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Imagining Land Use Futures: Applying the California Futures Model

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Abstract

The California Urban Futures Model (or CUF Model) is the first of a new generation of metropolitan planning models designed to help planners, elected officials, and citizen groups create and compare alternative land-use policies. This article explains how the CUF Model works and then demonstrates its use in simulating realistic alternatives for regional and subregional growth policy/planning. Part One explains the design principles and logic of the CUF Model. Part Two presents CUF Model simulation results of three alternatives for growth policy/ land-use planning alternatives for the San Francisco Bay and Sacramento areas. Part Three demonstrates the use of the CUF Model for evaluating alternative agricultural protection and zoning policies at the county, or sub-regional, level.

Comments

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Applying the California Urban Futures Model

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The California Urban Futures Model (or CUF Model) is the first of a new generation of metropolitan planning models designed to help planners, elected officials, and citizen groups create and compare alternative land-use policies. This article explains how the CUF Model works and then demonstrates its use in simulating realistic alternatives for regional and subregional growth policy/planning. Part One explains the design principles and logic of the CUF Model. Part Two presents CUF Model simulation results of three alternatives for growth policy/land-use planning alternatives for the San Francisco Bay and Sacramento areas. Part Three demonstrates the use of the CUF Model for evaluating alternative agricultural protection and zoning policies at the county, or subregional, level.

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Alternatives analysis is an essential part of plan-making and a critical tenant of planning theory. Yet all too often alternatives analysis is given short shrift. Instead of considering a full range of alternatives, the analysis is often limited to one or two variants of a common concept or plan. The lack of attention given alternatives analysis is not just a matter of time and money constraints. Building alternative scenarios about what the future might look like is hard work, especially when the future is ten or twenty years away. And good planning practice notwithstanding, many decision makers are simply not interested in considering truly different policies and plans—particularly if they conflict with the political status quo.

The California Urban Futures Model (or CUF Model, as it is more commonly known) is the prototype of a new generation of metropolitan planning model designed to help planners, elected officials, and citizen groups create and compare alternative land use policies. The CUF Model breaks new ground in a number of areas. It is the first large-scale metropolitan simulation model to use a geographic information system for data integration and spatial analysis, not just map display. It is the first operational metropolitan planning model to simulate the interactions between public land-use policies and private land developers regarding the location, scale, and density of proposed developments. Finally, it is the first large-scale planning model specifically designed to evaluate regional, subregional, and local land-use alternatives.

This article explains how the California Urban Futures Model works, and then demonstrates its use in simulating realistic regional and subregional growth policy/planning alternatives. The article has three parts. Part one explains the design principles and logic of the CUF Model. Part two presents CUF Model simulation results of three alternatives for growth policy/land-use planning for the San Francisco Bay and Sacramento areas. The three alternatives are a "Business-as-Usual" scenario, a "Maximum Environmental Protection" scenario, and a "Compact Cities" scenario. Part three demonstrates the use of the CUF Model for evaluating alternative policies on agricultural protection and zoning at the county, or subregional, level.

The results presented here focus on the future of the San Francisco Bay and Sacramento areas, and are highly detailed, some might say too detailed. We would disagree. Efforts such as the CUF Model are valuable precisely for their ability to present and compare the details of different urban development scenarios. While urban visionaries may want to look solely at big-picture alternatives, politicians, planners, and citizens want to know how particular land-use policies are going to play in their back yards.

An Overview of the California Urban Futures Model

The precise workings of the California Urban Futures Model have been detailed elsewhere (Landis 1994). In this section we summarize the logic of the CUF Model, explain its diverse heritage, and summarize how it differs from previous urban simulation efforts.

The Logic of the CUF Model

The CUF Model is designed around two very different units of analysis: political jurisdictions (incorporated cities and counties), and Developable Land Units (DLUs). Population growth, the demand side of the CUF Model, is projected for cities and counties. Development potential, the supply side of the CUF Model, is calculated in terms of DLUs.

The choice of political jurisdictions as the primary unit of analysis reflects the CUF Model's inherent policy orientation. Under California law, control of development and land uses rests solely in the hands of incorporated city and county governments (Governor's Office of Planning and Research, 1989).[1] Incorporated cities also have some measure of land-use control over directly adjacent, unincorporated areas. Known as "spheres of influence," these areas are established and updated by county Local Agency Formation Commissions, or LAFCOs. Spheres of influence were originally intended as flexible urban limit lines; they were to be the areas into which growing cities would eventually expand, and to which cities could economically provide local public services.[2]

Developable Land Units (DLUs) are the second primary unit of analysis in the CUF Model. DLUs are undeveloped areas inside and outside cities that are available for development or redevelopment. DLUs are polygon constructs generated through the geometric union and/or intersection of various environmental, market, and policy map layers. An example of a DLU would be an undeveloped site with steep slopes, served by sewers, zoned for light industrial uses, and located less than 500 meters from a major freeway. Depending on the number and complexity of the map layers which are used to generate them, DLUs may range in size from one to several hundred acres. The typical Bay Area county includes 30,000 to 50,000 DLUs. DLUs are not legal parcels; however, they may approximate collections of parcels in urbanized areas.

As figure 1 shows, the CUF Model is really four linked submodels, run recursively.

1. *The Bottom-Up Population Growth Submodel* is the demand side of the CUF Model: it generates five-year population growth forecasts for every city and county as a function of city size and growth history (Teitz 1990), outward expansion potential, and the adoption of specific policies intended to promote or retard growth. The Bottom-Up Population Growth Submodel consists of two linear regression equations, one for cities and one for counties. (See Landis 1994 for the variables, their definitions, and the regression results.) Unlike urban forecasting models, which project local population growth by distributing regional or county growth totals, the CUF Model projects each city's growth as a function of its current size, growth history, and growth policies. The population of each unincorporated area is calculated as the difference between projected county population and the sum of city population projections.
2. *The Spatial Database* is the supply side of the CUF Model. It includes the geometry, location, and attributes of each Developable Land Unit (DLU). It consists of a series of map layers that describe the environmental, land use, zoning, current density, and accessibility characteristics (or attributes) of all sites in the study region or county. These various layers can either be analyzed individually, or merged into a single DLU layer that includes all the relevant attribute information for each resulting DLU polygon.[3] The spatial database is also the primary tool for displaying the results of CUF Model runs in map form. Table 1 lists the map and data layers (and their sources) included in the spatial database.
3. *The Spatial Allocation Submodel* is a series of procedures for allocating projected population growth to appropriate DLUs. The primary function of the Spatial Allocation Submodel is to "clear the market": to match the demand for developable sites (as manifest in city and county population growth) to

