,767.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Patch Density	0.027	0.038	0.040	0.029	0.047	0.053	0.055	0.062
Patch Size Variance	7,867,201	5,024,516	5,125,581	6,940,817	36,892,930	29,185,897	27,661,359	24,203,030
Patch Size Standard Deviation	2,804.5	2,241.5	2,263.9	2,634.5	6,073.9	5,402.4	5,259.4	4,919.7
Total Edge (km)	559.0	552.8	562.6	587.4	1,008.0	1,006.0	1,005.0	1,045.2
Edge/Area Ratio (m/hectare)	27.5	28.5	28.3	29.5	20.8	21.0	21.1	22.2
Edge Density (m/hectare)	4.8	4.8	4.9	5.1	8.7	8.7	8.7	9.0

The results for Upland Redwood Forest land cover are also surprising. Of the three scenarios, it is *Scenario SC1: No Constraints* that consumes the least additional land and results in the least additional fragmentation. The most injurious scenario, ironically, is *Scenario SC3: Environmental Protection*. *Scenario SC3* shifts growth inland from coastal hillsides, thereby resulting in greater Upland Redwood Forest land loss and fragmentation. *Scenario SC1*, conversely, preserves Redwood land cover at the expense of Agricultural land.

These various results all point to an interesting and important policy conclusion: the adoption and implementation of policies designed to protect and conserve environmental features, such as riparian corridors, hillsides, and/or farmland, will not automatically—and not in all places—result in appropriate levels of land cover conservation.

Species Habitat Loss and Fragmentation

Most species occupy multiple vegetative land cover types. As a result, the effects of urban growth on the viability of particular species will ultimately depend on how it impacts multiple land covers. For each species identified by the user, the CURBA Model can calculate total habitat loss (across multiple vegetative land coverages) as well as changes in species-based habitat fragmentation. The link between vegetative land cover and species habitat is based on a series of wildlife habitat relationships as coded in second-generation GAP Analysis data.

Regardless of which of the three scenarios are pursued, the mammal species likely to suffer the most significant loss of habitat are the yuma myotis and the Brazilian free-tailed bat (Table 9). Under *Scenario SC1: No Constraints*, projected urban growth would result in a 976 hectare loss in yuma myotis and Brazilian free-tailed bat habitat. Under *Scenario SC2: Farmland Protection*, yuma myotis and Brazilian free-tailed bat habitat loss would actually increase slightly to 1,147 hectares. Under *Scenario SC3: Environmental Protection*, it would decline significantly to 771 hectares, while the loss of Upland Redwood Forest would increase to 1,232 hectares. On a percentage basis, the loss of yuma myotis and Brazilian free-tailed bat habitat would range from a high of 40.8 percent under Scenario SC2 to a low of 27.4 percent under Scenario SC3.

Six other mammal species would be subject to significant habitat losses under one or more scenarios: the red bat, the pallid bat, the red fox, the California myotis, the desert cottontail, and the big brown bat. Red bat habitat would decline by 9.2 percent under Scenario SC1, by 10.9 percent under Scenario SC2, and by 8.3 percent under Scenario SC3. Pallid bat habitat would decline by 7.8 percent under Scenario SC1, by 9.2 percent under Scenario SC2, and by 6.2 percent under Scenario SC3.

For most of the mammal species listed in Table 9, habitat loss would range between .5 and 2 percent, regardless of which scenario were pursued. Interestingly, while *Scenario SC3: Environmental Protection* results in the lowest level of habitat loss for species whose habitat is most precious (e.g., the yuma myotis, the Brazilian free-tailed bat, the red bat, and the pallid bat), it results in slightly higher levels of habitat loss for species whose habitat is more plentiful.

The CURBA Model can also tabulate changes in species habitat fragmentation. Table 10 presents such tabulations for two of Santa Cruz County's more threatened species—the red fox, and the yuma myotis.

Based on tabulations of patch number, mean patch size, and patch density, *Scenario SC1: No Constraints* results in the highest level of red fox habitat fragmentation, while *Scenario SC3: Environmental Protection*, results in the lowest. Indeed, the level of fragmentation under Scenario SC3 is only slightly higher than for the initial 1994 baseline. For the yuma myotis, however, it is *Scenario SC1: Not Constraints* which results in the smallest increment of habitat fragmentation, and *Scenario SC3: Environmental Protection* which results in the highest.

Readers should bear in mind that these results are based on the suitability of particular vegetative covers to particular species (as specified in the Wildlife Habitat Relationship table), and not on actual species sightings or population counts. Nonetheless, they reaffirm and indeed magnify earlier results that the match between policies designed to conserve and protect natural features versus policies designed to protect species habitat is not always a consistent one, and must be evaluated on a case-by-case basis.

Table 9: Santa Cruz County Alternative Year 2010 Development Scenarios: Habitat Loss by Species

		Initial 1994 Land Area	Scenario SC1: No Constraints		Scenario SC2: Farmland Protection		Scenario SC3: Environmental Protection	
Code	Mammal Species	hectares	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change
M023	Yuma Myotis	2,811	-976	-34.72%	-1,147	-40.80%	-771	-27.43%
M039	Brazilian Free-tailed Bat	2,811	-976	-34.72%	-1,147	-40.80%	-771	-27.43%
M033	Red Bat	10,731	-984	-9.17%	-1,166	-10.87%	-892	-8.31%
M038	Pallid Bat	12,456	-976	-7.84%	-1,147	-9.21%	-771	-6.19%
M147	Red Fox	14,356	-801	-5.58%	-311	-2.17%	-264	-1.84%
M028	California Myotis	18,257	-984	-5.39%	-1,166	-6.39%	-892	-4.89%
M047	Desert Cottontail	39,687	-1,992	-5.02%	-1,733	-4.37%	-1,362	-3.43%
M032	Big Brown Bat	20,879	-984	-4.71%	-1,165	-5.58%	-892	-4.27%
M018	Broad-footed Mole	29,469	-949	-3.22%	-531	-1.80%	-697	-2.37%
M134	California Vole	79,279	-2,397	-3.02%	-2,353	-2.97%	-2,594	-3.27%
M045	Brush Rabbit	102,572	-2,438	-2.38%	-2,434	-2.37%	-2,877	-2.80%
M081	Botta's Pocket Gopher	103,614	-2,438	-2.35%	-2,434	-2.35%	-2,877	-2.78%
M072	California Ground Squirrel	103,970	-2,438	-2.34%	-2,434	-2.34%	-2,877	-2.77%
M117	Deer Mouse	103,970	-2,438	-2.34%	-2,434	-2.34%	-2,877	-2.77%
M153	Raccoon	76,419	-1,516	-1.98%	-1,952	-2.55%	-2,364	-3.09%
M051	Black-tailed Hare	90,890	-1,159	-1.28%	-863	-0.95%	-1,263	-1.39%
M113	Western Harvest Mouse	97,986	-1,240	-1.27%	-1,003	-1.02%	-1,484	-1.51%
M162	Striped Skunk	97,986	-1,240	-1.27%	-1,003	-1.02%	-1,484	-1.51%
M015	Shrew Mole	52,921	-266	-0.50%	-425	-0.80%	-707	-1.34%
M157	Long-tailed Weasel	76,745	-324	-0.42%	-534	-0.70%	-1,117	-1.46%
M012	Trowbridge's Shrew	40,256	-165	-0.41%	-257	-0.64%	-477	-1.18%
M120	Pinyon Mouse	67,176	-268	-0.40%	-435	-0.65%	-775	-1.15%
M149	Gray Fox	69,234	-276	-0.40%	-454	-0.66%	-896	-1.29%
M127	Dusky-footed Woodrat	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M146	Coyote	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M152	Ringtail	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M161	Western-spotted Skunk	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M165	Mountain Lion	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M166	Bobcat	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M181	Mule Deer	70,276	-276	-0.39%	-454	-0.65%	-896	-1.28%
M060	Merriam's Chipmunk	21,795	-47	-0.22%	-97	-0.45%	-429	-1.97%
M006	Ornate Shrew	3,154	-6	-0.19%	-16	-0.51%	-146	-4.63%
M095	California Pocket Mouse	25,875	-47	-0.18%	-97	-0.37%	-429	-1.66%
M160	Badger	26,623	-47	-0.18%	-97	-0.36%	-429	-1.61%
M027	Long-legged Myotis	5,522	-8	-0.14%	-19	-0.34%	-121	-2.19%
M025	Long-eared Myotis	7,564	-8	-0.11%	-19	-0.25%	-121	-1.60%
M034	Hoary Bat	7,564	-8	-0.11%	-19	-0.25%	-121	-1.60%
M003	Vagrant Shrew	9,697	-6	-0.06%	-16	-0.17%	-146	-1.51%
M116	California Mouse	20,156	-10	-0.05%	-29	-0.14%	-189	-0.94%
M102	Narrow-faced Kangaroo Rat	14,997	-6	-0.04%	-16	-0.11%	-146	-0.97%

Table 10: Santa Cruz County Alternative Year 2010 Development Scenarios: Red Fox and Yuma Myotis Habitat Fragmentation

	Habitat: Red Fox				Habitat: Yuma Myotis			
Habitat Patch Measure	Initial (1994)	Scenario SC1	Scenario SC2	Scenario SC3	Initial (1994)	Scenario SC1	Scenario SC2	Scenario SC3
Total Area (hectares)	14,356	13,555	14,045	14,092	2,811	1,835	1,664	2,040
Percent of Landcape (%)	12.4	11.7	12.2	12.2	2.4	1.6	1.4	1.8
Largest Patch Index (%)	11.5	10.8	11.2	11.3	0.7	0.5	0.5	0.5
Number of Patches	29	39	33	29	102	89	96	115
Mean Patch Size (hectares)	495.0	347.6	425.6	485.9	27.6	20.6	17.3	17.7
Maximum Patch Size (hectares)	13,290.0	12,486.0	12,975.0	13,026.0	859.0	605.0	576.0	577.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Patch Density	0.025	0.034	0.029	0.025	0.088	0.077	0.083	0.100
Patch Size Variance	6,074,182	3,993,370	5,091,642	5,835,308	9,281	5,040	4,027	3,398
Patch Size Standard Deviation	2,464.6	1,998.3	2,256.5	2,415.6	96.3	71.0	63.5	58.3
Total Edge (km)	352.6	347.6	358.6	375.4	262.4	171.8	167.0	223.8
Edge/Area Ratio (m/hectare)	24.6	25.6	25.5	26.6	93.3	93.6	100.4	100.4
Edge Density (m/hectare)	3.1	3.0	3.1	3.2	2.3	1.5	1.4	1.9

San Joaquin County Development Scenarios

The California Department of Finance projects that the population of San Joaquin County will increase by more than 200,000 persons between 1995 and 2010. At the County's current average density of 20 persons per hectare, an additional 10,000 hectares (or approximately 25,000 acres) will be required to accommodate this level of population growth.

As is the case in Santa Cruz, we assumed that any and all growth policies would be pursued countywide. We looked at three alternatives:

1. ***Scenario SJ1***, entitled, *No Constraints*, permits urban development to occur just about anywhere in San Joaquin County, except on wetlands. Urban development is permitted on all types of farmlands, within floodzones, adjacent to rivers and streams, on hillsides of any slope, and outside existing sphere-of-influence boundaries.
2. ***Scenario SJ2***, entitled *Prime Farmland Protection*, assumes the adoption of zoning and other regulatory policies that would preclude the development of prime and unique agricultural lands. Approximately __ hectares of undeveloped land currently falls within these four categories. Scenario SJ2 would also prohibit development on wetlands. Other hazard areas and environmental resources such as floodzones, riparian zones, and hillsides would be unprotected.
3. ***Scenario SJ3***, entitled *Compact Growth,* would impose numerous limits on new development over and above the protection of prime and unique farmlands. Development would be prohibited from occurring on wetlands, on sites with slopes greater than 10 percent, and within FEMA-designated floodzones. Development would also be limited to sites within existing sphere-of-influence boundaries. To further reduce land consumption, Scenario SJ3 assumes the adoption of a development density floor of 25 persons per hectare—a level 20 percent higher than the current countywide average density.

Simulation Results

Map 5 presents baseline information for all three scenarios. The top panel, which is based on the results of the Urban Growth Model, shows the calculated probability that each undeveloped site will be urbanized: dark red sites are the most likely to be urbanized; light blue sites the least likely. The bottom panel of Map 5 shows San Joaquin County's major habitat zones, classified according to the Holland classification system. A comparison of the top and bottom panels of Map 5 reveals that the sites most attractive to development are in habitat areas classified as Orchards & Vineyards, or Row & Field Crops.

Maps 6 through 8 present the results of the various scenarios. The top panel of each map shows which sites are to be considered developable and undevelopable, given the constraints imposed under each scenario (development is allowed in the yellow areas, but precluded from the red ones). The bottom panel presents the growth allocation results for each scenario; existing development is in dark grey; projected new development is in red.

Under *Scenario SJ1: No Constraints*, almost every undeveloped site in San Joaquin County is considered developable (Map 6, top panel). Projected new development, however, is likely to favor sites at the edges of existing cities, especially Lodi, Stockton, and Manteca. These locations are flat and are well-served by existing infrastructure, especially regional highways. They are also less likely to arouse opposition by agricultural interests.

The effect of adopting policies designed to protect prime and unique farmland (Map 7: *Scenario SJ2: Farmland Protection*) is to place most of San Joaquin County (including every site west of Interstate 5) off-limits to development. As extreme as these constraints may seem, their effects are likely to be surprisingly small. The largest single effect would be to shift development, which otherwise would have occurred at the fringe around Lodi, south to Stockton, Manteca and Ripon. A secondary effect would be to shift development from the east side to the west side of Stockton, and from the south side of Tracy a few miles further westward to I-580.

As the top panel of Map 8 shows, the combination of farmland protection and anti-sprawl regulations—as posited under *Scenario SJ3: Compact Growth* —would be to place most of San Joaquin County off-limits to development. Even so, since most cities in San Joaquin County cities maintain significant reserves of undeveloped land within their spheres-of-influence, the effects of such regulations on prospective development patterns would likely be quite small. The most significant effects would be, first, to increase average (incremental) development densities from 21 to 28 persons per hectare; and second, to shift some growth from Tracy eastward to Manteca.