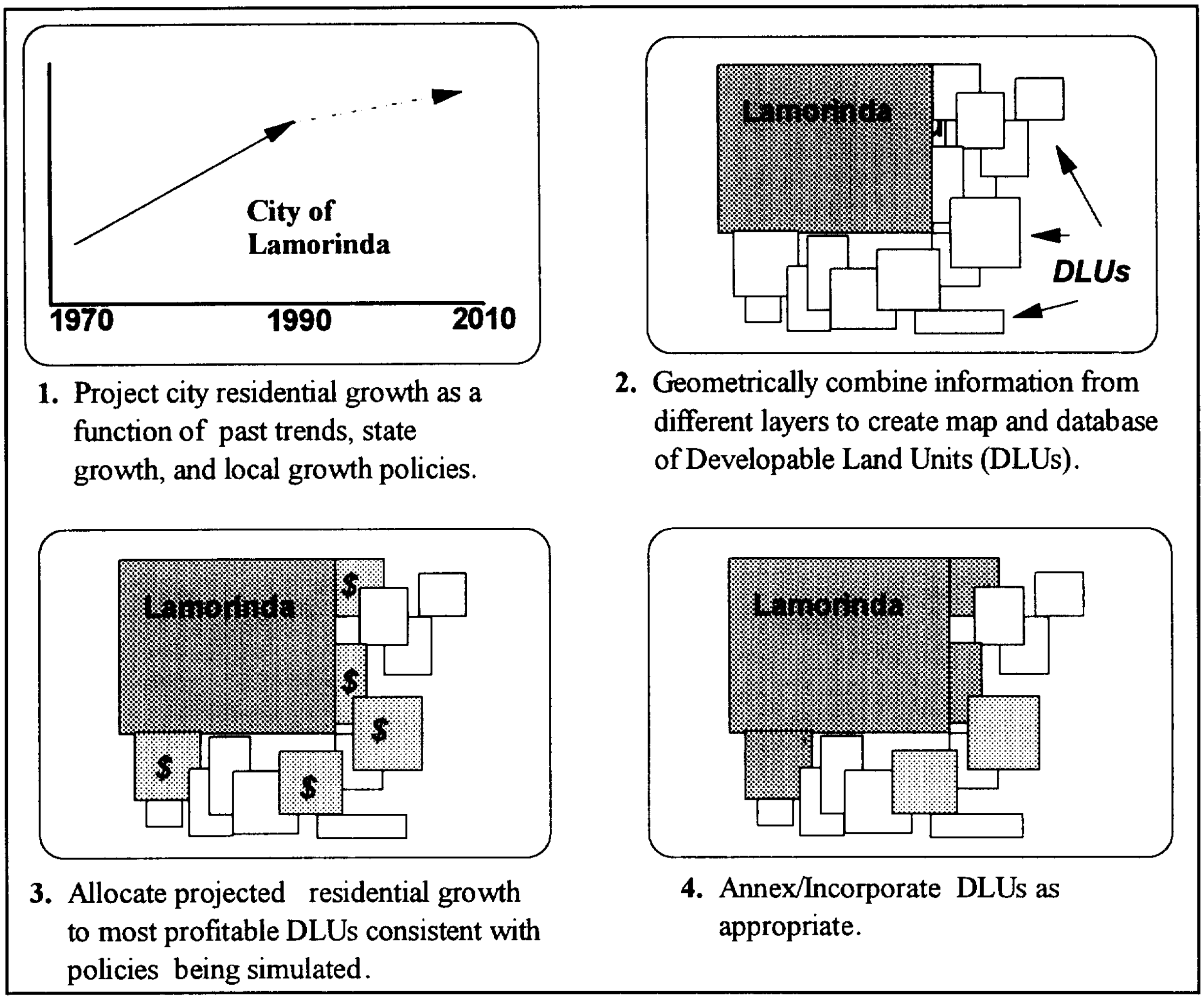

FIGURE 1. The logic of the CUF Model

the supply of developable sites (as described by the attributes, sizes, and location of DLUs).

4. *The Annexation-Incorporation Submodel.* This model is a series of decision rules for annexing newly developed DLUs to existing cities, or for incorporating clusters of DLUs into new cities.

Each run of the Spatial Allocation Submodel involves five steps:

- All undeveloped DLUs in a county are scored according to their potential profitability if residentially developed.
- DLUs that are unsuitable for development for environmental, ownership, or public policy reasons are eliminated from consideration.
- The remaining DLUs (those that may be developed) within each city and its sphere of influence are sorted from high to low in order of their potential profitability if developed.
- Within each city (and its sphere of influence), projected population growth is assigned to DLUs in order of DLU profit potential (from high to low). The choice of population allocation density is left to the user (the default is the current "market" density) and can vary by scenario. After the model has allocated as much population growth as will "fit" into the DLU with the highest profit potential, it moves to the next most profitable DLU, and so on. The allocation process is complete either when all forecast population growth is allocated, or when there is insufficient undeveloped land in the city to accommodate forecast growth. Depending on the land-use policy scenario chosen, the model can collect any unallocated population growth for potential spillover.
- The same procedure is used to allocate forecast county population growth (plus any unallocated spillover growth) to unincorporated county DLUs.

TABLE 1. The spatial database: selected layers

Layer	Source	Data Categories
City Boundaries	U.S. Census Bureau and local cities	
Sphere of Influence Boundaries	LAFCOs and local cities	
Wetlands	U.S. Geological Service	Bay wetlands, nonbay wetlands
Slope (100m × 100m cell)	U.S. Geological Service	0% slope; 1–2%; 3–5%; 6–8%; 9–10%; 11–15%; 19–24%; 25%+
Agricultural Land Type	California Farmland Mapping Project (1986)	Forest, Grazing, Locally-Important, Prime, State-Important, Unique, Other
General Plan Use Category	County and city general plans	Commercial, Industrial-Office, High-, Low-, and Moderate-Density Residential, Locally Extensive, Locally Intensive Agriculture, Diverse Agriculture, Grazing, Open Space, Rural Residential, Rural Resource Development, Urban Residential
Current Land Use (100m × 100m cell)	Association of Bay Area Government (1990)	Commercial, Industrial, Mixed-Use, Mobile Home, Public, Recreation, Low-, Moderate-, and High-Density Residential, Vacant
Major Highways and Roads	U.S. Census Bureau TIGER Files	Interstates, State highways, Major and minor arterials
Site Distance to Nearest City Boundary		Measured using GIS
"Infill" Percentage	U.S. Census Bureau	Calculated using 1980–1990 population growth and density by 1990 census tract
Market Housing Density	TRW-Redi transaction files	Calculated using the median lotsize for new homes built between 1985 and 1990
Typical New Home Price	TRW-Redi transaction files	Calculated using the median sales prices for new homes built between 1985 and 1990
New Home Production Costs	Calculated on the basis of fee and service standard data collected from cities, market size and quality levels, using distance to urban services, estimates of typical delay times, and site-specific slope and yield information	

The allocation process within a county is complete when either all forecast and spillover population growth is allocated, or there is insufficient undeveloped land in the county to accommodate forecast population growth. Unallocated population growth, if any remains, can be accumulated for later reallocation to those counties with remaining developable DLUs.

Implicit in this procedure is the assumption that it is profit-maximizing, private land developers who make the key development location and timing decisions that ultimately shape urban areas. These decisions are subject to governmental land use and environmental regulation (at the state, regional, county, or local levels) and may also be influenced by public infrastructure investments. Following economic theory, we assume land developers and homebuilders to be price-takers with respect to new home sale prices and raw land prices. We further assume that private housing developers will seek to develop or redevelop sites in order of expected profitability in accordance with prevailing or permitted development densities.[4]

Calculations of the profit potential of each DLU are thus a prerequisite to any growth allocation. DLU profit potential is calculated as follows:

Per-acre residential development profit (i,j,k)
= New home sales price (i,j,k)
− Raw land price (j,k)
− Hard construction costs (i,k)
− Site improvement costs (i,j,k)
− Service extension costs (j,k)
− Development, impact, service hookup, and planning fees (k)
− Delay and holding costs (k)
− Extraordinary infrastructure capacity costs, exactions, and impact mitigation costs (j,k).

The subscript i denotes the size and quality level of the typical new home in each community. The subscript j denotes the slope, environmental characteristics, and specific location of the homesite (or DLU). The subscript k denotes the jurisdiction in which the home is located.

All of the parameters in this equation are exogenous, making the model extremely data hungry. Specific estimates of each of these cost items for every city and county in the study region are reported in Pendall and Landis (1994).

Generally speaking, intracity housing cost differentials exceed intercity cost differentials. This is because housing production costs vary more according to site slope and distance to urban infrastructure than according to city. Exactly the opposite is true for profit differentials. Because housing prices vary so much between cities, profit differentials tend to vary much more between cities than within them.

In summary, the CUF Model "grows" each county and its constituent cities by determining how much new development to allocate to each Developable Land Unit during each model period, as a function of the profitability of developing that DLU as housing, the characteristics of the DLU itself, population growth in each city and county, and a series of development scenarios consisting of user-specified development restrictions and/or incentives.

Once the data and parameters required for the Spatial Database and Spatial Allocation Submodel have been assembled, any number of policy scenarios can be easily tested. "Running" a scenario consists of filling out a computerized *Scenario Form* (figure 2) indicating which specific development prohibitions, regulations, or incentives are to be applied in which areas. Each scenario takes about two minutes to run (using a Sun SparcStation LX) per county—even in counties with 30,000 DLUs or more. Most of the time required to run a scenario is for rendering the resulting map.

Model Design Principles

The CUF Model was designed with six practical and theoretical principles in mind.[5] The first was that the structure of the model should be theoretically sound and consistent with observed urban development processes.

A second principle was that the CUF Model should be useful as a policy simulation tool—to examine and contrast the land development implications of a wide variety of growth policy alternatives. Adherence to this principle dictated that the model be sensitive to numerous policy values, and that it be a straightforward procedure to change those values and rerun the model. A related goal was that the model be useful for testing investment-oriented policies (e.g., construction of new transportation or wastewater facilities) as well as regulatory policies (e.g., development prohibitions based on environmental or policy considerations; up- or down-zoning policies; and annexation and incorporation policies).

A third design principle was that the CUF Model should be spatially accurate, that is, capable of simulating metropolitan spatial growth as it actually occurs—site-by-site, city-by-city. In this context, being able to simulate where and at what densities growth is likely to occur is as important as being able to project how much growth is likely to occur. This requirement magnified both the complexity of the CUF Model and the volume of data required to build it.

Fourth, we required that the CUF Model make maximum use of existing information, including both tabular and map-based data. Fifth, we required that the CUF Model be expandable. By this we mean that it be capable of incorporating new information as it becomes available, and new theory as it is developed. To facilitate model updating (as well as to avoid the propagation of potential estimation errors), the CUF Model is designed as a modular system of related but independent submodels. Finally, and perhaps most important, we required that the structure and logic of the CUF Model be understandable to the planners and policy analysts who might use it, not just to the researchers who developed it.