Vegetative Land Cover Loss and Fragmentation

The differences in land cover loss between the three scenarios are also quite small. Regardless of which of the three scenarios are pursued, the four land cover types likely to be most affected by projected urban growth are Row & Field Crops, Orchards & Vineyards, Non-native Grasslands, and the so-called "Urban" category (Table 11). Under *Scenario SJ1: No Constraints*, projected urban growth would consume 4,800 hectares of crop land cover, 2,033 hectares of Orchard & Vineyard land cover, and 2,012 hectares of urban land cover. Under *Scenario SJ2: Farmland Protection*, crop land losses would decline only slightly to 4,552 hectares, while Orchard & Vineyard Forest land cover losses would decline to 1,906 hectares. On the downside, the loss of Non-native Grassland land cover would be substantially greater under Scenario SJ2 than under Scenario SJ1.

Compared to Scenario SJ1, *Scenario SJ3: Compact Growth* would preserve more than 1,200 hectares of Row and Field Crop land cover, and almost 300 hectares of Orchard & Vineyard land cover. Less Non-native Grassland land would be lost under Scenario SJ3 than under Scenario SJ2, but more than under Scenario SJ1. On a percentage basis, the loss of Row & Field Crops land would range from a high of 2.6 percent under Scenario SJ1, to a low of 1.9 percent under Scenario SJ3. The maximum percentage loss of Orchard & Vineyard land cover, 3.3 percent, would occur under Scenario SJ1. The maximum percentage loss of Non-native Grassland land, 2.9 percent, would occur under Scenario SJ2. Four other land cover types, General Agriculture, Laucustrine, Great Valley Cottonwood Riparian Forest, and Great Valley Mixed Riparian Forest, would be slightly impacted under one or more of the three scenarios.

Differences in land cover fragmentation between the three scenarios are also likely to be small (Table 12). Row & Field Crop, Orchard & Vineyard, and Agricultural land cover areas are today relatively unfragmented—a situation which would not change very much under any of the three scenarios. The two other land cover categories listed in Table 10, Great Valley Cottonwood Riparian and Great Valley Mixed Riparian, are currently much more fragmented—a situation which also would be little affected by the choice of development scenario.

Table 11: San Joaquin County Alternative Year 2010 Development Scenarios: Habitat Loss

	Initial 1994 Land Area	Scenario SJ1: No Constraints		Scenario SJ2: Farmland Protection		Scenario SJ3: Comapct Growth	
Vegetative Land Cover	hectares	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change
Row and Field Crops	186,634	-4,800	2.6%	-4,552	-2.4%	-3,556	-1.9%
Orchard & Vineyard	61,393	-2,033	3.3%	-1,906	-3.1%	-1,747	-2.8%
Non-native Grassland	53,631	-31	0.1%	-1,544	-2.9%	-121	-0.2%
Agriculture	14,034	-298	2.1%	-267	-1.9%	-267	-1.9%
Blue Oak Woodland	8,036	0	0.0%	0	0.0%	0	0.0%
Streams and Canals	5,304	-2	0.0%	0	0.0%	0	0.0%
Urban or Built-up	3,373	-2,012	59.7%	-1,561	-46.3%	-1,555	-46.1%
Foothill Pine-Oak Woodland	2,969	0	0.0%	0	0.0%	0	0.0%
Permanently-flooded Laucustrine Habitat	983	-50	5.1%	-5	-0.5%	-5	-0.5%
Great Valley Cottonwood Riparian Forest	922	-86	9.3%	-126	-13.7%	-85	-9.2%
Buck Brush Chaparral	493	0	0.0%	0	0.0%	0	0.0%
Strip Mines	468	-15	3.2%	-84	-17.9%	-84	-17.9%
Interior Live Oak Forest	457	0	0.0%	0	0.0%	0	0.0%
Open Foothill Pine Woodland	444	0	0.0%	0	0.0%	0	0.0%
Chamise Chaparral	435	0	0.0%	0	0.0%	0	0.0%
Coastal & Valley Freshwater	303	-6	2.0%	0	0.0%	0	0.0%
Coastal Brackish Marsh	301	0	0.0%	0	0.0%	0	0.0%
Juniper-Oak Cismontaine Woodland	240	0	0.0%	0	0.0%	0	0.0%
Great Valley Oak Riparian Forest	228	0	0.0%	0	0.0%	0	0.0%
Great Valley Mixed Riparian Forest	225	-47	20.9%	-1	-0.4%	-1	-0.4%
Great Valley Willow Scrub	167	0	0.0%	0	0.0%	0	0.0%
Valley Oak Woodland	66	0	0.0%	0	0.0%	0	0.0%
Eucalyptus	28	0	0.0%	0	0.0%	0	0.0%
Irrigated Hayfield	23	0	0.0%	0	0.0%	0	0.0%

Table 12: San JoaquinCounty Alternative Year 2010 Development Scenarios: Fragmentation Measures for Selected Habitats

Patch Measure	Land Cover: Agricultural Land				Land Cover: Row & Field Crops				Land Cover: Orchard or Vineyard			
	Initial (1994)	Scenario SJ1	Scenario SJ2	Scenario SJ3	Initial (1994)	Scenario SJ1	Scenario SJ2	Scenario SJ3	Initial (1994)	Scenario SJ1	Scenario SJ2	Scenario SJ3
Total Area (hectares)	14,034	13,736	13,767	13,767	186,634	181,834	182,182	183,078	61,393	59,360	59,487	59,646
Percent of Landcape (%)	3.8	3.7	3.7	3.7	50.6	49.3	49.3	49.6	16.6	16.1	16.1	16.2
Largest Patch Index (%)	0.7	0.7	0.7	0.7	33.7	32.8	32.8	33.0	5.4	5.1	5.2	5.2
Number of Patches	28	29	28	28	71	92	109	97	44	82	64	64
Mean Patch Size (hectares)	501.2	473.6	491.7	491.7	2,628.0	1,976.0	1,671.4	1,887.4	1,395.3	723.9	929.5	932.0
Maximum Patch Size (hectares)	2,719.0	2,719.0	2,719.0	2,719.0	124,394.0	121,230.0	121,087.0	121,876.0	20,047.0	18,833.0	19,155.0	19,163.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Patch Density	0.008	0.008	0.008	0.008	0.019	0.025	0.030	0.026	0.012	0.022	0.017	0.017
Patch Size Variance	664,966	658,174	673,160	673,160	262,026,679	192,574,884	162,371,032	184,728,134	19,766,140	10,058,981	12,835,717	12,919,415
Patch Size Standard Deviation	815.5	811.3	820.5	820.5	16,187.0	13,877.0	12,742.5	13,591.5	4,445.9	3,171.6	3,582.7	3,594.4
Total Edge (km)	311.0	297.8	296.0	296.0	1,759.8	1,764.0	1,863.0	1,846.8	1,052.0	1,045.8	1,075.4	1,075.8
Edge/Area Ratio (m/hectare)	22.2	21.7	21.5	21.5	9.4	9.7	10.2	10.1	17.1	17.6	18.1	18.0
Edge Density (m/hectare)	0.8	0.8	0.8	0.8	4.8	4.8	5.0	5.0	2.8	2.8	2.9	2.9

Patch Measure	Land Cover: Non-native Grasslands				Land Cover: Great Valley Cottonwood Riparian				Land Cover: Great Valley Mixed Riparian			
	Initial (1994)	Scenario SJ1	Scenario SJ2	Scenario SJ3	Initial (1994)	Scenario SJ1	Scenario SJ2	Scenario SJ3	Initial (1994)	Scenario SJ1	Scenario SJ2	Scenario SJ3
Total Area (hectares)	53,631	53,600	52,087	53,510	922	836	796	837	225	178	224	224
Percent of Landcape (%)	14.5	14.5	14.1	14.5	0.3	0.2	0.2	0.2	0.1	0.0	0.1	0.1
Largest Patch Index (%)	5.4	5.3	5.3	5.3	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Number of Patches	19	20	41	21	11	12	15	13	21	18	21	21
Mean Patch Size (hectares)	2,822.7	2,680.0	1,270.4	2,548.1	83.8	69.7	53.1	64.4	10.7	9.9	10.7	10.7
Maximum Patch Size (hectares)	19,845.0	19,748.0	19,526.0	19,740.0	183.0	183.0	183.0	183.0	41.0	41.0	41.0	41.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Patch Density	0.005	0.005	0.011	0.006	0.003	0.003	0.004	0.004	0.006	0.005	0.006	0.006
Patch Size Variance	41,440,521	39,464,768	19,237,748	37,840,236	3,048	3,798	3,930	3,836	158	138	156	156
Patch Size Standard Deviation	6,437.4	6,282.1	4,386.1	6,151.4	55.2	61.6	62.7	61.9	12.6	11.8	12.5	12.5
Total Edge (km)	613.8	614.6	654.0	610.2	62.2	56.6	55.0	57.2	33.2	27.8	33.4	33.4
Edge/Area Ratio (m/hectare)	11.4	11.5	12.6	11.4	67.5	67.7	69.1	68.3	147.6	156.2	149.1	149.1
Edge Density (m/hectare)	1.7	1.7	1.8	1.7	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1

Compared to current conditions, all three scenarios would result in somewhat higher levels of land cover fragmentation, especially in the cases of Row & Field Crop, and Orchard & Vineyard habitats. This result is not too surprising, given that most of the San Joaquin County's projected population growth will occur on currently cultivated lands.

Compared to the *No Constraints* scenario *(SJ1), Scenario SJ2: Farmland Protection* would result in lower levels of Orchard & Vineyard land cover fragmentation, but in noticeably higher levels of fragmentation for Row & Field Crop lands, Non-native Grassland lands, and Great Valley Cottonwood Riparian lands. What of *Scenario SJ3: Compact Growth*? Compared to *the No Constraints* scenario, it would result in comparable levels of fragmentation for all of the land cover categories shown in Table 10, except for Orchards & Vineyards. Compared to the *Farmland Protection* scenario, *Scenario SJ3: Compact Growth* would result in comparable or slightly reduced levels of fragmentation.

Species Habitat Loss and Fragmentation

The mammal species most threatened by urban growth in San Joaquin County are the same ones threatened by urban growth in Santa Cruz County: the yuma myotis, the Brazilian free-tailed bat, the pallid bat, the California myotis, the red bat, and the big brown bat. Two other species, the racoon and the river otter, face the possibility of significant habitat loss under one or more scenarios (Table 13). Under *Scenario SJ1: No Constraints*, projected urban growth would result in a loss of approximately 1,950 hectares of yuma myotis, California myotis, Brazilian free-tailed bat, pallid bat, and racoon habitat. These losses would be significantly reduced under both *Scenario SJ2: Farmland Protection* and *Scenario SJ3: Compact Growth.*

Note that the species threatened with the greatest absolute amounts of habitat loss (e.g., California ground squirrel, Botta's pocket gopher, western harvest mouse, and broad-footed mole) typically have the most habitat. This serves to lessen the impacts of urbanization on species viability. For most of the mammal species listed in Table 13, habitat loss would range between .2 percent and 3 percent, depending on the species and the scenario. For many of the species listed in Table 13, the actual amount of habitat lost under *Scenario SJ2: Farmland*

Protection exceeds than the amounts lost under the other two scenarios. In percentage terms, however, these differences tend to be rather small.

Several of the species that would suffer greater amounts of habitat loss under *Scenario SJ2: Farmland Protection* than under the other two scenarios are categorized as either endangered or threatened (or are candidates for listing) under the U.S. and/or California Endangered Species Acts. These include the kit fox and Heerman's kangaroo rat. To investigate further, we considered the effects of the three scenarios on kit fox and Heerman's kangaroo rat habitat fragmentation (Table 14). Based on tabulations of patch number, mean patch size, patch density, and edge area ratio, *Scenario SJ2: Farmland Protection* would result in far higher levels of kit fox habitat fragmentation, and somewhat higher levels of Heerman's kangaroo rat fragmentation, than either or the two other scenarios.

Scenario SJ1: No Constraints results in the highest level of red fox habitat fragmentation, while *Scenario SC3: Environmental Protection* results in the lowest. Indeed, the level of fragmentation under Scenario SC3 is only slightly higher than for the initial 1994 baseline. For the yuma myotis, however, it is *Scenario SC1: Not Constraints* which results in the smallest increment of habitat fragmentation, and *Scenario SC3: Environmental Protection* which results in the highest.

Readers should bear in mind that these results are based on the suitability of particular vegetative covers to particular species (as specified in the WHR table), and not on actual species sightings or population counts. Nonetheless, they reaffirm and indeed magnify earlier results that the match between policies designed to conserve and protect natural features versus policies designed to protect species habitat is not always a consistent one, and must be evaluated on a case-by-case basis.

El Dorado County Development Scenarios

The California Department of Finance projects that the population of El Dorado County will increase by 60,000 persons between 1995 and 2010. Most of this growth will occur in western part of the county along U.S. Highway 50. At the county's current average density of 12 persons per hectare, an additional 5,000 hectares (or approximately 12,500

Table 13: Santa Joaquin County Alternative Year 2010 Development Scenarios: Habitat Loss by Species