The Heritage of the CUF Model

The CUF Model has a diverse heritage. Some parts of the model, such as the Bottom-Up Population Growth Submodel, are to our knowledge entirely original.[6] Other parts represent extensions and adaptations of previous approaches. The concept, but not the mechanism, of sequential urban development is drawn from the original Lowry Model (Lowry 1964). The idea of Developable Land Units (DLUs)—sites that are homogeneous with respect to specific environmental or policy attributes—was first operationalized by Steinitz and Rogers (1968), and was a key component of the Metland Project at the University of Massachusetts (Fabos 1973; Fabos, Greene, and Joyner 1978).[7] The idea of allocating projected population growth to individual sites (as opposed to zones) in order of their attractiveness to private development was suggested by Weiss, Smith, Kaiser, and Kenney (1966), and further developed by Weiss, Donnelly, and Kaiser (1966). The use of environmental decision rules for growth allocation was popularized and made operational by McHarg in 1969, and has found many applications since. The CUF Model's inclusion of the economics of land development and homebuilding parallels the concepts first put forth as part of the NBER Urban Simulation Model (Ingram, Kain, and Ginn 1972).

Enter the Name of this Scenario: ______________________

A. *Select a population projection:* ABAG | Local | CUF

B. *Choose a transit scenario:*
- Without transit
- With transit

C. *Allow development in wetlands?* No | Yes

D. *Residential infill options:*
- Historic
- Market
- User Defined

E. *Slope restriction on hillside development?* None — Full

F. *Residential development can be assigned to the following farmland types:*
- Grazing
- Locally Important
- Prime
- State Important
- Unique
- Other

G. *Residential development can be assigned to the following General Plan categories:*
- Agriculture
- Land Extensive Agriculture
- Land Intensive Agriculture
- Diversified Agriculture
- Rural Resource
- Public
- Commercial
- Openspace
- Industrial and Office
- Hi-density Residential
- Mod-density Residential
- Lo-density Residential
- Urban Residential

H. *Where do population spillovers go?*
- Unincorporated Areas
- All Areas

I. *Choose a residential density for development in cities:*
- Market
- Historic
- Compact City
- General Plan

J. *Choose a residential density for development in unincorporated areas:*
- Market
- Historic
- Compact City
- General Plan

Do you want to have a report of results? Yes | No

Do you want to view the resulting map? Yes | No

FIGURE 2. Sample form for constructing growth allocation scenarios

Comparisons with Other Operational Urban Forecasting/Simulation Models

The CUF Model differs from most other *operational* urban forecasting/simulation models in a number of significant ways.[8] The first is in its detailed representation of the supply side of urban land and housing markets, and in its use of GIS to assemble and manage the supply side. GIS makes it possible to incorporate a wide variety of available map-based data directly into the model.

A second point of difference is that the CUF Model allocates growth to individual sites, and not into aggregate representations of space such as traffic analysis zones or census tracts. A third point of difference is the importance the CUF Model assigns to residential land developers. The CUF Model assumes that the role of residential land developers is to serve as intermediaries between households (the ultimate demanders of land), and the various suppliers of inputs into the development process. Thus, the CUF incorporates localized differences in the cost and revenue structure of residential land development, and uses that information in a process that mimics decisionmaking by private land developers.[9]

Work-trip travel times (or distances)—the key determinant of growth patterns in the majority of urban growth models—enter the CUF Model only indirectly, as an exogenous determinant of intercity housing price differentials. Last, and perhaps most important, the CUF Model was designed with the specific purpose of making it easy to simulate the development effects of locally-based land-use and development policies. The critical exogenous variables in the CUF Model are development policies, not travel times or distances.

The CUF Model has certain deficiencies in comparison to other urban forecasting and simulation models. In its current form the CUF Model allocates residential growth, but not commercial or industrial growth. Employment growth is treated as exogenous and is specified at the county level. This means that the CUF Model cannot be used to address jobs-housing balance. Because it does not deal explicitly with travel times or costs, the CUF Model is not a spatial-interaction model. Distance and/or travel times are not explicit mediating factors in determining urban structure, as they are in almost all other urban simulation models.

Finally, the CUF Model is not required to reach any sort of equilibrium.[10] Individuals or households in one part of the region or a county may emerge with higher levels of utility than individuals or households in other parts. And in its current version, excess demand, or spillover, does not feed back into housing prices or land costs.

Using the CUF Model for Regional Growth Modeling

This section summarizes the results of the first test of the CUF Model: an analysis of three alternative Year 2010 regional growth policies. The "region," in this example, consists of the nine counties of the San Francisco Bay Area: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma Counties, and five adjoining counties: Santa Cruz, Sacramento, San Joaquin, Stanislaus, and Yolo. The latter counties were included because they are fast-growing in their own right, and to examine the implications of potential spillover growth from the San Francisco Bay Area. The model results are presented in tabular form because the study region is so large that it would be difficult to discern differences from a map.

Three Regional Growth-Policy Scenarios

The three Year 2010 scenarios that were tested are described below.

Scenario A: Business as Usual. This baseline scenario assumes that the development process will continue to be guided entirely by the preferences of the private marketplace (in terms of development densities and potentially profitable development sites), subject to existing, locally-based growth policies (in terms of which uses are permitted where). Growth policies and restrictions would not necessarily be coordinated between neighboring cities or within counties. Hillside and wetland development would be permitted. New development would continue to be permitted in unincorporated areas beyond existing city spheres of influence. Should there be insufficient developable land in a city sphere-of-influence to accommodate projected population growth for that city, the excess would spill over into nearby unincorporated areas.

Scenario B: Maximum Environmental Protection. This scenario assumes the coordinated adoption of stringent environmental protection policies by all city and county governments in the region. Such policies would comprise:

- A prohibition on the development of hillsides with slopes in excess of 15 percent
- A prohibition on the development of all areas currently identified as wetlands, regardless of their seasonal status
- A prohibition on the development of all incorporated and unincorporated lands currently designated under the California Farmland Mapping Project as being "prime agricultural," "unique,"

"of locally-designated importance," and "of state-designated importance"

- Changes to local zoning ordinances to require that the average density of new home construction be equivalent to existing average residential densities. Under this scenario, cities would grow at their historical densities rather than those determined in the marketplace.

Scenario C: Compact Cities. This scenario assumes the county-wide adoption of policies designed to promote compact and contiguous development forms. It is based on the view that new residential development should occur only in and around existing urban areas. To promote such a goal, this scenario assumes the region-wide adoption of three sets of polices:

- That all new residential development occur at an average density of 4,500 persons per square kilometer (approximately 18 persons per acre) or greater
- That all cities adopt a policy of accommodating 20 percent of their projected population growth in the form of "infill" (developable or redevelopable parcels within city boundaries)
- That counties adopt policies designed to direct new development in unincorporated areas to within 1,000 meters of existing city boundaries, or within city spheres of influence.

In terms of environmental protection, this scenario would prohibit hillside and wetland development. It would also limit the development of agriculturally sensitive lands to sites currently within existing city spheres of influence.[11] Spillover growth, should any occur, would be channeled into predesignated "new towns," currently consisting of freestanding, unincorporated clusters of residential development.

Computer models such as the CUF Model are not particularly adept at interpreting policies such as those outlined above. To make policies understandable to a computer, they must first be transformed into "rule inputs." The three scenarios described above were coded into four sets of rule inputs, presented in outline form in table 2.

In terms of implementation, all three policy scenarios are quite reasonable. Even the most stringent policy scenario, *Scenario C: Compact Cities,* calls for only modest increases in residential densities (in the Bay Area, for example, from the existing average of 5.5 units per acre to 7.5 units per acre) and infill levels. Such changes could be readily accomplished by adopting "density floors" as part of local zoning ordinances.[12] And while absolute prohibitions on the development of steep slopes and wetlands (*Scenario B: Maximum Environmental Protection,* and *Scenario C: Compact Cities*) might seem extreme to some, in reality most steeply sloped areas and many wetland parcels are not particularly attractive to residential developers. Thus, such prohibitions would have only a marginal effect overall on land supplies.

Although these three policy scenarios may be programmatically feasible, they are probably not politically, or even constitutionally feasible—at least not yet (Sanders 1989). Repeated suggestions of regional government aside, there are currently no planning agencies or institutions anywhere in California able to coordinate zoning and land-use policies among cities, let alone among counties. Except for a few counties such as Contra Costa and San Diego, California jurisdictions continue to pursue land-use policies and zoning in near perfect isolation from one another. Indeed, many California communities still compete with each other to attract revenue-rich land uses. Still, political winds do shift: the fact that an otherwise beneficial policy is not politically feasible under the current system of metropolitan governance should not rule out its consideration.

Model Results—Business as Usual

Scenario A: Business as Usual, assumes that regional development patterns will continue to be shaped through a patchwork of local general plans and zoning regulations, and that no attempt will be made to coordinate land use or environmental regulations across existing units of government. For the entire 14-county study region, a total of 162,964 acres of currently undeveloped land would be required to accommodate projected population growth in the year 2010 (table 3). Given current policy and market trends, new development would occur at an average density of 18 persons per acre.