		Initial 1994 Land Area	Scenario SJ1: No Constraints		Scenario SJ2: Farmland Protection		Scenario SJ3: Compact Growth	
Code	Mammal Species	hectares	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change	1994-2010 loss (ha)	1994-2010 Pct. change
M023	Yuma Myotis	12,439	-1,932	-15.53%	-494	-3.97%	-1,488	-11.96%
M039	Brazilian Free-tailed Bat	12,907	-1,947	-15.08%	-1,578	-12.23%	-1,572	-12.18%
M038	Pallid Bat	14,755	-1,947	-13.20%	-1,578	-10.69%	-1,572	-10.65%
M028	California Myotis	16,074	-1,994	-12.41%	-1,621	-10.08%	-1,574	-9.79%
M153	Racoon	16,294	-1,979	-12.15%	-1,537	-9.43%	-1,490	-9.14%
M033	Red Bat	75,599	-4,012	-5.31%	-3,443	-4.55%	-3,237	-4.28%
M032	Big Brown Bat	77,467	-4,027	-5.20%	-3,527	-4.55%	-3,321	-4.29%
M163	River Otter	1,133	-47	-4.15%	-1	-0.09%	-1	-0.09%
M047	Desert Cottontail	146,580	-4,507	-3.07%	-5,405	-3.69%	-3,776	-2.58%
M117	Deer Mouse	147,716	-4,513	-3.06%	-5,405	-3.66%	-3,776	-2.56%
M134	California Vole	81,408	-2,480	-3.05%	-3,499	-4.30%	-2,029	-2.49%
M045	Brush Rabbit	84,145	-2,473	-2.94%	-3,499	-4.16%	-2,029	-2.41%
M158	Mink	1,864	-53	-2.84%	-43	-2.31%	-2	-0.11%
M072	California Ground Squirrel	333,695	-9,307	-2.79%	9,857	2.95%	-7,332	-2.20%
M081	Botta's Pocket Gopher	272,302	-7,274	-2.67%	-7,951	-2.92%	-5,585	-2.05%
M147	Red Fox	216,646	-5,546	-2.56%	-4,564	-2.11%	-3,649	-1.68%
M051	Black-tailed Hare	213,763	-5,145	-2.41%	-4,762	-2.23%	-3,825	-1.79%
M113	Western Harvest Mouse	331,000	-7,301	-2.21%	-3,296	-2.51%	-5,777	-1.75%
M018	Broad-footed Mole	317,476	-6,873	-2.16%	-7,290	-2.30%	-5,401	-1.70%
M162	Striped Skunk	144,120	-2,501	-1.74%	-3,844	-2.67%	-2,221	-1.54%
M157	Long-tailed Weasel	129,560	-2,197	-1.70%	-3,577	-2.76%	-1,954	-1.51%
M160	Badger	128,631	-2,079	-1.62%	-3,534	-2.75%	-1,952	-1.52%
M112	Beaver	7,832	-105	-1.34%	-48	-0.61%	-7	-0.09%
M139	Muskrat	7,832	-105	-1.34%	-48	-0.61%	-7	-0.09%
M077	Wester Gray Squirrel	3,725	-47	-1.26%	-1	-0.03%	-1	-0.03%
M104	Heerman's Kangaroo Rat	103,027	-1,160	-1.13%	-3,247	-3.15%	-1,674	-1.62%
M029	Small-footed Myotis	6,830	-47	-0.69%	-128	-1.87%	-128	-1.87%
M034	Hoary Bat	10,913	-47	-0.43%	-43	-0.39%	-2	-0.02%
M127	Dusky-footed Woodrat	11,851	-47	-0.40%	-43	-0.36%	-2	-0.02%
M152	Ringtail Racoon	12,148	-47	-0.39%	-43	-0.35%	-2	-0.02%
M146	Coyote	13,001	-47	-0.36%	-43	-0.33%	-2	-0.02%
M149	Gray Fox	13,001	-47	-0.36%	-43	-0.33%	-2	-0.02%
M161	Western Spotted Skunk	13,001	-47	-0.36%	-43	-0.33%	-2	-0.02%
M166	Bobcat	13,001	-47	-0.36%	-43	-0.33%	-2	-0.02%
M006	Ornate Shrew	43,225	-150	-0.35%	190	0.44%	190	0.44%
M148	Kit Fox	30,301	-70	-0.23%	-1,654	-5.46%	-190	-0.63%
M031	Western Pipstrelle	9,614	-15	-0.16%	-84	-0.87%	-84	-0.87%
M037	Twonsens's Big-eared Bat	9,614	-15	-0.16%	-84	-0.87%	-84	-0.87%
M087	San Joaquin Pocket Mouse	62,336	-31	-0.05%	-1,544	-2.48%	-121	-0.19%
M120	Pinyon Mouse	190	0	0.00%	0	0.00%	-1	-0.53%
M181	Mule Deer	12,199	0	0.00%	0	0.00%	-1	-0.01%

Table 14: San Joaquin County Alternative Year 2010 Development Scenarios: Kit Fox and Heerman's Kangaroo Rat Habitat Fragmentation

	Habitat: Kit Fox				Habitat: Heerman's Kangaroo Rat			
Habitat Patch Measure	Initial (1994)	Scenario SC1	Scenario SC2	Scenario SC3	Initial (1994)	Scenario SC1	Scenario SC2	Scenario SC3
Total Area (hectares)	30,541	30,470	28,887	30,351	103,485	102,325	100,238	101,811
Percent of Landcape (%)	8.3	8.3	7.8	8.2	28.0	27.7	27.2	27.6
Largest Patch Index (%)	8.0	7.9	7.4	7.9	12.7	12.7	12.7	12.7
Number of Patches	25	22	52	30	21	47	57	40
Mean Patch Size (hectares)	1,221.6	1,385.0	555.5	1,011.7	4,927.9	2,177.0	1,758.6	2,545.3
Maximum Patch Size (hectares)	29,428.0	29,004.9	27,435.0	28,996.0	47,061.0	46,937.0	46,996.0	46,996.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Patch Density	0.007	0.006	0.014	0.008	0.006	0.013	0.015	0.011
Patch Size Variance	34,537,196	38,068,487	14,447,916	27,941,406	157,767,064	73,413,329	58,756,282	85,413,900
Patch Size Standard Deviation	5,876.8	6,169.0	3,801.0	5,286.0	12,560 5	8,568.0	7,665.3	9,242.0
Total Edge (km)	220.4	217.0	271.4	221.6	995.2	995.0	1,053.2	1,006.6
Edge/Area Ratio (m/hectare)	7.2	7.1	9.4	7.3	9.6	9.7	10.5	9.9
Edge Density (m/hectare)	0.6	0.6	0.7	0.6	2.7	2.7	2.9	2.7

acres) will be required to accommodate this level of population growth. Our projections and analysis of El Dorado County cover only the western side, consisting mostly of privately owned land. Since Forest Service lands are not covered by the Farmland Mapping and Monitoring Project, we were unable to include most of the east side of the county, including the Lake Tahoe Basin, in the Urban Growth Model. As a result, we could not calculate projected urbanization probabilities for the east side.

As is the case for Santa Cruz and San Joaquin, we assumed that any and all growth policies would be undertaken countywide. We considered three alternatives:

1. ***Scenario ED1***, entitled *No Constraints*, permits urban development to occur just about anywhere in El Dorado, except on wetlands. Urban development is permitted on all types of farmlands, within floodzones, adjacent to rivers and streams, on hillsides of any slope, and outside existing sphere-of-influence boundaries.
2. ***Scenario ED2***, entitled *Environmental Protection*, assumes the adoption of zoning and other regulatory policies that would preclude the development of wetlands, areas within FEMA designated floodzones, on sites with slopes greater than 10 percent, and within 300 meters of a river or streams. Development would also be limited to sites within 500 meters of existing sphere-of-influence boundaries.
3. ***Scenario ED3***, entitled *Compact Growth*, would impose additional limits on new development over and above *Scenario ED2: Environmental Protection*. In addition to protecting hillsides, floodzones, and riparian areas, Scenario ED3 would limit new development to sites within three kilometer of Highway 50.[7] To further reduce sprawl and land consumption, Scenario ED3 assumes the adoption of a development density floor of 20 persons per hectare—a level 67 percent higher than the current countywide average density.

Simulation Results

Map 9 presents baseline information for all three scenarios. The top panel, which is based on the results of the Urban Growth Model, shows the calculated probability that each undeveloped site will be urbanized: dark red sites are the most likely to be urbanized; light blue sites the least likely. Countywide, the sites most likely to be urbanized are those

[7] Because so few urban places in El Dorado County are incorporated or have a sphere-of-influence, city and sphere-of-influence boundaries can not be consistently used to limit development.

on flat or slightly-sloped land adjacent to existing urban areas. The bottom panel of Map 9 shows El Dorado's major habitat zones, classified according to the Holland classification system. A comparison of the top and bottom panels of Map 9 reveals that the sites most attractive to development are various types of pine and oak woodlands.

Maps 10 through 12 present the results of the various scenarios. The top panel of each map shows which sites are to be considered developable and undevelopable, given the constraints imposed under each scenario (development is allowed in the yellow areas, but precluded from the red ones). The bottom panel presents the growth allocation results for each scenario; existing development is in dark grey, projected new development is in red.

Under *Scenario ED1: No Constraints*, almost every undeveloped site in San Joaquin County is considered developable (Map 10, top panel). Unlimited land supplies notwithstanding, projected new development is likely to favor sites at the edges of existing cities, especially Placerville, Shingle Springs, and Camino. These locations are flat, and are well-served by existing infrastructure, especially Highway 50. Smaller increments of urban development are likely to occur north and south of Placerville along California Highway 49. The resulting land use pattern may be said to be "sprawling" in the sense that new development is far-flung, but "compact" in that new development is mostly adjacent to existing urban areas.

Prohibiting development along rivers, streams, and hillsides—as *Scenario ED2: Environmental Protection* would do—would place a lot of El Dorado County off-limits to development (Map 11, top panel), but have little effect on future development patterns. This is because most of El Dorado's hillside and riparian areas are outside the path of likely development. Indeed, a careful comparison of *Scenarios ED1: No Constraints* and *ED2: Environmental Protection* reveals almost no difference. In El Dorado, as in Santa Cruz County, the countywide pursuit of environmental protection policies may be a good way to preserve sensitive environmental areas, but it is not likely to help contain sprawl.

As the top panel of Map 12 shows, the combination of environmental protection and anti-sprawl regulations—as posited under *Scenario ED3: Compact Growth*— would be to place all of El Dorado County except the Highway 50 corridor off-limits to development. As the bottom panel of Map 12 shows, the effect of such policies would be to promote incremental development at the boundaries of existing urban places, where, because high-quality land is limited, it would have to occur at the incredibly high (for El Dorado County) density of 36 persons per hectare, or approximately 14 persons per acre. While such an outcome is certainly interesting for illustrative purposes, it is highly unrealistic.

Vegetative Land Cover Loss and Fragmentation

Differences in land cover loss between Scenarios ED1 and ED2 are quite small (Table 15). Under *Scenario ED1: No Constraints*, projected urban growth would consume 734 hectares of Westside Ponderosa Pine, 735 hectares of Foothill Pine-Oak Woodland, 604 hectares of Non-native Grassland, 300 hectares of Interior Live Oak Woodland, 300 hectares of Black Oak Woodland, 207 hectares of Agricultural Land, and 224 hectares of Chamise Chaparral. The largest percentages of land cover loss would be for Agricultural Land (-5.2 percent), Blue Oak Woodland (-4.2 percent), Black Oak Woodland (-3.5 percent), and Interior Live Oak Woodland (-2.9 percent). Amounts of Westside Ponderosa Pine Forest and Sierran Mixed Coniferous Forest—the two largest land cover classes in El Dorado County—would each decline by less than one percent. Larger increments of every land cover type would be lost under Scenario ED2 than under Scenario ED1.

Compared to Scenario ED1, *Scenario ED3: Compact Growth* would preserve more than 500 hectares each of Westside Ponderosa Pine Forest, and Foothill Pine-Oak Woodland, and more than 200 hectares each of Non-native Grasslands, Interior Live Oak Woodland, Black Oak Woodland, and Agricultural Land. All of these savings would as a result of higher development densities.

Current fragmentation levels in El Dorado County vary widely between different land cover types (Table 16). Agricultural lands, for example, are highly fragmented, as are Black and Blue Oak Woodland lands. Foothill Pine-Oak Woodlands, Westside Ponderosa Pine Forest, and Sierran Mixed Coniferous Forest lands, by contrast, are far less fragmented, as well as far more extensive. None of the three future scenarios would have significant incremental effects on the fragmentation of Agricultural lands, Black Oak Woodland, Blue Oak Woodland, Westside Ponderosa Pine, or Sierran Mixed Coniferous Forest. Of the three

Table 15: El Dorado County Alternative Year 2010 Development Scenarios: Habitat Loss

	Initial 1994 Land Area	Scenario ED1: No Constraints		Scenario ED2: Environmental Protection		Scenario ED3: Compact Growth	
Vegetative Land Cover	hectares	1994-2010 change	1994-2010 Pct. change	1994-2010 change	1994-2010 Fct. change	1994-2010 change	1994-2010 Pct. change
Westside Ponderosa Pine Forest	108,861	-734	0.7%	-863	-0.8%	-242	-0.2%
Sierran Mixed Coniferous Forest	98,341	-153	0.2%	-231	-0.2%	-49	0.0%
Foothill Pine-Oak Woodland	39,643	-735	1.9%	-779	-2.0%	-218	-0.5%
Permanently Flooded Laucustrine Habitat	19,932	-1	0.0%	0	0.0%	0	0.0%
Jeffrey Pine-Fir Forest	19,908	0	0.0%	0	0.0%	0	0.0%
Non-native Grassland	17,411	-604	3.5%	-660	-3.8%	-325	-1.9%
Red Fir Forest	16,860	0	0.0%	0	0.0%	0	0.0%
Bare, exposed Rock	15,315	0	0.0%	0	0.0%	0	0.0%
Red Fir Pine Forest	14,493	0	0.0%	0	0.0%	0	0.0%
Lodgepole Pine Forest	10,849	0	0.0%	0	0.0%	0	0.0%
Interior Live Oak Woodland	10,458	-300	2.9%	-418	-4.0%	-136	-1.3%
Chamise Chaparral	10,144	-224	2.2%	-268	-2.6%	-122	-1.2%
Montane Manzanita Chaparral	10,106	0	0.0%	0	0.0%	0	0.0%
Jeffrey Pine Forest	9,772	0	0.0%	0	0.0%	0	0.0%
Black Oak Woodland	8,585	-300	3.5%	-363	-4.2%	-205	-2.4%
Black Oak Forest	7,115	0	0.0%	0	0.0%	0	0.0%
Mixed Montane Chaparral	6,820	0	0.0%	0	0.0%	0	0.0%
Urban or Built-up	5,726	-74	1.3%	-69	-1.2%	-8	-0.1%
Interior Live Oak Forest	5,297	-61	1.2%	-83	-1.6%	-46	-0.9%
Agricultural Land	4,000	-207	5.2%	-302	-7.6%	-99	-2.5%
Mid-elevation Conifer Plantation	3,515	0	0.0%	0	0.0%	0	0.0%
Blue Oak Woodland	3,343	-142	4.2%	-189	-5.7%	-84	-2.5%
Open Foothill Pine Forest	2,403	-39	1.6%	-70	-2.9%	0	0.0%
Whitebark Pine Mountain Hemlock	1,916	0	0.0%	0	0.0%	0	0.0%
Canyon Live Oak Forest	1,739	-11	0.6%	-16	-0.9%	0	0.0%
Whitebank Pine Forest	1,721	0	0.0%	0	0.0%	0	0.0%
Sierran White Fir Forest	1,582	0	0.0%	0	0.0%	0	0.0%
Non-Serpentine Foothill Pine Woodland	1,091	-19	1.7%	-25	-2.3%	-10	-0.9%
Whitebark Pine Lodgepole Pine Forest	965	0	0.0%	0	0.0%	0	0.0%
Montane Riparian Scrub	792	0	0.0%	0	0.0%	0	0.0%
Leather Oak Chaparral	777	0	0.0%	0	0.0%	0	0.0%
Eastside Ponderosa Pine Forest	671	0	0.0%	0	0.0%	0	0.0%
Aspen Forest	644	0	0.0%	0	0.0%	0	0.0%
Big Sage Scrub	469	0	0.0%	0	0.0%	0	0.0%
Upper-elevation Conifer Plantation	326	0	0.0%	0	0.0%	0	0.0%
Transitional Bare Areas	253	0	0.0%	0	0.0%	0	0.0%
Buck Brush Chaparral	213	0	0.0%	0	0.0%	0	0.0%
Montane Ceanothus Chaparral	135	0	0.0%	0	0.0%	0	0.0%
Sub- and Alpine Meadow	113	0	0.0%	0	0.0%	0	0.0%
Sphagnum Bog	108	0	0.0%	0	0.0%	0	0.0%
Great Valley Cottonwood Riparian Forest	94	0	0.0%	0	0.0%	0	0.0%
Scrub Oak Chaparral	70	0	0.0%	0	0.0%	0	0.0%
Huckleberry Oak Chaparral	23	0	0.0%	0	0.0%	0	0.0%

Table 16: El Dorado County Alternative Year 2010 Development Scenarios: Fragmentation Measures for Selected Habitats

	Land Cover: Agricultural Land				Land Cover: Black Oak Woodland				Land Cover: Blue Oak Woodland				and Cover: Interior Live Oak Woodlan			
Patch Measure	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3
Total Area (hectares)	4,000	3,793	3,698	3,901	8,585	8,285	8,222	8,380	3,343	3,201	3,154	3,259	10,458	10,158	10,040	10,322
Percent of Landcape (%)	0.9	0.8	0.8	0.8	1.9	1.8	1.8	1.8	0.7	0.7	0.7	1	2.3	2.2	2.2	2.2
Largest Patch Index (%)	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.6	0.2	0.2	0.2	0	0.8	0.7	0.7	0.8
Number of Patches	29	31	33	32	38	46	45	43	23	24	22	20	26	29	38	25
Mean Patch Size (hectares)	137.9	122.4	112.1	121.9	225.9	180.1	182.7	194.9	145.3	133.4	143.4	163	402.2	350.3	264.2	412.9
Maximum Patch Size (hectares)	1,475.0	1,427.0	1,386.0	1,475.0	2,600.0	2,584.0	2,564.0	2,600.0	999.0	989.0	975.0	999	3,552.0	3,459.0	3,316.0	3,540.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1	1.0	1.0	1.0	1.0
Patch Density	0.006	0.007	0.007	0.007	0.008	0.010	0.010	0.009	0.005	0.005	0.005	0	0.006	0.006	0.008	0.005
Patch Size Variance	94,789	83,651	75,094	86,768	270,769	227,484	220,965	243,769	68,183	64,334	67,636	76,268	791,164	682,501	514,541	798,110
Patch Size Standard Deviation	307.9	289.2	274.0	294.6	520.4	477.0	470.1	493.7	261.1	253.6	260.1	276	889.5	826.1	717.3	893.4
Total Edge (km)	178.2	168.4	168.4	174.0	303.6	294.2	295.8	295.8	136.8	128.2	126.6	129	326.8	321.0	322.8	322.6
Edge/Area Ratio (m/hectare)	44.6	44.4	45.5	44.6	35.4	35.5	36.0	35.3	40.9	40.0	40.1	40	31.2	31.6	32.2	31.3
Edge Density (m/hectare)	0.4	0.4	0.4	0.4	0.7	0.6	0.6	0.6	0.3	0.3	0.3	0	0.7	0.7	0.7	0.7

	Land Cover: Foothill Pine-Oak Woodland				Land Cover: Westside Ponderosa Pine Forest				Land Cover: Sierran Mixed Coniferous Forest			
Patch Measure	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3	Initial (1994)	Scenario ED1	Scenario ED2	Scenario ED3
	39,643	38,908	38,864	39,425	108,861	108,127	107,998	108,619	98,341	98,188	98,110	98,292
Percent of Landcape (%)	8.5	8.4	8.4	8.5	23.5	23.3	23.3	23.4	21.2	21.2	21.2	21.2
Largest Patch Index (%)	4.3	3.4	4.2	4.3	9.7	9.6	9.7	9.7	5.4	5.4	5.4	5.4
Number of Patches	46	47	68	47	77	93	91	86	57	60	62	61
Mean Patch Size (hectares)	861.8	827.8	571.5	838.8	1,413.8	1,162.7	1,186.8	1,263.0	1,725.3	1,636.5	1,582.4	1,611.3
Maximum Patch Size (hectares)	19,967.0	15,721.0	19,498.0	19,772.0	44,977.0	44,585.0	44,856.0	44,969.0	24,859.0	24,834.0	24,833.0	24,838.0
Minimum Patch Size (hectares)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Patch Density	0.010	0.010	0.015	0.010	0.017	0.020	0.020	0.019	0.012	0.013	0.013	0.013
Patch Size Variance	9,940,947	6,759,464	6,561,583	9,577,963	33,636,643	27,556,690	28,370,838	30,206,656	24,154,864	23,030,612	22,338,983	22,712,149
Patch Size Standard Deviation	3,152.9	2,599.9	2,561.6	3,094.8	5,799.7	5,249.4	5,326.4	5,496.1	4,914.8	4,799.0	4,726.4	4,765.7
Total Edge (km)	994.2	987.4	996.8	988.8	2,395.6	2,395.0	2,407.6	2,387.0	1,903.5	1,906.0	1,910.6	1,904.8
Edge/Area Ratio (m/hectare)	25.1	25.4	25.6	19.5	22.0	22.1	22.3	19.5	19.4	19.4	19.5	19.5
Edge Density (m/hectare)	2.1	2.1	2.1	2.1	5.2	5.2	5.2	5.1	4.1	4.1	4.1	4.1

scenarios, *ED2: Environmental Protection* would most increase the level of fragmentation among Interior Live Oak Woodland and Foothill Pine-Oak Woodland.

Summary Comparisons

Compared side-by-side, the nine scenarios presented in this chapter reveal a lot about the CURBA Model, about the ability of alternative regulatory policies to protect habitat, and about the relationship of urban development and growth to habitat loss and quality.

As is always the case with statistical models, the quality of outputs depends on the robustness of the underlying equations. In El Dorado County, for example, the underlying urban growth equations generate a far more dispersed pattern of projected urban development than would likely be the case. Projected urban growth patterns—and the impacts of those patterns on habitat fragmentation—are also highly sensitive to the densities at which growth is allocated. Here again, El Dorado County provides a good example: the level of habitat loss and the fragmentation is far greater under the 13 person-per hectare *Environmental Protection Scenario* than under the 31 person-per-hectare Compact Growth scenario.

As a result, growth policies and regulations which have the effect of boosting growth densities and minimizing sprawl do a far more effective job preserving habitat and minimizing habitat fragmentation than policies intended solely to protect sensitive environmental resources such as hillsides or farmlands. This result is evident from all three case examples. Policies which protect sensitive environmental areas which specifically include unique or threatened habitats—such as riparian zones—can also be effective. Policies and programs designed to protect farmland may not necessarily promote habitat conservation. In Santa Cruz County, for example, the effect of adopting farmland protection policies would likely be to shift future urban growth from less habitat areas to more sensitive ones. The various county results also confirm that the best way to protect habitat is to protect set aside large, contiguous areas of land, and to preclude them from development. This may be done through municipal regulation, through purchase, or through the use of large-scale partnership approaches such as NCCPs. *Any other approach,* *no matter how well-intended is likely to be second best.*

Finally—and surprisingly—the scenario results indicate that the situation may not be as dire as it is sometimes portrayed. Even in San Joaquin County, which is projected to grow by more than 200,000 persons between 1995 and 2010, the impact of urbanization on *non-agricultural* is projected to be quite low. Under the least restrictive *SJ1: No Constraints* scenario, less than 300 hectares (approximately 750 acres) of non-agricultural and non-urban habitat will be converted to urban uses by the year 2010. (Ironically, significantly more non-agricultural habitat is converted to urban uses under *Scenario SJ2: Farmland Protection,* than under the No Constraints scenario.) In Santa Cruz County, which is projected to grow by about 50,000 person between 1995 and 2000, the threat is somewhat greater: depending on which policies are pursued where, the amount of redwood and evergreen forest loss could approach 4 percent. In western El Dorado County, which is also projected to grow by about 50,000 persons, between one percent and three percent of key forest and grassland habitats are at risk, depending on the form and density of future urbanization.

This last finding should in no way be regarded as justification for inactivity. As the various fragmentation results demonstrate, the quality and spatial configuration of habitat loss may be as important as the amount of loss. What the CURBA Model results show above all is that carefully considered urban growth policies and conservation efforts can have a significant impact on reducing habitat losses and fragmentation.

Chapter Four: Running the CURBA Model

This chapter explains how to use the Policy Simulation and Evaluation component of the CURBA Model. This component, henceforth referred to as the CURBA/PSE Model, consists of a series of compiled Avenue scripts which reference pre-associated ArcView datasets. Keybourd and mouse commands are indicated in **bold Arial typeface.** Display windows and options are indicated in plain Arial typeface.

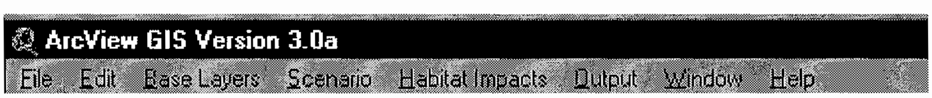
To run the CURBA/PSE Model, users should:

1. Have previously installed ArcView 3.0a, ArcView Spatial Analyst, and ArcView Dialog Designer;
2. Have downloaded the CURBA/PSE Model and associated datasets to their hard disk (see Appendix C);
3. Have created a **c:\temp** directory on their hard drive.

STEP ONE: Accessing and Starting the CURBA/PSE Model

The first step in running the CURBA/PSE Model is to start ArcView 3.0a. Once ArcView has loaded, users should select the **Open Project** command from the **File** menu, and find and start the ArcView project file named **curba.apr.** Starting this project file will add the Spatial Analyst and Dialog extensions, as well as set the working directory to c:\temp.

The CURBA/PSE Model menu-bar is composed of eight menu items:



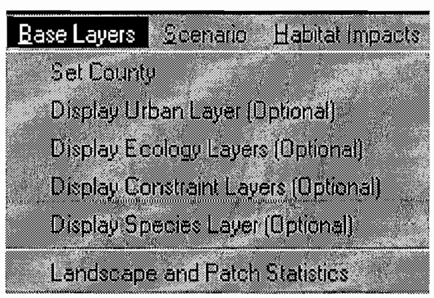
The **File** and **Edit** menu items are an expanded set of the basic ArcView File and Edit commands. **File** allows you to save your work, print, exit, etc. **Edit** enables you to copy, paste, rename, and delete themes, map elements, and graphics.

The core of the CURBA/PSE Model consists of four menu items: **Base Layers, Scenario, Habitat Impacts,** and **Output**. (The CURBA/PSE Model command structure generally follows a *left to right* logic: Users choose commands from a pull-down menu, enter appropriate choices, and then continue with the next command to the right.) **Base Layers** is used to select themes for display and to calculate baseline statistics. **Scenario** is used to construct alternative development scenarios based on different estimates of population growth, allocation densities, and development constraints. The **Habitat Impact** menu is used to analyze the effects of the different scenarios on habitat area and fragmentation. Habitat impacts can be measured according to vegetative land cover, affected vertebrate species, or special study areas. The **Output** menu is used to construct maps and reports for plotting and printing.

To the right of the core menu are two additional pull-down menus: **Windows** and **Help**. As in ArcView 3.0, **Windows** allows users to toggle between different views and layouts. The **Help** menu accesses information about commands and procedures.

STEP TWO: Loading and Displaying Base Data Layers

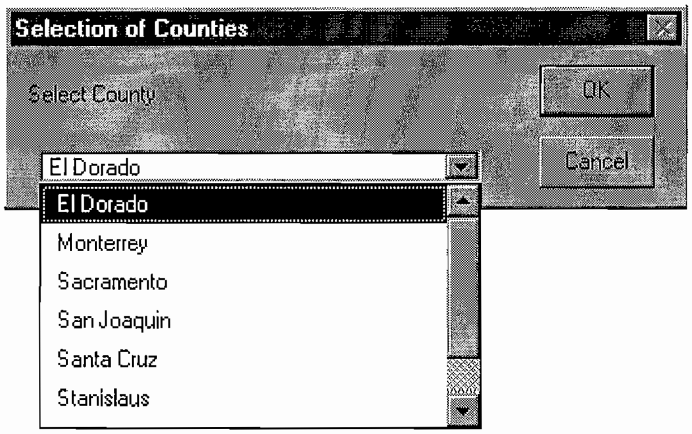
The first step in running the CURBA/PSE Model is to choose a study area and load the appropriate base layers. This is accomplished using the **Base Layers** menu.



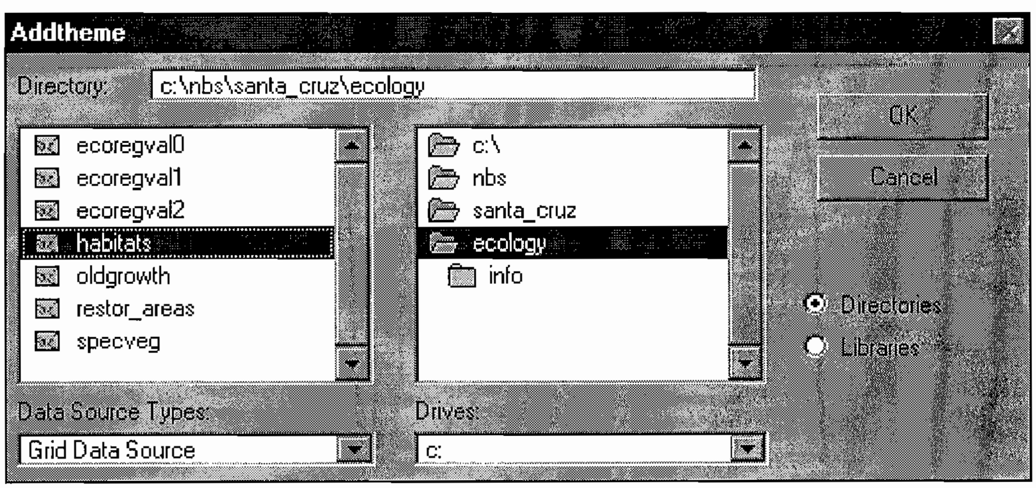
As shown above, the **Base Layers** menu consists of the following options:

- **Set County:** Because CURBA/PSE datasets are organized and referenced by county, the first thing you *always* need to do is to select a study county. Skipping this step will cause the CURBA/PSE model to fail.
- **Display Urban Layer:** This option allows users to display one or more map layers showing the extent of past or current urbanization. At least one urban layer must be selected.