Projections of additional land consumption vary sharply by county. On the high end, a combination of significant population growth and fairly low densities would mean that 23,375 additional acres of Contra Costa County and 20,509 additional acres of Sonoma County would be developed by the year 2010. By contrast, in Santa Clara County, where new residential densities are considerably higher than in either Contra Costa or Sonoma Counties, a greater increment of population growth may be accommodated on far less land (11,860 additional acres). Higher average densities would also lead to comparatively less land development in Alameda County (12,306 acres) and Marin County (4,991 acres). Exactly the opposite would be true in Napa County, where, as a result of low residential densities, more than 8,772 additional acres would be developed by the year 2010 despite only modest population growth.

Under *Scenario A,* nearly half of the land required

TABLE 2. Summary of regional growth allocation decision rules, by scenario

Allocation Rule	Scenario A: Business as Usual	Scenario B: Maximum Environmental Protection	Scenario C: Compact Cities
Development Prohibitions	None	1. 15% slope and greater 2. Wetlands 3. All prime and unique agricultural lands	1. 15% slope and greater 2. Wetlands 3. Prime and unique agricultural lands outside city spheres of influence
Residential Allocation Densities	1985–90 market (varies by city)	Avg. City Density (varies by city)	Countywide minimum
Share of City Population Growth Allocated as Infill	1980–90 share (varies by city)	1980–1990 share (varies by city)	20% minimum
City Spillover Growth (if any) Allocated to:	Unincorporated areas	Unincorporated areas	Pre-designated "new towns"
Growth in Unincorporated Areas Allocated to:	Unincorporated areas	Unincorporated areas	Unincorporated areas

TABLE 3. CUF Model results: land development requirements for different policy scenarios

			Additional Acres Required for Development			Average Growth Density (in persons per acre)		
County	Existing Developed Acreage 1990	Forecast Population Growth: 1990–2010	Scenario A: Bus. as Usual	Scenario B: Max. Env. Prot.	Scenario C: Compact Cities	Scenario A: Bus. as Usual	Scenario B: Max. Env. Prot.	Scenario C: Compact Cities
Alameda	135,732	258,030	12,306	12,602	8,624	21.0	20.5	29.9
Contra Costa	132,841	305,322	23,376	19,051	11,935	13.1	0.0	25.6
Marin	40,500	107,533	4,991	5,708	2,693	21.5	18.8	39.9
Napa	18,705	81,948	8,772	6,252	3,830	9.3	13.1	21.4
Sacramento	133,483	398,261	27,972	28,367	23,079	14.2	0.0	17.3
San Francisco	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
San Joaquin	43,094	262,478	11,638	9,291	9,316	22.6	0.0	28.2
San Mateo	72,573	58,847	49	49	49	N/A	N/A	N/A
Santa Clara	177,121	362,234	11,861	8,031	10,230	30.5	45.1	35.4
Santa Cruz	27,552	151,858	13,146	14,282	6,721	11.6	0.0	22.6
Solano	42,847	158,027	8,080	6,375	5,090	19.6	24.8	31.0
Sonoma	60,292	302,724	20,509	19,521	17,272	14.8	15.5	17.5
Stanislaus	43,885	349,537	16,630	12,750	14,851	21.0	0.0	23.5
Yolo	22,115	62,524	3,682	5,189	3,089	17.0	0.0	20.2

to accommodate projected population growth in the four Central Valley counties of Sacramento, San Joaquin, Stanislaus, and Yolo would be in Sacramento County—despite the fact that only 38 percent of projected population growth in the four counties would occur in Sacramento County. This is so because Sacramento County is likely to develop at significantly lower densities than either San Joaquin or Stanislaus counties. Given the continuation of current trends and current policies, Sacramento County will develop at an incremental density of 14.2 persons per acre—a level far below that of San Joaquin County (22.6 persons per acre) or Stanislaus County (21.0 persons per acre). Yolo, the fourth county in the region, would also develop at comparatively low population densities (17.0 persons per acre). What's behind such sharp differences in density? During the past few years, planners and elected officials in San Joaquin and Stanislaus counties have been busy encouraging (and in some cases requiring) builders to develop at higher densities, and in locations adjacent to existing development. This has not been the case in Sacramento and Yolo Counties.

Acreage totals and gross densities can be difficult to understand. To put the various land conversion estimates into context, we compared them with existing levels of urbanization. The biggest relative gainers under *Scenario A* would be Santa Cruz and Napa counties, which would see their urbanized land totals rise by 47.7 percent and 46.1 percent, respectively, by the year 2010. Other counties with big percentage gains would be Stanislaus (+37.9 percent), Sonoma (+34 percent), and San Joaquin (+27 percent). At the other end of the spectrum, projected new development by the year 2010 would increase the amount of urbanized land area by only .1 percent in San Mateo County, and by 6.7 percent in Santa Clara County. Increases in urbanization levels in the remaining counties would range from 16.6 percent (Yolo County) to 21 percent (Sacramento County).

The ability of individual cities to accommodate additional residential development within their existing spheres of influence would also vary by county. In Marin and Santa Clara Counties, for example, all projected new residential development could be accommodated within existing city spheres of influence. Under *Scenario A: Business as Usual,* more than 90 percent of projected residential development in Alameda, Contra Costa, and Solano Counties could be accommodated within the boundaries of existing spheres of influence. By contrast, because they do not contain adequate growing room, existing city spheres of influence in Napa and Sonoma counties could accommodate only 27 percent and 23 percent, respectively, of projected new residential development.

In Stanislaus and San Joaquin counties, where the boundaries of spheres of influence are used as a policy mechanism to guide new development, 92 percent and 88 percent, respectively, of anticipated new residential development would occur within existing sphere boundaries. In Sacramento County, by way of contrast, only 42 percent of new residential development would occur within the boundaries of existing spheres of influence. Continuing a longstanding trend, the majority of Sacramento County's projected residential development would occur in currently unincorporated areas outside existing spheres. In Yolo County, nearly 80 percent of projected new residential development would occur within existing spheres of influence.

Model Results—Maximum Environmental Protection

Scenario B: Maximum Environmental Protection assumes the regionwide adoption of environmental protection policies that would prohibit the development of hillsides, wetlands, and prime and/or unique agricultural lands located outside existing city spheres of influence. By themselves, environmental protection policies may not deter urban sprawl. Indeed, depending on the location, they may in fact contribute to it.

In order to reduce overall land consumption, *Scenario B* stipulates that cities and counties amend their zoning ordinances and general plans to provide for minimum "density floors," meaning that the average density of every new residential development would have to exceed some specific level. In this scenario, that level is arbitrarily set to the current average residential density of each city. Consistent with the land and environmental conservation theme of this scenario, any city-based population growth that could not be allocated within the corresponding city sphere of influence would remain unallocated. Such a policy would, in essence, turn the existing boundaries of spheres of influence into fixed urban limit lines.

Implementing *Scenario B* would lead to both more and less land conversion than would *Scenario A,* depending on the county (table 3). In Contra Costa County, for example, land conversion would decline from 23,376 acres under *Scenario A* to 19,051 acres under *Scenario B.* In Napa County, 6,252 acres would be needed under *Scenario B* to accommodate projected population growth for the year 2010, as compared with 8,772 acres needed under *Scenario A.* Comparing land conversion in Santa Clara, Solano, and Sonoma counties also reveals declines in land consumption for *Scenario B* as compared to *Scenario A.* By contrast, urban land conversion would increase in Alameda and Marin counties under *Scenario B.* This is so because the policies proposed under *Scenario B* would preempt sites in those counties that, had they been developed (as under *Scenario A),* would have been developed at higher densities.

A similar pattern emerges in the Sacramento-San Joaquin-Stanislaus-Yolo area. Because it would shift development outward from parcels that are environmentally sensitive but contiguous to existing development, *Scenario B* would actually result in greater land consumption in Sacramento and Yolo counties than would *Scenario A.* In the former case, the difference in required land between the two scenarios is quite small: less than 400 acres. In the latter case, the difference is far more significant: 1,500 acres. Land consumption in Stanislaus and San Joaquin counties, by contrast, would decline significantly under *Scenario B,* because the development displaced from lower-density, environmentally sensitive sites would be redirected to less sensitive and higher-density sites.

This result—that environmental protection policies may either encourage or discourage land consumption, depending on the county—is also revealed by a comparison of incremental densities and development locations. For example, in Contra Costa, Napa, Santa Clara, San Joaquin, Solano, Sonoma, and Stanislaus counties, the average densities of new development are higher under *Scenario B* than under *Scenario A*. By contrast, in Alameda, Napa, Sacramento, and Yolo counties, they are somewhat lower.

Model Results—Compact Cities

Scenario C: Compact Cities embodies the view that new residential development should occur only in and around existing urban areas. If implemented, the policies proposed under *Scenario C* would result in significant reductions in land consumption as compared with *Scenario A: Business as Usual* (table 3). These reductions would arise in two ways. First, cities where there is currently no infill development would be required to steer 20 percent of their projected growth into infill sites. This would significantly reduce pressures for land consumption at the urban fringe. Second, cities where the only form of new development is very low-density housing would be required to promote a greater mix of residential densities. As with *Scenario B*, such a requirement could take the form of density floors, averaged across larger projects.