Urbanization layers are available for most counties for 1986 and 1994. Before selecting an urban layer for display, make sure the Data Source Type is set to **Grid Data Source.** In addition, make sure that the **Directory** option is selected.

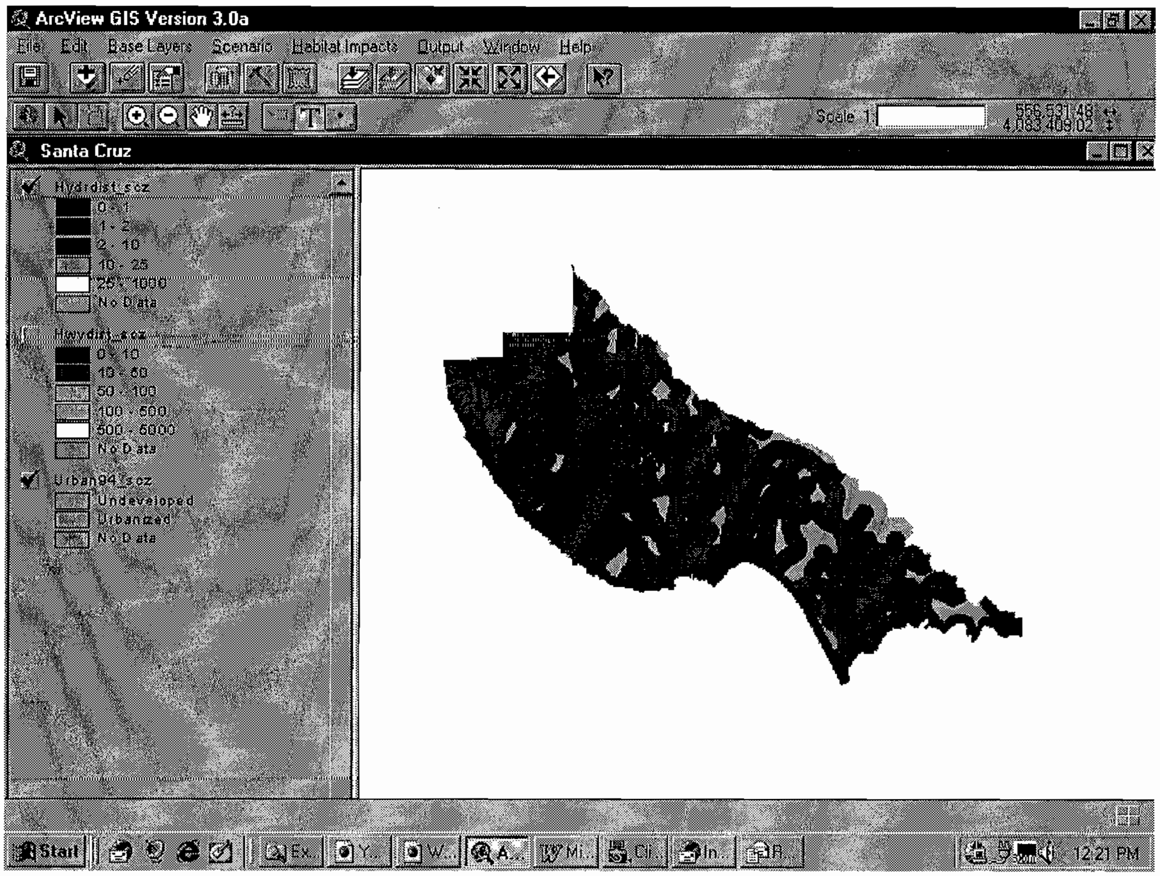


- **Display Ecology Layers:** This option allows users to display one or more ecological layers, including: **Habltats**; **Ecoregval0** (which stands for eco-regional value with no weights); **Ecoregval1** (which stands for eco-regional value with weights); **Ecoregval2** (which stands for eco-regional value with conservative weights); Areas of Potential Restoration **(restor_areas)**; and Significant Natural Areas **(signatural)**. Additional ecological layers are available for Santa Cruz county, including Old Growth Redwood Areas **(oldgrowth)** or Areas of Special Vegetation **(specveg)**. After you click **OK**, the selected layer will appear in your display.



- **Display Constraint Layers:** This option allows users to display one or more development constraint layers including slopes, wetlands, and agricultural land types. Users can also display the distance from any undeveloped grid-cell to the nearest highway, hydographic feature, or urbanized grid-cell.

- **Display Species Layer:** This option allows users to display species habitat locations. Users can select as many species as they want according to their popular or scientific name.



STEP THREE: Adjusting Your View

ArcView will display all of the map layers and theme legends you have selected in the *Legend/Table of Contents*. The check marks to the right of each legend indicate which layers are visible. Clicking on the check mark (to turn it on or off) will display or hide the associated map. Maps are displayed and refreshed in inverse order of their appearance in the *Legend/Table* *of Contents* (i.e., maps at the bottom are drawn first). Depending on the composition of a particular layer, you may or may not be able to see the other map layers beneath it. To change the drawing order, simply drag the theme legend up or down to the desired position.

- **Changing the Colors of a Layer:** You can change the color of a particular layer or theme simply by double-clicking on its legend. This will bring up the *Legend Editor* window. Double-clicking on the color you wish to change will bring up the *Fill Palette.* Click on the *Color Brush*  icon, make sure the level is set to **Foreground**, and then click on the new color. Then click **Apply**.

- **Displaying Additional Layers:** You can display additional map layers at any time simply by clicking on the **Add Theme** (layer) button: 

- **Zooming:** The following buttons are available to for zooming in and out of a view:

Zoom to Full Extent: Displays the complete area of the active layer (theme). A layer becomes active when you click on its legend in the table of contents.

Zoom In: Zooms in on the center of the map.

Zoom Out: Zooms out from the center of the map.

Zoom to Selected: Zooms to the selected area. (This command will not be available of you have not previously selected an area.)

Zoom Previous: Returns to the previous display.

Zoom In: Allows you to click on what you want to be the new center of the map or to draw a square in the map while holding down the left button of the mouse. The area inside the square will be displayed in the map window.

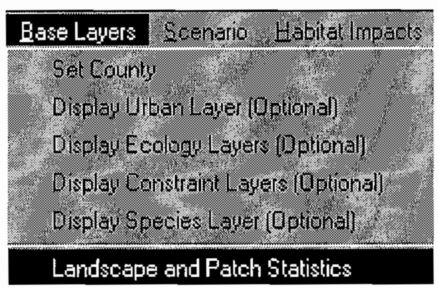
Zoom Out: Allows you to click on what you want to be the new center of the map or to draw a square in the map while pressing the left button of the mouse. The current display will be redrawn inside the square.

Pan: Allows you to move the map by dragging it in any direction to a new position. You can do that by holding down the left button of the mouse while you move it to the new position.

- **Deleting Layers:** Unneeded layers and themes can be deleted at any time by, first making them active (clicking on them to "raise" them in the *Table of Contents*); and then by choosing **Delete Theme** from the **Edit** menu, or by clicking the *Delete Theme* icon. You can delete many layers at once if you hold down the **Shift** key while clicking on the legends of the layers you want to delete.
  Note: As part of the scenario-building process, CURBA/PSE creates many new grid layers in the C:\TEMP directory. Before deleting a CURBA/PSE-generated grid layer, make sure you have either exported it to a new grid file, or else renamed it using the **Manage Grids** command in the **File** menu.

STEP FOUR (Optional): Calculating Baseline Patch and Landscape Statistics

The **Landscape and Patch Statistics** option allows you to calculate various patch and landscape statistics for any of the layers you have added to your map display. Patches are defined as the "basic elements or units that make up a landscape,"[1] and patch statistics are used to "quantify the areal extend and spatial distribution of patches within a landscape."[2]



CURBA/PSE will first query you for the environmental layer(s) you want to analyze. *You may analyze only those layers you have previously added to your view display list.* CURBA/PSE will next ask you to select the classifications or classes in the selected layer (landscape) that you want to analyze. The option, **All of them together (Landscape Statistics)** will allow you to analyze the landscape (layer) as a whole. Once CURBA/PSE has completed its calculations, it will generate a table of statistics

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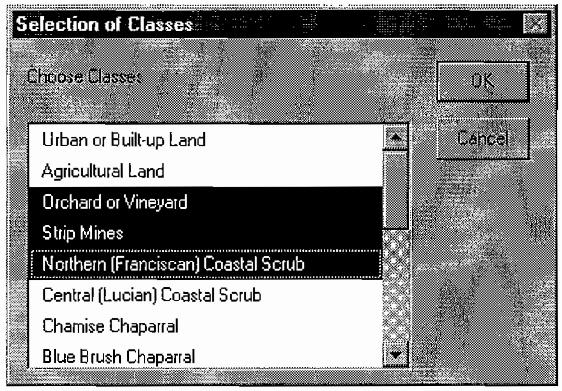
1 United States Department of Agriculture. *Fragstats: Spatial Pattern Analysis Program for Quantifying Landscape structure.* p 5.

2 Ibid. P.12



CURBA/PSE automatically generates the following patch statistics:

1. **Total Area** (ha): This is the total area in hectares of each land use or vegetation class.
2. **Percent of Landscape**: This is the ratio of (land use or vegetation) class area to total landscape area, multiplied by 100. The landscape area is *always* the total area of the layer you are using. A value close to 100 percent means that most of the landscape is composed of the same classification.
3. **Largest Patch Index**: This is the area of the largest patch of a particular (land use or vegetation) class divided by the total landscape area, and multiplied by 100. A value close to 100 percent means that most of the landscape is composed of one patch.
4. **Number of Patches**: This is a count of the number of non-adjacent patches of the same classification in the landscape.
5. **Maximum patch size** (ha): This is the area of the biggest patch of a particular class.
6. **Minimum patch size** (ha): This is the area of the smallest patch of a particular class.
7. **Patch Density**: This is the number of patches per 100 hectares. It is calculated by multiplying the total number of patches of a given class by 100, and dividing the product by the total area of the landscape.
8. **Patch Size Variance**: This is the variance of the area of patches of the same class.
9. **Patch Standard Deviation**: This is the standard deviation of the area of the patches of the same class.
10. **Total Edge**: This is the total of the perimeters of patches of the same class.
11. **Edge Density** (m/ha): This is the total edge of a given land use or vegetation class divided by the total area of the landscape.

c:\windows\temp\l.dbf

Statistics	Orchard or Vineyard	Strip Mines	Northern (Franciscan) Coastal Scrub
Total Area (ha)	368.000	168.000	416.000
Percent of Landscape (%)	0.319	0.145	0.360
Largest Patch Index (%)	0.189	0.145	0.339
Number of Patches	2.000	1.000	2.000
Mean Patch Size (ha)	184.000	168.000	208.000
Maximum Patch Size (ha)	218.000	168.000	392.000
Minimum Patch Size (ha)	150.000	168.000	24.000
Patch Density	0.002	0.001	0.002
Patch Size Variance	2312.000	0.000	67712.000
Patch Size Standard Deviation	48.083	0.000	260.215
Total Edge (km)	23.600	8.400	19.600

STEP FIVE: Building a Scenario

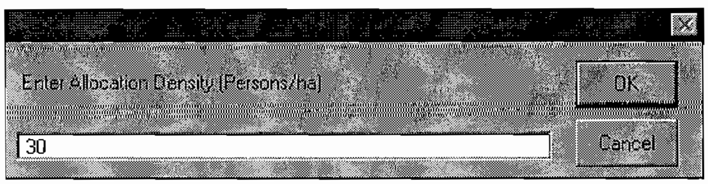
Future development scenarios are constructed using the **Scenario** menu. The Scenario menu is organized sequentially into six steps: (1) Select Development Probability Grid; (2) Set Initial Urban Layer; (3) Choose Projections; (4) Set Development Constraints and Policies; (5) Display Projected Development Allocation; and (6) Generate Future Urban Layer.

1. The first step in developing a scenario is to **Select a Development Probability Grid.** The probability grid is a cell-by-cell listing of the probability that each undeveloped hectare grid-cell will be urbanized in the future. It is generated in ARC/Info using the results of the Urban Growth Model. This command is optional, as default probability grids are included in each CURBA/PSE dataset.

2. The second step in developing a scenario is to **Set an Initial Urban Layer**. This is the layer to which future development will be added. For this command to work, you must have previously added an urban layer using the **Add Urban Layer** command in the **Base Layers** menu. Subsequent commands will not work if you do not set an initial urban layer.

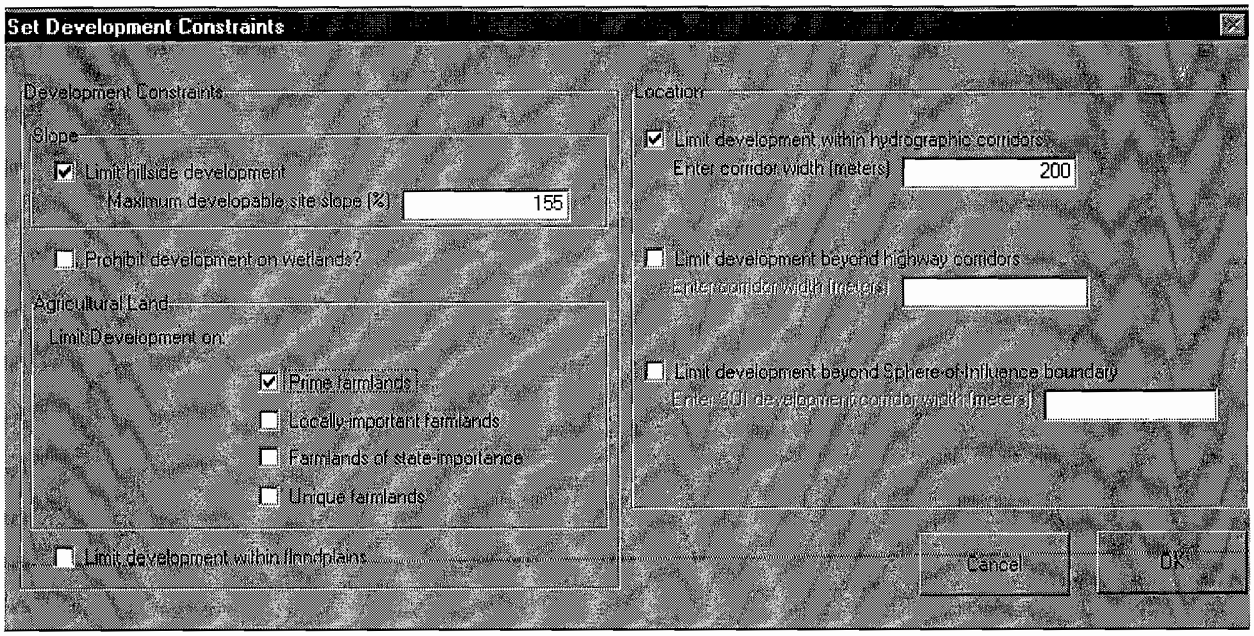
3. **Choose Projections**: The third step in developing a scenario is to set forth the projected amount of growth to be allocated. This is done using two pop-up dialog boxes. The first, shown below, queries the user for the total increment of population growth for the study county during the forecast period:

After entering a projection, click **OK**. A second dialog box queries the user for the projected countywide allocation density, expressed in terms of persons per hectare:



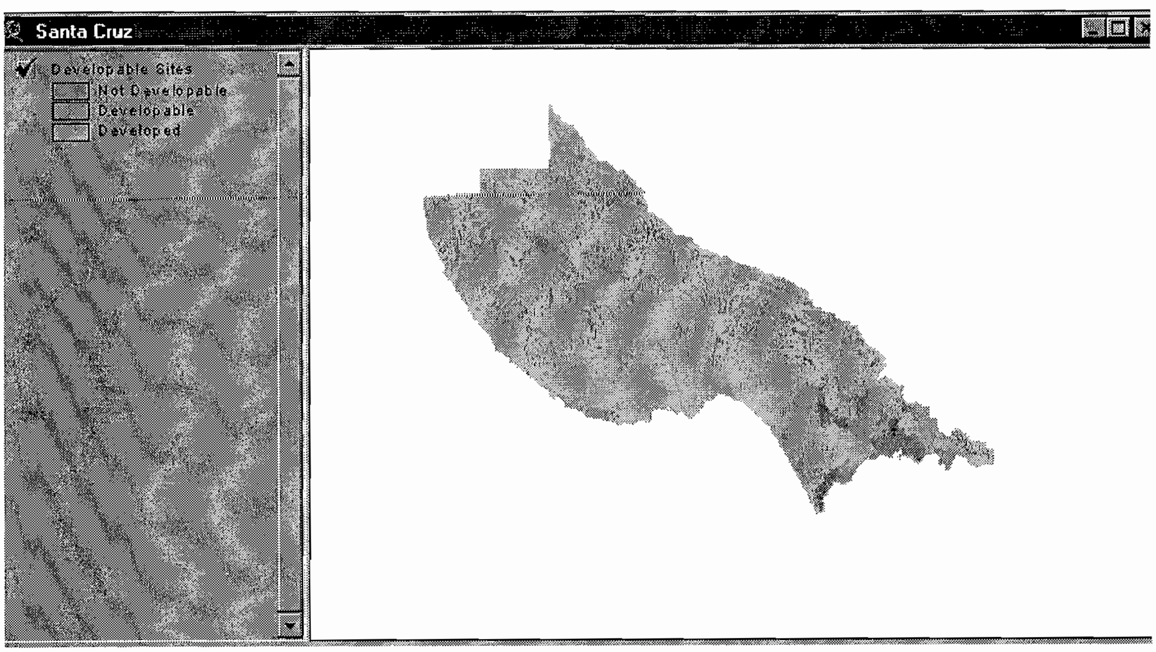
After entering a starting allocation density, click **OK**. The CURBA/PSE Model utilizes these entries to calculate the total amount of land area required to accommodate projected population growth. By respecifying different growth increments and allocation densities, users can easily and quickly test multiple population and density projections.

4. **Set Development Constraints and Policies**: This command allows users to limit where future development may occur, and as such, forms the heart of the scenario-building process. Choosing this command causes the *Development Constraints* menu to pop up. By checking the appropriate boxes and/or entering thresholds, users can: (i) prohibit or limit development on hillsides of different slopes; (ii) prohibit development on designated wetlands; (iii) prohibit or limit development on different types of farmlands; (iv) prohibit or limit development within specified hydrographic or riparian corridors; (v) limit or prohibit development beyond specified highway and road corridors; and (vi) prohibit or limit development beyond jurisdictional and/or sphere-of-influence boundaries. Unless otherwise specified, all limitations and prohibitions are applied on a countywide basis. To finalize the selected mix of constraints, click on the **OK** button. If the **OK** button is not

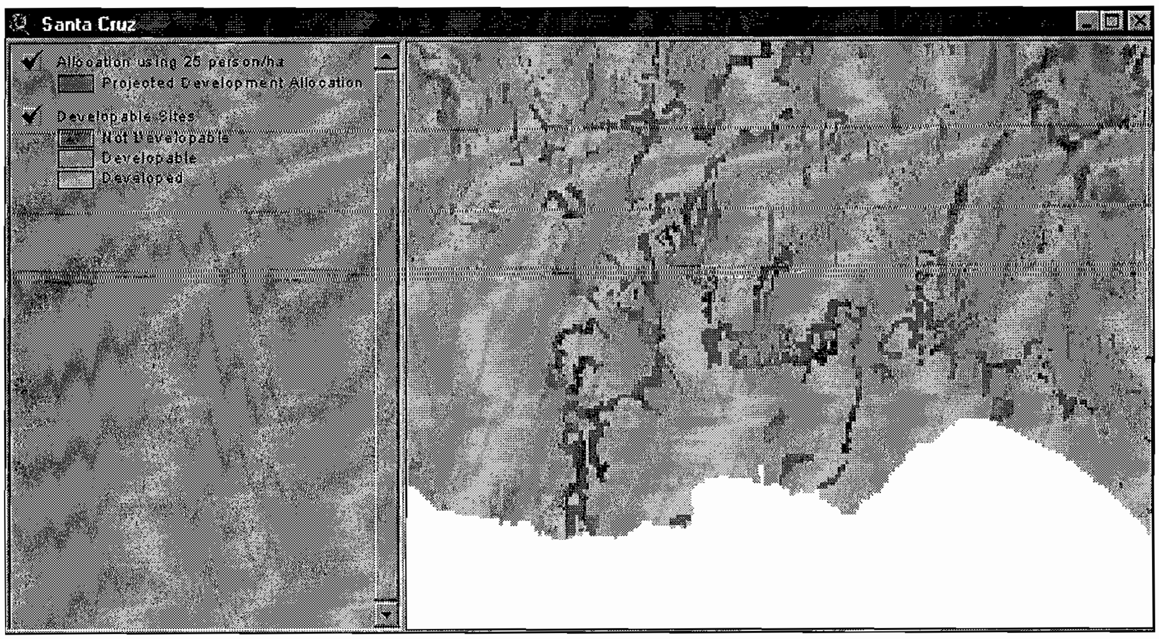


available, it is because a particular constraint is not fully specified (e.g. the hillside box is

checked, but no slope limitation is specified.). Based on the selected set of policy constraints, CURBA/PSE will display a grid map of which cells are available for future development and which sites are prohibited from development.

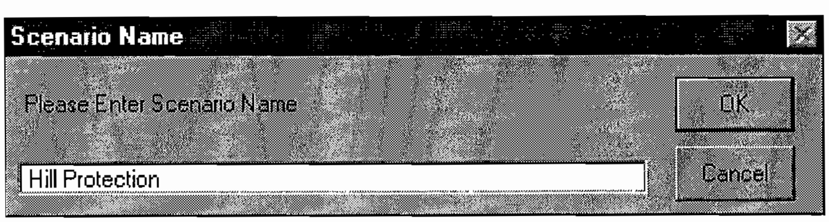


5. **Display Allocation of Future Development:** CURBA allocates projected population growth (from STEP 3, above) to permissible development sites (from STEP 4, above), in order of their development probability. This step displays the outcome of the allocation process in map form. Depending on the availability of sites and the distribution of development probabilities, the resulting allocation density may be either higher (if there are not enough available sites) or lower (if there are many developable sites with the same probability) than the starting allocation density, from STEP 3, above. Existing development is indicated in light grey; newly developed sites are indicated in dark grey. Note: this command may be unavailable if you skipped any of the previous steps.

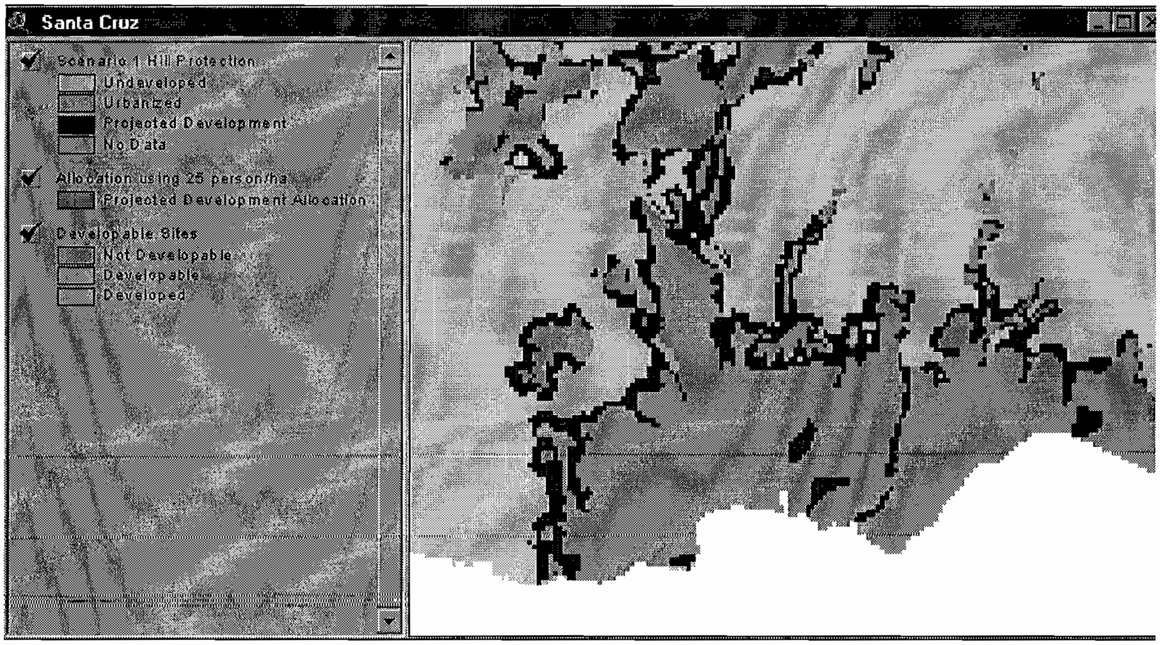


If, upon viewing the map, you wish to alter your scenario, you can go back to STEP 3, to enter new population projections and allocation densities; or to STEP 4, to enter a different set of development constraints.

6. **Generate Future Urban Layer**: This command saves the completed development scenario to a grid file. Upon choosing this command, the CURBA/PSE Model will query you for a scenario name:



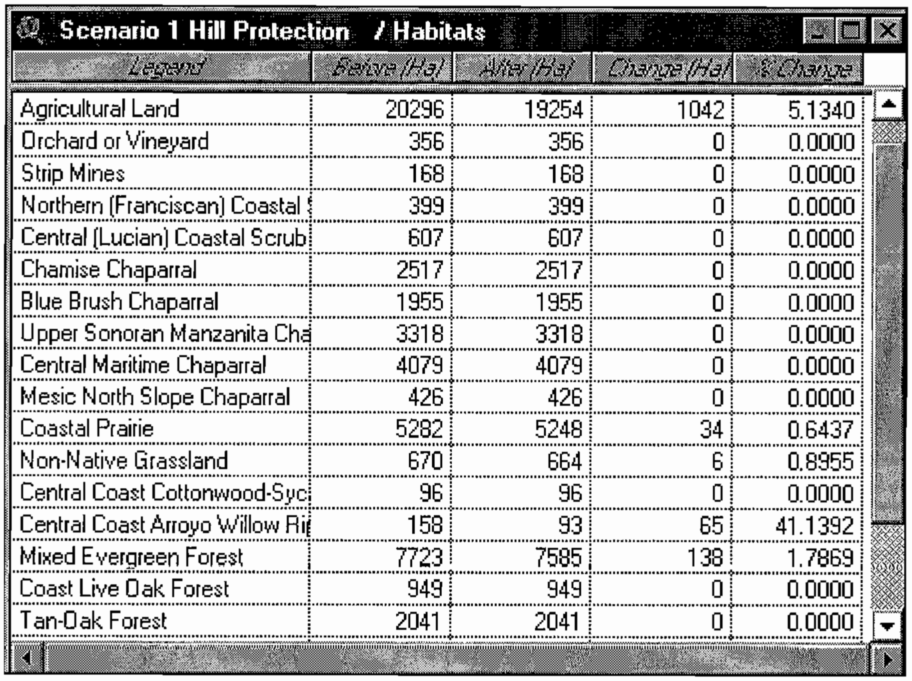
Upon naming your scenario and clicking **OK**, the CURBA/PSE Model will display a map of the completed scenario:



STEP SIX: Analyzing Habitat Impacts

The **Habitat Impacts** menu is used to analyze the habitat impacts associated with one or more development scenarios. Users can analyze and evaluate: (i) changes in habitat area, organized by vegetation class; (ii) changes in multiple habitat areas, organized by species type and name; (iii) changes in habitat area, organized by eco-regional value; (iv) changes in significant resource or environmental study areas; and (v) changes in the level of habitat fragmentation, organized by vegetation class, species, or eco-regional value:

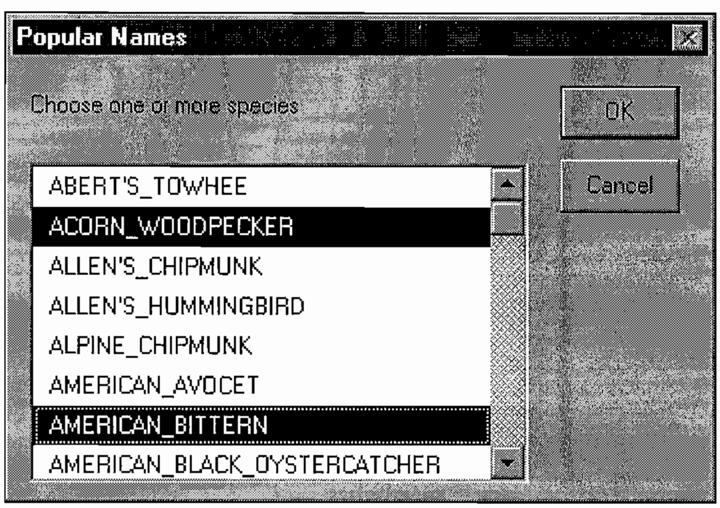
- **Habitat Area Changes:** Depending on how they are specified, different scenarios (as generated in STEP 5) will lead to different levels of habitat loss. Selecting this menu item directs the CURBA/PSE Model to generate a summary table of habitat area changes, organized by Holland vegetation class. (Note: if you have previously generated multiple scenarios, the CURBA/PSE Model will first query you for the scenario name.)