Comparing *Scenario C* with *Scenario A* shows a 35-percent reduction in land conversion in the nine counties that have traditionally defined the Bay Area, and a 16 percent reduction in Sacramento, San Joaquin, Stanislaus, and Yolo counties. Because the same number of new residents would be accommodated on less land, incremental densities would rise: to 26.9 persons per acre of new residential development in the nine-county Bay Area (up from 17.3 persons per acre), and to 21.3 persons per acre in the Sacramento-San Joaquin-Stanislaus-Yolo area (up from 17.9 persons per acre).

Among Bay Area counties, land consumption would be reduced by more than 50 percent in Contra Costa, Santa Cruz, and Napa counties, and by a third or more in Marin, Alameda and Solano counties. The reduction in land conversion would be less significant—although readily observable—in Santa Clara and Solano counties. Following the downward trend in land consumption, incremental development densities would rise the most in Contra Costa, Santa Cruz, and Napa Counties.

Because development forms are already fairly compact in three of the four counties of the Sacramento-San Joaquin-Stanislaus-Yolo area, *Scenario C* would have less effect in this area than in the nine-county Bay Area. As compared with *Scenario A*, urban land conversion would fall 20 percent in San Joaquin County, 18 percent in Sacramento County, 17 percent in Yolo County, and 11 percent in Stanislaus County. Average incremental densities would increase by two to three persons per acre in all four counties. Finally, as in the nine-county Bay Area, *Scenario C* would shift relatively little development in these four counties back into a current sphere of influence.

The Urbanization of Environmentally Sensitive Lands

Growth invariably affects the natural environment. Urban development consumes land previously used for farming, forestry, or open space. It disrupts local ecosystems, and adds to air and water pollution. Exactly how growth impacts the natural environment depends on much more than the amount of growth; it also depends on the form, pattern, and location of growth. For example, growth policies that promote new development close to existing urban areas would generate far different environmental impacts than would growth policies that encourage decentralization. Because it allocates growth on a site-by-site basis, the CUF Model is uniquely suited to examining the environmental impacts associated with different development forms.

Table 4 summarizes how much land of different types would be developed in the Greater Bay Region under each of scenarios *A: Business as Usual; B: Maximum Environmental Protection; and C: Compact Cities.* For four different land characteristics, the results under each scenario are shown in table 4. The land characteristics comprise: (1) the amount of acreage projected to be developed within 1,000 meters of existing urban development; (2) the acreage of projected development on hillsides with slopes of five percent or more; (3) the amount of wetland acreage projected to be developed; and (4) the amount of land projected to be developed that is currently designated as prime agricultural, of state importance, or locally unique.

Development Within 1,000 Meters of an Existing Urban Area

Regardless of the policy scenario chosen, most of the new development projected for the study area will occur within 1,000 meters of existing urban development. Compared to *Scenario A: Business as Usual*, compact growth policies (*Scenario C*) would tend to increase the level of contiguous urban development, but environmental preservation policies *(Scenario B)* would tend to reduce contiguous development.

To illustrate, consider the cases of Alameda and Stanislaus counties. In Alameda County, 98 percent of new development would occur within 1,000 meters of an existing area under both *Scenarios A and C*. Under *Scenario B*, by contrast, the share of Alameda County's growth that would occur within 1,000 meters of an existing urban area would fall to 91 percent. In Stanis-

TABLE 4. Environmental characteristics of developed land for Scenarios A, B, and C, by county*

County	2010 Scenario	Additional Acreage Required	Acreage of Newly Developed Land: within 1,000m of Urban Area	>5% Slope	on Desig. Wetlands	on Agriculturally Sensitive Land
Alameda	Scenario A: Bus. as Usual	12,306	12,041	9,148	225	271
	Scenario B: Max. Env. Protect.	12,602	11,475	8.651	0	0
	Scenario C: Compact Cities	8,624	8,473	6,711	0	383
Contra Costa	Scenario A: Bus. as Usual	23,376	22,135	5,520	2,392	3,239
	Scenario B: Max. Env. Protect.	19,051	12,931	2,263	0	0
	Scenario C: Compact Cities	11,934	10,205	919	0	1,003
Marin	Scenario A: Bus. as Usual	4,991	4,991	482	1,497	10
	Scenario B: Max. Env. Protect.	5,708	5,708	865	0	0
	Scenario C: Compact Cities	2,693	2,693	329	0	10
Napa	Scenario A: Bus. as Usual	8,772	8,181	25	796	1,507
	Scenario B: Max. Env. Protect.	6,251	6,103	237	0	0
	Scenario C: Compact Cities	3,830	3,830	0	0	308
Sacramento	Scenario A: Bus. as Usual	27,972	25,244	0	1,636	11,231
	Scenario B: Max. Env. Protect.	28,367	8,886	0	0	0
	Scenario C: Compact Cities	23,079	21,754	0	0	2,767
San Joaquin	Scenario A: Bus. as Usual	11,639	11,639	0	132	10,445
	Scenario B: Max. Env. Protect.	9,291	5,286	0	0	0
	Scenario C: Compact Cities	9,316	9,177	0	0	7,824
Santa Clara	Scenario A: Bus. as Usual	11,861	11,858	1,188	678	5,347
	Scenario B: Max. Env. Protect.	8,030	7,996	998	0	0
	Scenario C: Compact Cities	10,229	10,194	570	0	5,145
Santa Cruz	Scenario A: Bus. as Usual	13,146	12,790	465	0	3,017
	Scenario B: Max. Env. Protect.	14,282	13,697	986	0	0
	Scenario C: Compact Cities	6,721	6,465	365	0	98
Solano	Scenario A: Bus. as Usual	8,080	8,080	0	343	2,029
	Scenario B: Max. Env. Protect.	6,375	5,046	0	0	0
	Scenario C: Compact Cities	5,090	5,080	0	0	1,518
Sonoma	Scenario A: Bus. as Usual	20,509	19,691	48	1,662	6,972
	Scenario B: Max. Env. Protect.	19,520	18,659	60	0	0
	Scenario C: Compact Cities	17,272	16,406	47	0	502
Stanislaus	Scenario A: Bus. as Usual	16,630	15,177	0	0	13,015
	Scenario B: Max. Env. Protect.	12,750	6,333	10	0	0
	Scenario C: Compact Cities	14,850	12,511	0	0	10,415
Yolo	Scenario A: Bus. as Usual	3,682	3,682	0	1,048	2,598
	Scenario B: Max. Env. Protect.	5,189	4,702	0	0	0
	Scenario C: Compact Cities	3,088	3,088	0	0	1,611
Total	Scenario A: Bus. as Usual	162,964	155,510	16,874	10,409	59,681
	Scenario B: Max. Env. Protect.	147,416	106,823	14,071	0	0
	Scenario C: Compact Cities	116,726	109,878	8,942	0	31,583

*Because detailed environmental data were not available for San Francisco and San Mateo counties, they do not appear in the table.

laus County, the pursuit of environmental protection policies without also encouraging compact growth would reduce the share of new development contiguous to existing urban areas from 91 percent to 50 percent. Although the magnitude of this effect differs sharply among counties, these dynamics are generally the same: by protecting close-in, environmentally sensitive sites from the developers' bulldozer, environmental preservation policies would tend to displace growth outward, where it would occur at slightly lower densities.

Across the region, shifting from current policies (*Scenario A*) to environmental protection policies (*Scenario B*) would reduce the amount of land developed within 1,000 meters of existing urban areas from 155,510 acres to 106,823 acres. Shifting to policies that favor compact growth (*Scenario C*) would reduce the amount of land developed within 1,000 meters of existing urban areas to 109,878 acres; however, most of this reduction in land consumption would result from higher densities.

Hillside Development. Except where they can get premium prices for views, private developers prefer not to build on hillsides. Houses built on hillsides cost more to build than do those built on flat sites, and they require more extensive and costly infrastructure. Because of unfavorable economics, only a small share of projected new residential development in the study area would occur on hillsides, even without further regulation. Even in Marin and Santa Clara counties, both of which lack level development sites, hillside development would account for less than ten percent of newly developed residential acreage by the year 2010. The hillside acreage consumed by new residential development would be similarly minimal in Napa, Sacramento, San Joaquin, Santa Cruz, Solano, Sonoma, Stanislaus, and Yolo counties. Only two counties, Alameda and Contra Costa, will continue to experience intense pressure for hillside development. Regionwide, hillside development would total 16,874 acres under *Scenario A: Business as Usual,* 14,071 acres under *Scenario B: Maximum Environmental Protection,* and 8,942 acres under *Scenario C: Compact Cities.*

Wetlands Development. The term "wetlands" covers a wide variety of site types. Some wetlands are almost continually underwater. Other wetlands are wet for only a few days a year. Development of this latter wetland type is not particularly costly, and requires only minimal drainage improvements and regrading.