Scenario 1 Hill Protection / Habitats

Legend	Before (Ha)	After (Ha)	Change (Ha)	% Change
Agricultural Land	20296	19254	1042	5.1340
Orchard or Vineyard	356	356	0	0.0000
Strip Mines	168	168	0	0.0000
Northern (Franciscan) Coastal S	399	399	0	0.0000
Central (Lucian) Coastal Scrub	607	607	0	0.0000
Chamise Chaparral	2517	2517	0	0.0000
Blue Brush Chaparral	1955	1955	0	0.0000
Upper Sonoran Manzanita Cha	3318	3318	0	0.0000
Central Maritime Chaparral	4079	4079	0	0.0000
Mesic North Slope Chaparral	426	426	0	0.0000
Coastal Prairie	5282	5248	34	0.6437
Non-Native Grassland	670	664	6	0.8955
Central Coast Cottonwood-Syc	96	96	0	0.0000
Central Coast Arroyo Willow Ri	158	93	65	41.1392
Mixed Evergreen Forest	7723	7585	138	1.7869
Coast Live Oak Forest	949	949	0	0.0000
Tan-Oak Forest	2041	2041	0	0.0000

- **Species Affected (Complete List, Amphibians, Birds, Mammals, Reptiles):** These menu items direct the CURBA/PSE Model to produce summary tables of habitat change for one or more species. You may access the different species lists comprehensively (Complete List), or by subset (Amphibians, Birds, Mammals, Reptiles). When the appropriate species pick-list is displayed, use the mouse to indicate which particular species you are interested in. You can select multiple species by holding down the **Shft** key. When you are done selecting species, click on **OK**.



As above, the resulting summary table will be in dBase IV format. Note that the table header includes the scenario name, the type of species list, and the summary table file name and location (e.g. Scenario2-25 persons/ha / Species Lost (Amphibians) / c:\nbs\results\table1.dbf).

Scenario 2 25 person/ha / Species Lost (Amphibians)/c:\nbs\santa_cruz\constraints\scenario 2 .dbf

Code	Index	Popular Name	Scientific Name	Before (Ha)	After (Ha)	Change (Ha)	% Change
A006	6	ROUGH-SKINNED_NEWT	Taricha_granulosa	53927	53328	599	1.1108
A012	12	ENSATINA	Ensatina_eschscholtzi	37755	37435	320	0.8476
A014	14	CALIFORNIA_SLENDER_SAL	Batrachoseps_attenuatus	3154	3132	22	0.6975
A020	20	BLACK_SALAMANDER	Aneides_flavipunctatus	53769	53232	537	0.9987
A022	22	ARBOREAL_SALAMANDER	Aneides_lugubris	40308	39988	320	0.7939

- **Eco-regional Value (Weights, Conservative Weights, No Weights)**: These menu items are used to generate a before-and-after summary table of habitat loss by high, medium, or low eco-regional value. Users can choose unweighted estimates, estimates based on conservative weights, or estimates based on general weights:

Scenario 1 Hill Protection / Ecoregional Value -With

Legend	Before (Ha)	After (Ha)	Change (Ha)	% Change
Low Value	3691	3691	0	0.0000
Medium Value	20239	20134	105	0.5188
High Value	48349	47292	1057	2.1862

- **County Special Features**: This menu section allows you to analyze the effects of projected urbanization on three Santa Cruz County natural areas: (i) Old Growth Redwood Areas; (ii) Special Vegetation Areas; and, (iii) Significant Natural Areas.

- **Areas of Potential Restoration**: This option produces a table of natural area loss for pre-identified potential Restoration Areas. It is currently available for use only in Santa Cruz County.

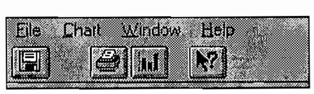
- **Fragmentation Statistics (Habitat, Species, Eco-regional Values)**: These menu options direct CURBA/PSE to calculate 11 before-and-after patch and landscape fragmentation statistics for specific habitat, species, or eco-regional value classes. In addition to total area, the calculated statistics include: percent of landscape; largest patch index; number of patches; maximum patch size; minimum patch size; patch density; patch size variance; patch standard deviation; total edge; and edge density. After choosing which summary level to analyze (Habitat, Species, Eco-regional value), the CURBA/PSE Model will query you for the name of the scenario you wish to analyze. When the appropriate species pick-list is displayed, use the mouse to indicate which habitats, species, or eco-regional values you are interested in. You can select multiple species by holding down the **Shft** key. When you are done making your selection, click on **OK**. As with all previous tables, note that this one is in dBase IV form. Note also that the that the table header includes the scenario name, the type of species list, and the summary table file name and location.

Scenario 1 Hill Protection /Fragmental Statistics (Species)/c:\nbs\santa_cruz\constraints\...

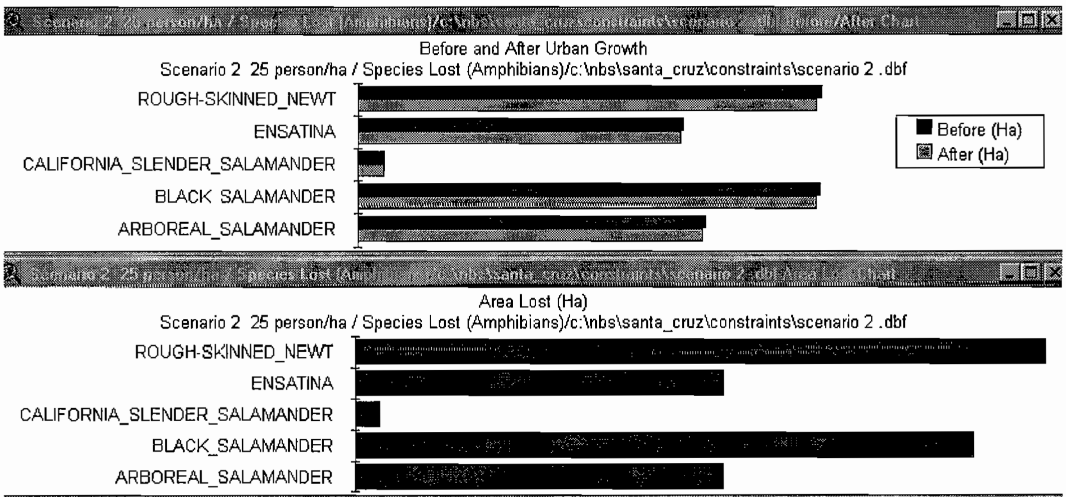
Before/After	Statistics	ACORN_WOODPECKER	ARBOREAL_SALAMANDER
Before	Total Area (ha)	8333.000	50064.002
Before	Percent of Landscape (%)	7.213	43.336
Before	Largest Patch Index (%)	1.706	40.939
Before	Number of Patches	128.000	51.000
Before	Mean Patch Size (ha)	65.102	981.647
Before	Maximum Patch Size (ha)	1971.000	47295.002
Before	Minimum Patch Size (ha)	1.000	1.000
Before	Patch Density	0.111	0.044
Before	Patch Size Variance	53585.163	43777331.037
Before	Patch Size Standard Deviation	231.485	6616.444
Before	Total Edge (km)	461.200	942.400
Before	Edge Density (m/ha)	3.992	8.157
		0.000	0.000
After	Total Area (ha)	6825.000	49585.998
After	Percent of Landscape (%)	5.908	42.922
After	Largest Patch Index (%)	1.466	39.781
After	Number of Patches	116.000	53.000
After	Mean Patch Size (ha)	58.836	935.585
After	Maximum Patch Size (ha)	1694.000	45956.998
After	Minimum Patch Size (ha)	1.000	1.000
After	Patch Density	0.100	0.046
After	Patch Size Variance	45845.877	39761334.592
After	Patch Size Standard Deviation	214.117	6305.659
After	Total Edge (km)	339.200	940.200
After	Edge Density (m/ha)	2.936	8.138

STEP SEVEN: Charting (Optional)

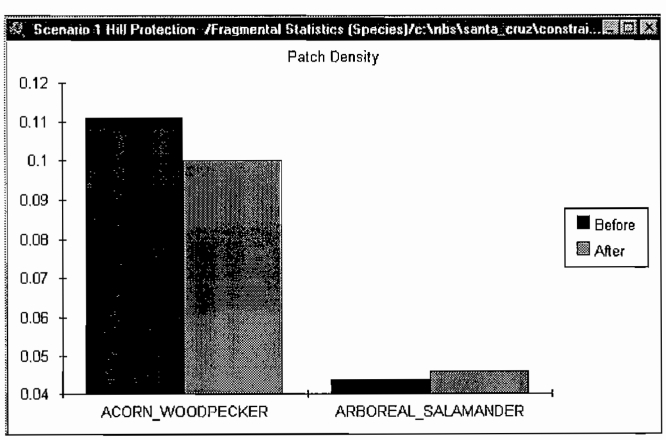
In addition to generating summary tables, the CURBA/PSE Model can also produce summary charts. To access CURBA/PSE's chart-building capabilities, make the summary table you wish to chart active, then click on the **CHART** menu or icon. Alternately, you can go to the **OUTPUT** menu and choose **GET CHART.**



Depending on the type of summary table you are working from, CURBA/PSE will present you with three charting options: (i) a *before-after chart*; (ii) an *area-lost chart*; and (iii) a *percentage-area-lost chart*. Choose the type of chart you wish to produce, then choose the habitat or species classes you wish to chart. The following example graphic shows a before-and-after chart and area-lost chart for five species.

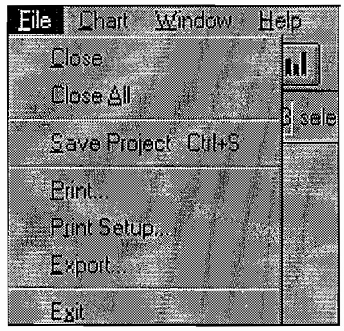


Note that you can only chart patch and landscape statistics using a before-after format. Patch and landscape statistics can only be charted one at a time. Note also that patch statistics charts replace each other, and do not accumulate, unlike habitat and species area charts.



STEP EIGHT: Printing or Exporting Summary Tables

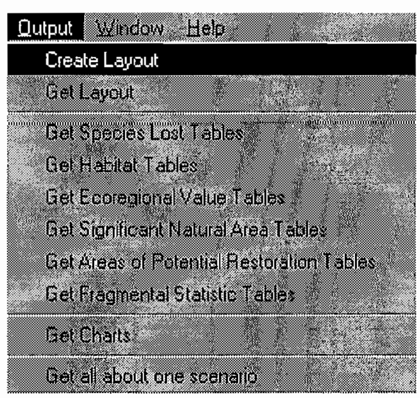
Summary tables and charts may be printed using the **Print** command, located in the **File** menu.



Alternately, the **Export** command can be used to export summary tables in dBase or delimited-text format. (Note that the habita-lost and species-lost tables, and patch and landscape tables, are already in dBase form; **Export** enables you to assign new names to them, or to write them to other directories.)

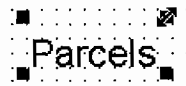
STEP NINE: Creating and Editing Layouts

The CURBA/PSE Model enables you to access ArcView's layout commands directly from the main menu. To do so, click on the **Output** menu, then choose **Create Layout**. To retrieve a previously created layout, choose **Get Layout**.



CURBA/PSE will create a layout using whatever view is currently active. Prior to creating a layout, you may want to use ArcView's zooming tools ( ) to zoom in, zoom out, or pan to a different area of the map. As above, you can turn individual map layers on or off by clicking on the legend check box.

- **To move layout features**: Make sure the pointer icon is active, then click on the feature you wish to move. Wait for the corner "grab handles" to appear; then, using the mouse, drag it to a new location.



- **To change feature size**: Make sure the pointer icon is active, then click on the feature you want to shrink or enlarge (e.g. the map, legend, title). When the corner grab handles appear, grab the one you wish to stretch; then, holding down the left mouse key, stretch it to its new location. Then place the mouse in one of the four corners. Finally, while holding down the left button of the mouse, drag it to the new size.

- **To change or edit the title:** Double click on the title. Then, type in your changes.

- **To enter new text**: Click on the text button: . Then, click on the place where you want to add the text and enter it.

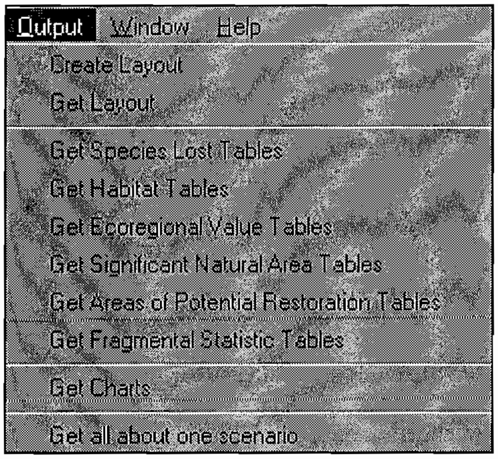
- **To draw graphic features:** If you want to draw graphic features such as lines, square, polygons, circles, etc., click on the figures tool: . Hold down the left mouse button, until a menu of feature types appears. Click on the feature you want to use and then draw it using the mouse.

- **To delete a feature:** To delete a feature (a title, a figure, a legend, etc.) click on it and then go to **Edit** menu and choose **Delete**. You can also use the **delete** button on the keyboard.

- **To print**: Go to **File** and choose **Print,** or press the print icon: . Be sure to check the print setup before printing. Make sure that the orientation of the page (portrait or landscape) is consistent with your layout.

STEP TEN: Pulling It All Together

You may, at any time, use the Output menu to review, print, or plot any or all of the tables and charts you have created.



Use this option to get any of the layouts you have

Use this option to get any of the tables you have created.

Use this option to get any of the charts you have created.