Cost issues aside, not all wetland areas in the study area are threatened by urban development. Three counties, San Francisco, Santa Cruz, and Stanislaus, include virtually no wetland areas. In three other counties, Alameda, Santa Clara, and Solano, the number of wetland acres threatened by imminent urban development is quite small. Existing environmental protection policies already limit the development of bayfront wetland areas in Napa and San Mateo counties. Only in Contra Costa, Marin, Sacramento, San Joaquin, Sonoma, and Yolo Counties does urban development currently threaten large amounts of wetland acreage. Under *Scenario A: Business as Usual,* almost 2,400 acres of wetlands in Contra Costa County would be converted to residential uses by the Year 2010. Under the same scenario, 1,662 wetland acres in Sonoma, and 1,636 wetland acres in Sacramento County would be developed. And in Marin, Yolo, and Napa counties, the pursuit of current policies would mean the ultimate development of 1,497, 1,048, and 796 acres of wetlands, respectively.

Under *Scenarios B: Maximum Environmental Protection* and *C: Compact Cities,* none of these wetland areas would be available for development. Implementation of either of these two policy scenarios would preserve more than 10,000 acres of wetland area throughout the Greater Bay Area.

Agriculturally Sensitive Lands. Because of the importance of agriculture to the California economy, the urbanization of agricultural lands has long been a major public policy concern within the state. Currently, and notwithstanding initiatives to the contrary, the protection of agriculturally sensitive lands is entirely a matter of local zoning policy.

In 1986, the California Farmland Mapping Project inventoried all lands suitable for agricultural use in California and divided them into five categories: (1) prime agriculture, (2) agricultural lands of state importance, (3) agricultural lands of local importance, (4) unique agricultural lands, and (5) field and grazing lands. Land was classified on the basis of current use, soil quality, and slope. As noted earlier, this inventory is a key layer in the CUF Model's spatial database.

As in the case of wetlands, the threat to agricultural lands varies widely by county. Not surprisingly, it is in the Central Valley that urbanization poses the biggest threat to agricultural lands. In San Joaquin County, for example, more than 90 percent of projected urban development under *Scenario A: Business as Usual,* would occur on prime agricultural lands, unique agricultural lands, and agricultural lands of state importance. In Stanislaus County, more than 85 percent of projected new development would occur on agriculturally sensitive lands. In Yolo and Sacramento counties, 71 percent and 44 percent, respectively, of projected urban development would occur on agriculturally sensitive lands. Among Bay Area counties, agriculturally sensitive lands are most at risk under *Scenario A* in Sonoma County (6,972 acres, or 34 percent of newly developed land), Contra Costa County (3,240 acres, or 14 percent of newly developed land), Santa Cruz County (3,017 acres, or 23 percent), and Solano County (2,030 acres, or 25 percent of newly developed land). Only in Alameda, Marin, San Francisco, and San Mateo counties does urbanization not pose a significant threat to agriculturally sensitive lands.

Scenario B: Maximum Environmental Protection assumes the adoption of policies that would prohibit the development of agriculturally sensitive lands. If adopted, such policies would substantially alter the pattern of new development, especially in the Central Valley. Generally speaking, new development in Sacramento, San Joaquin, and Stanislaus counties would be shifted eastward, from the fertile and flat areas between Interstate 80 and Highway 99, toward the Sierra foothills. In none of these counties, however, would prohibiting the development of agriculturally sensitive lands impose an absolute limit on the supply of developable sites.

Under *Scenario C: Compact Cities,* local governments would require developers to build at somewhat higher residential densities and in locations contiguous to existing development. The extent to which such policies would also serve to preserve agriculturally sensitive lands would vary by county. In Stanislaus County, for example, adopting policies consistent with *Scenario C* would result in the preservation of 3,587 acres of agriculturally sensitive land. Similar policies adopted throughout San Joaquin County would result in the preservation of 2,621 acres of agriculturally sensitive land. The same policy shift in Sacramento and Yolo Counties would result in the preservation of 8,464 and 988 acres, respectively, of agriculturally sensitive land. Across the study area, shifting from current policies (*Scenario A*) to polices favoring environmental protection (*Scenario B)* would save nearly 60,000 acres of agriculturally sensitive lands—most of which are currently classified as prime agricultural lands. Shifting to policies that favor compact growth forms (*Scenario* C) would save about 21,800 acres of agriculturally sensitive lands throughout the region.

Summary of Regional Choices

The CUF Model provides a window into the processes of growth and development in the San Francisco Bay and Sacramento areas. By doing so, it also provides fresh insights into the growth planning choices those areas face:

1. There is ample developable land to accommodate projected population growth in the San Francisco Bay and Sacramento areas without unduly harming environmental and sensitive lands. With careful planning, accommodating growth and environmental protection need not be mutually exclusive goals.
2. Because growth potential, land forms, and the economics of development vary widely by city and by county, any single set of development policies applied uniformly throughout regions as large as the San Francisco and Sacramento areas will have vastly different effects in different locations. For example, the same environmental protection policies that reduce urban land conversion in one county may increase it in another.
3. Policymakers must realize that growth, like money, is "fungible." Restricting it in one jurisdiction will almost always cause it to spill over into a different jurisdiction.
4. "Reasonable" compact growth policies (such as those articulated in *Scenario C*) could significantly reduce the amount of undeveloped land needed to accommodate projected population growth in the San Francisco and Sacramento areas. Such policies would not seek to substitute apartment buildings and urban lifestyles for single-family houses and suburban living. Nor would they promote the total infill and "densification" of existing urban areas. Instead, they would promote small but significant increases in residential densities (leaving it up to the community and developer to decide exactly how to meet policy standards), while also encouraging suburban communities to create new infill opportunities.

Using the CUF Model for County and Local Growth Planning

Although originally designed as an aid to regional growth planning, the CUF model can also be used at the subregional, or county, level. This section summarizes the use of the CUF Model to examine the development impacts of Measure A, a farmland preservation ordinance adopted in Solano County in 1984, and just recently renewed. This analysis was undertaken as a pilot study in cooperation with the Association of Bay Area Governments, and substitutes their population projections for those of the CUF Model (ABAG 1990).

Solano County Growth Context and Policy Scenarios

Situated midway between San Francisco and Sacramento, Solano County is currently one of the Bay Area's growth hot spots. According to the Association of Bay Area Governments, the population of Solano County is projected to grow by 201,000 persons by the year 2010. The majority of the county's growth would occur in three cities, Fairfield (+68,127), Vacaville (+44,571), and Vallejo (+29,830).

Like most parts of California, Solano County and its constituent cities are somewhat schizophrenic about growth. Solano residents and officials want job growth and economic development, but are concerned about the impacts of growth on the natural and the historic environments. In recent years, Solano County has witnessed the widespread conversion of agricultural land to urban uses. To slow the rate of farmland conversion, Solano County residents enacted Measure A by initiative in 1984. Measure A does two things. First, it prohibits urbanization of unincorporated county lands outside existing city spheres of influence.[13] Second, and more significantly, it limits the density of new development on county lands that the county general plan designates as used for either "intensive agriculture" or "extensive agriculture."[14] Because such lands cannot be intensively developed, the effect of Measure A has been to make them less attractive to large-scale subdividers and homebuilders. Before it was reenacted in 1994, Measure A was set to expire in 1995. How would development patterns in Solano County have changed had Measure A not been reenacted?

Solano County is similar to other developing California communities in another respect: Under current zoning, the supply of vacant land reserved for future commercial and service growth far exceeds the likely demand. The supply of land reserved for housing, by contrast, tends to lag behind demand. How would development patterns in Solano County change if some sites currently reserved for commercial uses were made available for housing development? Four policy scenarios developed for Solano County explore these possibilities (table 5):

1. *Solano Scenario One* assumes that the current land use designations in the general plan would remain in place, and that Measure A (limiting the density of development on extensive and intensive agricultural lands to 40 acres and 80 acres per dwelling unit, respectively,) would be reenacted in 1995. This is the status quo.
2. *Solano Scenario Two* assumes that the current land-use designations in the general plan would remain in place, but that Measure A would expire in 1995. This would open many lands in agricultural use to more intense development. Whether a particular site were developed would depend on its profitability in residential use.
3. *Solano Scenario Three* assumes that the current land use designations in the general plan can be changed, and that Measure A would expire in 1995. The effect of this change would be to open many agricultural parcels to more intense development, as well as to allow residential development on commerce-designated and agricultural sites. As with *Scenario Two,* above, whether a particular site were subsequently developed would depend on its profitability in residential use.
4. *Solano Scenario Four* assumes that current general plan designations can be changed, but that Measure A would remain in place. This would allow residential development on commerce-designated and agricultural sites (within city spheres of influence), but limit the density of development on intensive and extensive agricultural sites.

Simulation Results

None of these four policy scenarios would displace development from Solano County; in all four cases, there is more than enough developable land in Solano County to accommodate projected population growth. Under *Scenarios Two* and *Three* (in which Measure A is allowed to expire in 1995), each Solano County city would be able to accommodate its projected level of growth within its current sphere of influence. Growth would not be displaced from one community to another.

The same cannot be said for *Scenarios One* and *Four,* in which Measure A is assumed to remain in effect through 2010. The cities of Benicia and Suisun City both contain extensive farmlands that would be precluded from urban development under Measure A, so both cities would become large growth exporters (table 6). Benicia would export 12,032 residents to other parts of the county, while Suisun City would export 6,620 residents. Most of this displaced growth would spill over into Vallejo, whose population would increase by an additional 16,386 residents. Dixon is the other Solano county city that would be a large net importer of growth under *Scenario One.* The same pattern, albeit at a reduced level, is also evident under *Scenario Four* (Measure A in effect, current general plan limits released): Benicia and Suisun City would export growth to Vallejo.

A picture, as the saying goes, is worth a thousand words; and one of the useful aspects of the CUF Model is its ability to present results in easy-to-understand

TABLE 5. Summary of Solano County land-use and development scenarios for year 2010

Scenario	Land Development Prohibitions: Environmental Characteristics	Land Development Prohibitions: General Plan/Zoning Prohibitions	Growth Allocation Densities: Urban Areas	Growth Allocation Densities: Agricultural Areas (Measure A)	Spillover Growth Allocated to:
Current GP and Measure A remain.	Wetlands, Slopes > 15%	Public uses, commercially-zoned, office and industrial, open space, watershed	General-Plan-based	Limited by Measure A	Anywhere in Solano County
Current GP remains. Measure A expires.	Wetlands, Slopes > 15%	Public uses, commercially-zoned, office and industrial, open space, watershed	General-Plan-based	General-Plan-based	Anywhere in Solano County
Current GP and Measure A both expire.	Wetlands, Slopes > 15%	Public uses, open space	Market-based	Market-based	Anywhere in Solano County
Measure A without current GP.	Wetlands, Slopes > 15%	Public uses, open space	Market-based	Limited by Measure A	Anywhere in Solano County

TABLE 6. Summary of Solano County year 2010 growth projections and allocations by city and scenario

City	Population Growth to be Allocated 1990–2010*	Scenario 1: Allocated Population	Scenario 1: Spillover (+: exporter −: importer)	Scenario 2: Allocated Population	Scenario 2: Spillover (+: exporter −: importer)	Scenario 3: Allocated Population	Scenario 3: Spillover (+: exporter −: importer)	Scenario 4: Allocated Population	Scenario 4: Spillover (+: exporter −: importer)
Benicia	14,644	2,612	12,032	14,644	0	14,644	0	11,435	**3,209**
Dixon	5,763	7,402	*−1,639*	5,763	0	5,763	0	5,763	0
Fairfield	40,876	41,078	*−202*	40,876	0	40,876	0	40,876	0
Rio Vista	0	0	0	0	0	0	0	0	0
Suisun City	11,140	4,520	6,620	11,140	0	11,140	0	7,245	**3,895**
Vacaville	22,285	22,710	*−425*	22,285	0	22,285	0	22,285	0
Vallejo	7,457	23,843	*−16,386*	7,457	0	7,457	0	14,561	*−7,104*
Unincorporated	10,149	10,149	0	10,149	0	10,149	0	10,149	0
Total	112,314	112,314	0	112,314	0	112,314	0	112,314	0

Source: Association of Bay Area Governments, *Projections '92*
*Estimates do not include 88,624 residents allocated to infill areas.

map form. Figures 3 and 4 graphically compare projected development patterns under *Solano Scenarios One* (which would maintain Measure A and current zoning designations) and *Two* (which would allow Measure A to expire but maintain current zoning designations). Existing urban development is indicated in light gray. Projected new development is indicated in dark gray.

Under *Solano Scenario One* (figure 3: Measure A and current general plans remain in place), new, lower-density, single-family residential development (defined as fewer than six persons per acre) would be focused (1) along the northern edge of Fairfield, east of I-80; (2) along the eastern and northern edges of Vacaville; and (3) along Dixon's northwestern edge, south of I-80. Somewhat higher-density, single-family subdivisions would be concentrated (1) along the eastern edge of Vallejo, and, (2) in the West Fairfield-Cordelia Junction area. Although most of the residential development anticipated under *Scenario One* would not be far from I-80, very little new development would actually front on the interstate.

Except in Vacaville, the pattern of development

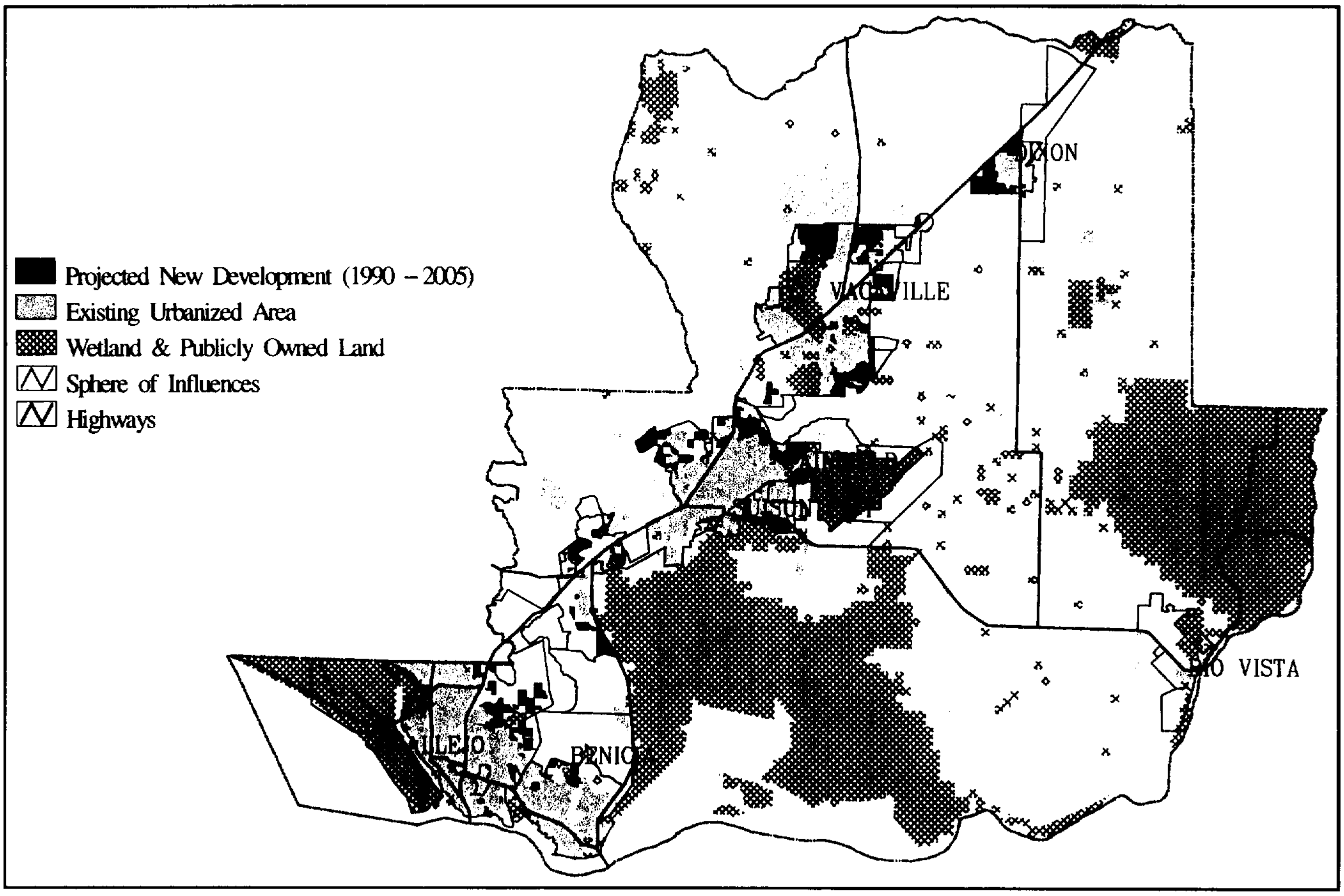

FIGURE 3. Solano Scenario One: Current General Plan; Measure A remains in force.

under *Scenario Two* (figure 4: Measure A expires but current general plans remain in place) would be very different from that under *Scenario One*. Specifically, new, single-family, residential development would be concentrated in eastern Fairfield instead of northern Fairfield, and in southeastern Dixon instead of northwestern Dixon. New residential development would also be scattered among the hills and valleys north of Benicia. Eastern Vallejo would remain relatively undeveloped. The pattern of new residential development under *Scenario Three* (Measure A expires/ current general plan limits are released) would be very similar to that under *Scenario Two*.