Use this option to get all the tables and charts for a given

Chapter Five: Conclusions and Caveats

Conclusions

The California Urban and Biodiversity Analysis Model represents a significant step forward in the ability of policy-makers and planners to project and evaluate the possible effects of alternative urban growth patterns and policies on natural habitat quality and biodiversity. The CURBA Model achieves significant advances on three fronts. First, it allows planners, policy-makers, interest groups, and residents to better understand the forces and factors behind recent urbanization trends and patterns. Second, it allows them to more easily project future urban growth patterns, and to investigate the sensitivity of projected urban growth patterns to alternative regulatory and environmental policies. Lastly, by bringing together previously unrelated spatial data sources in a common framework, it allows policy-makers, urban and environmental planners, wildlife ecologists, natural scientists, and everyone else concerned with the future of the natural environment to constructively evaluate the effects of projected urban growth on habitat integrity and quality.

The CURBA Model also demonstrates the incredible amount of spatial data and useful analytical power it is now possible to put on a desktop. The Policy Simulation and Evaluation component of the CURBA Model runs entirely in ArcView, a powerful and flexible mapping program which, as this article makes clear, can also serve as a robust, beyond-the-state-of-the-art analytical and simulation tool. A typical run of the CURBA Model makes use of a dozen grid layers, each of which commonly includes a million-plus hectare grid cells. Yet running the CURBA Model—including generating maps and reports—typically takes less than 10 minutes per scenario.

And Caveats

To properly use the CURBA Model, one must also understand its limitations. First and foremost, the model results are only as good as the quality of the underlying data. To the extent that data are mis-classified, or that map feature boundaries which are supposed to line up do not (particularly between different map layers), the model is likely to produce erroneous and biased results. This is especially true when analyzing inter-scenario differences in land cover and habitat fragmentation.

The probability scores generated by the Urban Growth Model component are a second possible source of bias. To the extent that the model equations do a poor job explaining historical urban growth patterns, or to the extent that the factors driving future development patterns differ from those of the past, the CURBA Model may direct future development to some unlikely locations.

Third, the forward effects of regulatory constraints on development are notoriously difficult to predict. Simply removing inappropriate sites from consideration for development greatly oversimplifies how real-world land and development markets react to regulatory constraints. Nor is the model in its current form able to project the likely effects of new investments (such as roads) on future development patterns.

Fourth, the model treats all urban development as homogeneous, and does not distinguish between different land uses or allow for the possibility of redevelopment. Nor is the model in its current form able to simulate a variety of development densities. Implicit in the model results is the assumption that all forms and patterns of urban growth represent the same level of habitat decline. While this true for many species, it is certainly not true for all species.

Lastly, users should remember that although related, land cover, habitat quality, and biodiversity are not the same thing. Having large amounts of contiguous land cover is a necessary condition for species health and biodiversity, but it is not sufficient. The sensitivity of species health to habitat area and land cover fragmentation varies widely by species, by area, and by fragmentation measure. Significant gaps in scientific knowledge regarding the linkages between habitat quantity, quality, and species biodiversity still remain—gaps which must be filled before models like CURBA can be used to their full potential.

Directions for Future Research and Development

The version of the CURBA Model presented in this report is only a start; many improvements to the Model still remain to be undertaken. Among them:

- The Model should be extended to cover all California counties.
- The Model should be able to simulate a broader array of conservation, regulatory, and investment policies, both at the sub-county (e.g., city or town) and regional, or multi-county, levels. In particular, users should be able to input a range of allocation densities, and/or specify development patterns consistent with current or projected plans.
- Additional versions of the Urban Growth Model should be tested, with the goal of making the estimated equations more robust. Ideally, the CURBA Model structure should be modified to permit local users to estimate and apply their own urban growth equations.
- Users should be able to aggregate currently distinct vegetative covers and species types into their own classes.
- The interface and analysis procedures should be upgraded to distinguish and identify multi-species, and species-rich habitats.
- Provisions for species census or sighting data layers should be incorporated.

All of these improvements are modest and incremental. They make it possible to better use current data and science. Ultimately, additional scientific research and data collection will be necessary to relate alternative measures of habitat size and fragmentation to ecological and species health; and to identify which urban development types and forms are compatible or incompatible with species health biodiversity.

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Appendix A: Urban Growth Model: Full Specification Results for El Dorado, Monterey, Nevada, Placer, Sacramento, San Joaquin, Santa Cruz, and Stanislaus Counties

(**Dependent Variable:** Likelihood of Urbanization between 1986 and 1994)

Independent Variable	El Dorado County	Monterey County	Nevada County	Placer County	Sacramento County	San Joaquin County	Santa Cruz County	Stanislaus County
Distance to city limits (meters)			-.0629				0.5643*	
Distance to existing urban development (meters)	-.3353*	-.0773*	-.1159*	-0.1392*	-.1359*	-.0252*	-.5806*	-.2266*
Distance to major highway (meters)	-.00567*		-.0176*					
Distance to nearest highway-squared				.00005*	-.00011*	-.00002*	-.00006*	-.00000266*
Distance to Grass Valley city limits (meters)			.0556*					
Distance to Nevada City city limits (meters)			.00937*					
Locally-important farmland	-.736*							
Pct. of neighboring cells in urban use		-.225*	-.1412*	-.2448*	-.1283*	.1577*	-.00557	-.185*
Percent slope	-.2028*		-.1106*					
Slope less than 2% (0/1)					.4879*	2.71*	.2078*	1.3056*
Square of slope		-0.0236*		-.0118*	-.0355*		-.00709*	
Within 100m of nearest highway (0/1)		.262*		-.8992*	-.761*	-1.1559*	0.1874*	
Within census-designated place (0/1)	1.1748*							
Within city limits (0/1)			1.0059*					
Within sphere-of-influence (0/1)		1.8803*	1.0621*	.8543*	.1906*	1.7543*	0.0753	1.4174*
Within wetland area (0/1)	-2.6988*							
Within Auburn city limits (0/1)				1.9585*				
Within Carmel city limits (0/1)		1.8904*						
Within Colfax city limits (0/1)				1.5757*				
Within Escalon city limits (0/1)						3.3986*		
Within Folsom city limits (0/1)					1.392*			
Within Galt city limits (0/1)					2.302*			
Within Grass Valley city limits (0/1)			1.7696*					
Within King City city limits (0/1)		2.3454*						
Within Lincoln city limits (0/1)				1.7414*				
Within Lodi city limits (0/1)						1.8014*		
Within Manteca city limits (0/1)						3.6449*		
Within Marina city limits (0/1)		2.3902*						
Within Monterey city limits (0/1)		1.44*						
Within Nevada City sphere-of-influence (0/1)			-1.4817*					
Within Newman city limits (0/1)								.8445*
Within Riverbank city limits (0/1)								1.7071*
Within Rocklin city limits (0/1)				2.6922*				
Within Roseville city limits (0/1)				2.5419*				
Within Salinas city limits (0/1)		3.7346*						
Within Santa Cruz city limits (0/1)							.5643*	
Within Scott's Valley city limits (0/1)							1.3639*	
Within Stockton city limits (0/1)						3.9562*		
Within Tracy city limits (0/1)						4.5934*		
Within Waterford city limits (0/1)								1.1105*
Within Watsonville city limits (0/1)							1.9281*	
Intercept	0.0833*	-2.6478	-2.4394*	-.7986*	-1.2896*	-7.1605*	-2.3285*	-2.5534*
Goodness of fit measures								
Log-likelihood ratio	9,377.7	13,425.7	4,033.2	18,811.4	35,419.0	13,516.7	4,801.6	17,087.1
Chi-squared	6,702.0	8,346.1	2,060.8	14,319.1	14,495.0	6,399.0	2,525.5	16,120.6
Pct. concordant predictions	96.1%	87.1%	91.8%	95.5%	90.0%	86.4%	86.2%	69.7%

Appendix B1: California Habitats (Holland Classification)

Code	Superclass	Vegetation Cover/Habitat	Code	Superclass	Vegetation Cover/Habitat
1	11	Urban or Built-up Land	110	52	Coastal Brackish Marsh
2	12	Agricultural Land	113	52	Coastal and Valley Freshwater Marsh
3	12	Row and Field Crops	117	61	Central Coast Cottonwood-Sycamore Riparian Forest
4	12	Irrigated Hayfield	118	61	Central Coast Live Oak Riparian Forest
8	12	Pasture	119	61	Central Coast Arroyo Willow Riparian Forest
9	12	Orchard or Vineyard	123	61	Great Valley Cottonwood Riparian Forest
11	12	Deciduous Orchard	124	61	Great Valley Mixed Riparian Forest
13	12	Eucalyptus	125	61	Great Valley Valley Oak Riparian Forest
14	14	Mid-elevation Conifer Plantation	133	62	Sycamore Alluvial Woodland
15	14	Upper-elevation Conifer Plantation	141	63	Great Valley Willow Scrub
16	15	Streams and Canals	143	63	Montane Riparian Scrub
17	15	Permanently-flooded Lacustrine Habitat	148	71	Oregon Oak Woodland
19	15	Bays and Estuaries	149	71	Black Oak Woodland
21	17	Beaches and Coastal Dunes	150	71	Valley Oak Woodland
22	17	Sandy Area Other than Beaches	151	71	Blue Oak Woodland
23	17	Bare Exposed Rock	152	71	Interior Live Oak Woodland
24	17	Strip Mines	153	71	Coast Live Oak Woodland
25	17	Transitional Bare Areas	154	71	Alvord Oak Woodland
36	32	Central (Lucian) Coastal Scrub	157	71	Open Foothill Pine Woodland
37	32	Venturan Coastal Sage Scrub	158	71	Serpentine Foothill Pine-Chaparral Woodland
39	32	Diablan Sage Scrub	159	71	Non-Serpentine Foothill Pine Woodland
48	35	Great Basin Mixed Scrub	160	71	Foothill Pine-Oak Woodland
50	35	Big Sagebrush Scrub	162	71	Juniper-Oak Cismontane Woodland
51	35	Low Sagebrush Scrub	169	81	Mixed Evergreen Forest
54	35	Subalpine Sagebrush Scrub	171	81	Coast Live Oak Forest
67	37	Chamise Chaparral	172	81	Canyon Live Oak Forest
70	37	Mixed Montane Chaparral	173	81	Interior Live Oak Forest
71	37	Montane Manzanita Chaparral	174	81	Black Oak Forest
72	37	Montane Ceanothus Chaparral	175	81	Tan-Oak Forest
74	37	Huckleberry Oak Chaparral	176	81	Aspen Forest
75	37	Bush Chinquapin Chaparral	179	82	Upland Redwood Forest
76	37	Mixed Serpentine Chaparral	185	83	Monterey Pine Forest
77	37	Leather Oak Chaparral	187	83	Knobcone Pine Forest
78	37	Buck Brush Chaparral	190	84	Coast Range Mixed Coniferous Forest
79	37	Blue Brush Chaparral	191	84	Santa Lucia Fir Forest
82	37	Scrub Oak Chaparral	192	84	Coast Range Ponderosa Pine Forest
83	37	Interior Live Oak Chaparral	193	84	Coulter Pine Forest
84	37	Upper Sonoran Manzanita Chaparral	198	84	Westside Ponderosa Pine Forest
85	37	Northern Maritime Chaparral	199	84	Eastside Ponderosa Pine Forest
86	37	Central Maritime Chaparral	200	84	Sierran Mixed Coniferous Forest
88	37	Mesic North Slope Chaparral	201	84	Sierran White Fir Forest
89	37	Coastal Sage-Chaparral Scrub	204	85	Jeffrey Pine Forest
91	42	Coastal Prairie	205	85	Red Fir (Lodgepole Pine)-Western White Pine Forest
95	42	Non-Native Grassland	206	85	Jeffrey Pine-Fir Forest
98	42	Northern Hardpan Vernal Pool	207	85	Red Fir Forest
101	42	Montane Meadow	211	86	Lodgepole Pine Forest
102	42	Subalpine or Alpine Meadow	217	86	Whitebark Pine Forest
107	52	Sphagnum Bog			

Appendix C: CURBA Model Data Structure: including data files for El Dorado, Monterey, Nevada, Placer, Sacramento, San Joaquin, Santa Cruz, and Stanislaus Counties

Directory/File names	Data types	File type
Nbs	Master Directory	Directory
Legends	Common legends	Directory
Citydist.avl	Distance to city	Map legend
Developable.avl	Developable land	Map legend
Farmland.avl	Farmland type	Map legend
Floodzne.avl	Floodzone location	Map legend
Furban.avl	Future urbanized	Map legend
Hwydist.avl	Distance to Highway	Map legend
Hydrdist.avl	Distance to hydrological features	Map legend
Probs_de.avl	Development probability	Map legend
Slope.avl	Site slope	Map legend
Urban.avl	Urbanized	Map legend
Wetlands.avl	Wetlands	Map legend
El_Dorado		County Data Directory
Monterey		County Data Directory
Placer		County Data Directory
Nevada		County Data Directory
Sacramento		County Data Directory
Stanislaus		County Data Directory
San Joaquin		County Data Directory
Santa Cruz		County Data Directory
Constraints	Constraints layers	Data Directory
Citydist_scz (grid layer)	Distance to nearest city	Grid layer
Farm_scz (grid layer)	Farmland type	Grid layer
Floodmap_scz (grid layer)	Flood zones	Grid layer
Hwydist_scz (grid layer)	Distance to highway	Grid layer
Hydrdist_scz (grid layer)	Distance to hydrological features	Grid layer
Slope_scz (grid layer)	Site slope	Grid layer
Wetlands_scz (grid layer)	Wetlands	Grid layer
Ecology	Ecological layers	Data Directory
Ecoregval0	Ecoregional weighing factor	Grid layer
Ecoregval1	Ecoregional weighing factor	Grid layer
Ecoregval2	Ecoregional weighing factor	Grid layer
Habitats	Vegetative habitat layers	Grid layer
Restor_areas	Restoration area layers	Grid layer
Oldgrowth	Oldgrowth forest layers*	Grid layer
Specveg	Special vegetation areas*	Grid layer
SNA	Special natural areas	Grid layer
Ecoregval.avl	County-based legend	Legends file
Habitats.avl	County-based legend	Legends file
Restor_areas.avl	County-based legend	Legends file
Oldgrowth.avl	County-based legend	Legends file
Specveg.avl	County-based legend	Legends file
Logit		Data Directory
Scores	Development probability scores	Grid layer
Species		Data Directory
Sid_scz	Species identification layer	Grid layer
Speclist.dbf	Species list	dbf file
Vert_scz.dbf	Vertebrates list	dbf file
Urban		Data Directory
Urban86_scz	1986 Urbanized sites	Grid layer
Urban94_scz	1994 Urbanized sites	Grid layer