Summary: How and Why Measure A Works

There can be little doubt from these simulations that Measure A is achieving its desired effect of preventing many hundreds of acres of exurban agricultural land and open space from being intensely urbanized. (Measure A was designed to protect areas in active agricultural use; the extent to which it actually protects agriculture as opposed to general open space varies by city and county area). Removing Measure A, as suggested under *Scenarios Two* and *Three*, would lead to the suburban development of thousands of additional acres of farmland and openspace.[15]

The CUF Model simulation results also reveal the inherent fungibility of growth. If it is precluded from occurring in one location, it usually finds another. Another effect of Measure A has been to displace growth from rapidly growing cities such as Benicia and Suisun City to other cities—chiefly Vallejo and Dixon. To the extent that such spillover growth makes better use of existing infrastructure and services, this effect may be desirable. To the extent that Measure A pushes growth into underserviced cities, it may not.

Caveats and Conclusions

The California Urban Futures Model breaks new ground in a number of areas. First, it incorporates a GIS to assemble, manage, display, and make available millions of pieces of information describing land development potential. Second, it recognizes the importance of land developers and homebuilders as central actors in determining the pattern, location, and density of new development. It thus explicitly incorpo-

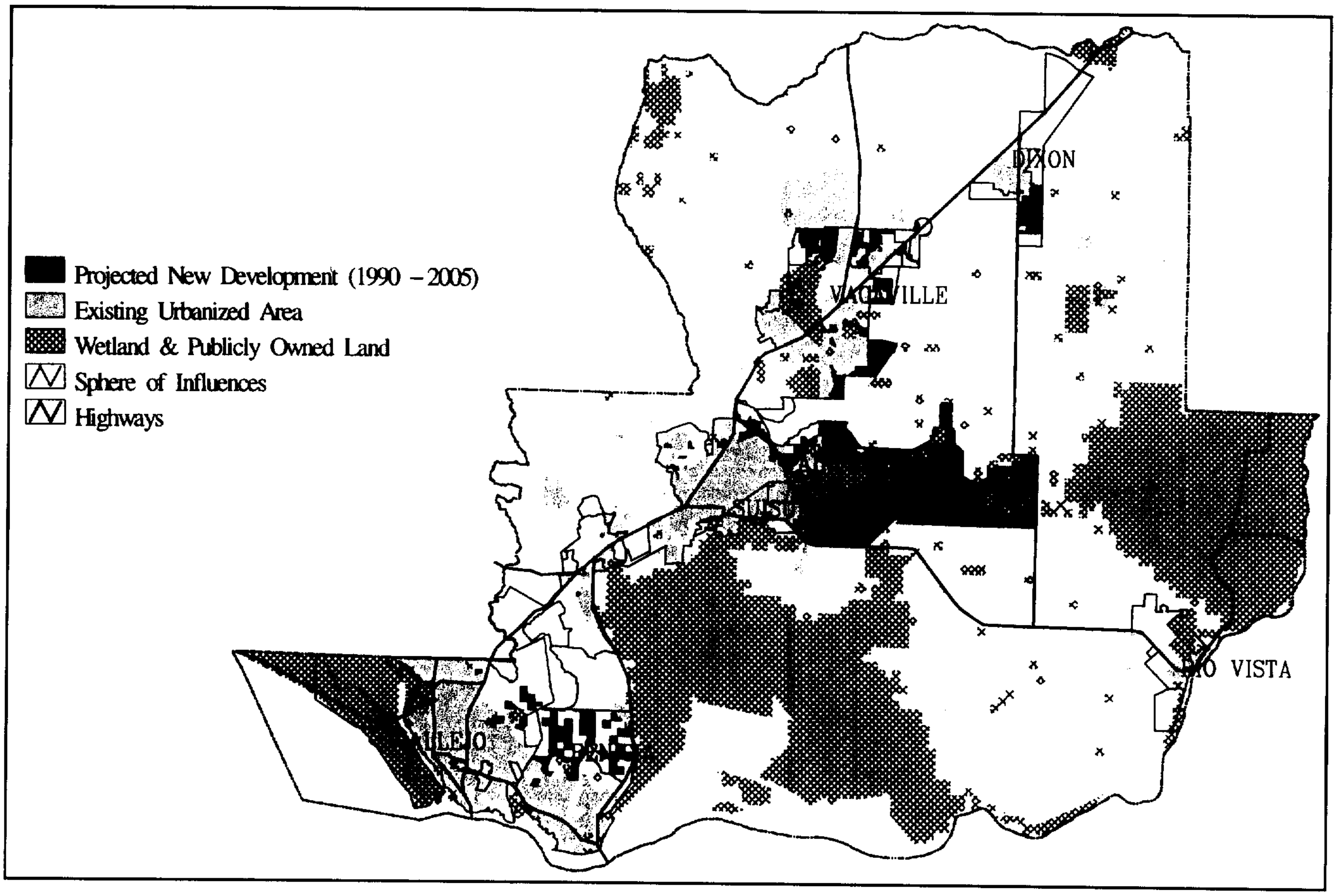

FIGURE 4. Solano Senario Two: Current General Plan remains in force; Measure A expires in 1995.

rates the profit calculations of private land developers. Third, through the Bottom-Up Population Growth Submodel and the Spatial Allocation Submodel, it explicitly incorporates realistic local development policies and policy options into the growth forecasting process. Finally, it is both easy to use and visual: new policy scenarios can be simulated in a matter of hours, and the results of those simulations can be presented in map form at almost any level of detail.

The current version of the CUF Model is not without its limitations. Housing prices—a key signal in the allocation process—are at present exogenous to the model. An improved version of the model would make them endogenous. The current version of the model forecasts employment growth only at the county level, and does not distribute it to individual DLUs. Finally, because the process of allocating growth depends primarily on the calculation of development profitability, the current version of the model is insufficiently sensitive to the impacts of major new infrastructure investments.

These limitations notwithstanding, this article demonstrates the power and potential of a new generation of urban simulation models to inform planners at all levels about the dynamics of urban growth and the spatial implications of alternative development policies. The promise of this new generation of models lies in three areas. First, they provide an effective framework for collecting and organizing the millions of pieces of information about urban development and its impacts that are now available. Second, because models lack imagination, they force researchers and model users to be explicit about their assumptions and about their knowledge of causes and effects. Properly used, models force one to be honest about what is known and what is unknown about processes of urban development. This type of formalism has an additional benefit. It allows people to think consistently about the future, holding certain factors static while allowing other factors—policy variables—to vary. In complicated, dynamic systems such as urban areas, this "what-if" capability is extremely useful. Finally, models such as the CUF Model are useful because of what they teach their users about the organization, structure, and dynamics of complicated urban systems. Used in this way, models can be powerful tools.

AUTHOR'S NOTE

The construction, testing, and use of the California Urban Futures Model were undertaken at the Institute of Urban and Regional Development with funds from the California Policy Seminar, the University of California Transportation Center, and the Association of Bay Area Governments. Key contributors to the development of the CUF Model included Michael Teitz, Ted Bradshaw, Peter Hall, Edward Egan, Ayse Pamuk, Rolf Pendall, David Simpson, Qing Shen, and Ming Zhao.

NOTES

1. Municipal utility districts, regional authorities, and census-designated places do not have control over land uses and/or development in California.
2. One effect of Proposition 13 has been to cause incorporated cities to compete with each other and with their counties for development projects that generate a surplus of tax/fee revenues over public service expenditures. Such competitive behavior has substantially undermined the long-term planning value of spheres of influence.
3. The spatial database is generated using ARC/INFO, a powerful geographic information system, by "unioning" different ARC/INFO coverages. Each input coverage can have a different geometry and attribute structure.
4. Redevelopment can be simulated in two ways. Either it can be included as general infill (which reduces the amount of population growth to be allocated), or potentially redevelopable sites can be coded as vacant, making them available for allocation; this is the same as noting that their current developed use has no economic value.
5. Over a twenty-year period, Lee (1973, 1994) has offered a cogent perspective on practical principles of large-scale model design.
6. The bottom-up nature of urban growth has recently been explored through fractal models (Batty 1991, 1992).
7. Earlier versions of the DLU concept were based on rectangular grid cells: geometrically identical features having different attributes. CUF Model DLUs are polygons of different size and shapes. The geometry of CUF Model DLUs is determined by the map layers that are "unioned" to generate them.
8. For comparisons of currently operational regional forecasting models, see Wegener 1993; Batty 1978, 1979, and 1994; Kim 1989; and Putman 1979.
9. Growth allocation in most other urban models is based on maximizing accessibility to job locations and local services (Wegener 1994).
10. Indeed, one of the uses of the CUF Model is to demonstrate when particular policies will induce a disequilibrium, that is, generate spillover.
11. Or, in cities in which sphere-of-influence lines are purposely drawn too tightly (in order to deter growth), to sites within 1,000 meters of existing city lines.
12. Most zoning codes limit maximum allowable site densities, but say little about minimum densities. The idea of a zoning "floor" is that for specific sites, the average density cannot go below a certain level.
13. Cities can, however, annex parcels that are beyond their sphere-of-influence boundaries (subject to LAFCO approval), and then rezone such parcels to either higher or lower densities.
14. Densities are limited to one unit per forty acres, or one unit per eighty acres, depending on the agricultural designation in the Solano County General Plan.
15. Measure A permits such lands to be developed, but at very low densities.

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