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Governor

A REVIEW OF LAND USE/LAND COVER AND AGRICULTURAL CHANGE MODELS

PIER PROJECT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grant Program
- Energy-Related Environmental Research
- Energy Systems Integration Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

The work described in this report was conducted under the Dynamic Ecosystem Modeling for California contract, contract number 500-02-004, and Work Authorization MR-024, by Stratus Consulting Inc.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-4628.

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Abstract

This review summarizes many of the leading land use/land cover change models being used to predict urban/rural land use change, as well as those more specific to agricultural land use change. This assessment was conducted to examine model differences and assess which models may be most appropriate for use in Public Interest Energy Research (PIER) Climate Change studies. Models were identified through literature reviews, Internet searches, and consultation with sources at the University of California Agricultural Issues Center, Davis. Although numerous models were identified, this review focused only on those that are predictive and appropriate in spatial and temporal scale to the broader study. This report provides an overview of the models examined, a brief assessment for their usability in the PIER project, and a comparison chart of select factors of the models examined. Of the 39 leading land use/land cover change models examined, only 11 met the criteria established for use in the PIER climate change and ecosystems project. This report recommends that either the current or updated version (in development) of the University of California, Berkeley's California Urban and Biodiversity Analysis Model (CURBA) is the most appropriate model to use in the PIER Climate Change studies.

Keywords: land use/land cover change, urban/rural land use change, agricultural land use change, urbanization, land use models

1. Introduction

This assessment was conducted to examine model differences and assess which models may be most appropriate for use in the Public Interest Energy Research (PIER) Climate Change study. The models considered include those addressing urban/rural land use change, as well as those more specific to agricultural land use change.

This review summarizes many of the leading land use/land cover change models currently being used to predict future development and several studies that examine the factors involved in farmland conversion. The review first describes the criteria used to select models for inclusion into the review, followed by a brief overview of the models examined, a brief assessment for their usability in the PIER project, and a comparison chart of select factors of the models examined. It should be noted that these descriptions are intentionally brief and additional review of the model and/or consultation with the developer should be conducted before model selection for use in the broader study.

2. Methods

Researchers collected the list of models from a literature review, Internet searches, and consultation with sources at the University of California Agricultural Issues Center, Davis. Numerous models were identified, but this review focused only on those that are predictive and appropriate in spatial and temporal scale to the broader study. More specifically, the models reviewed met the following criteria:

- predictive to at least 100 years in the future and with time steps appropriate for inclusion with the full study (with the exception of the agriculture-specific studies)
- spatially explicit, with a spatial resolution of at least 1 square kilometer (km^2) and a domain that could be used for the entire state of California
- easily transferable to other regions (if developed outside of California)
- publicly available at little to no cost
- use easily obtainable data sets (e.g., publicly available data sets)
- able to be run with common hardware and software configurations

Of the original 39 models considered, 11 met all these criteria. Although many source documents were examined, this review relied heavily on a 260-page summary document of 22 current models compiled by the U.S. Environmental Protection Agency (U.S. EPA 2000).

3. Model Overviews

Below is a brief overview of each of the models examined, and an assessment of each model's potential usability in this project. More specific details of each model (e.g., variables addressed, spatial/temporal scales) can be found in the comparison chart (Table 1) at the end of this section.

3.1 California Urban and Biodiversity Analysis Model (CURBA) (John Landis, Michael Reilly, Pablo Monzon, and Chris Cogan; University of California, Berkeley)

The CURBA model is composed of two separate models: (1) the urban growth model, which creates calibration equations from past urbanization patterns and uses them to project future development, and (2) the Policy Simulation and Evaluation Model, which evaluates the effects of alternative development policies on future urbanization patterns and the associated impacts on habitat integrity (U.S. EPA 2000). CURBA assumes that past trends will continue into the future. Variables used in the CURBA model include land use types, topographic and hydrologic features, transportation networks, zoning, and various socioeconomic data (e.g., population and employment levels). While the CURBA model is restricted to only urban/nonurban categories, it is currently being updated to output 10 density classes of urbanization and utilizes census tract data instead of the California Department of Conservation's Farmland Mapping and Monitoring Program data. The updated model should be completed in the spring of 2005 (J. Landis, University of California, Berkeley, personal communication, October 2004).

Assessment: The output from the CURBA model has already been used in 39 counties in California and over time periods that can be used in the current project. Outputs from the updated version (10 urban density classes, instead of urban/nonurban) would make the model more useful for the project.

3.2 Growth Simulation Model (GSM) (Joe Tassone, Maryland Department of Planning)

The GSM conducts an inventory of the supply of developable land by examining availability for additional development based on land use plans and management programs. The GSM is highly flexible in terms of data needed. However, variables such as distance from highways, schools, retail services, and undeveloped land are used to rate the probability of conversion. Growth distribution within the landscape is then based on capacity for additional development, the probability of conversion, and county-specific information on recent development patterns and trends related to the market in the area. The allocated land is then: (1) converted to a specific land use/land cover to accommodate the expected growth, (2) maintained or converted to forested or other vegetation cover to meet management policies (e.g., requirements of forest conservation, stream buffer protection, open space), or (3) allowed to remain in its existing condition (U.S. EPA 2000).

Assessment: This is potentially a good model for use on the project but would require a lot of data preparation to get many of the inputs needed for a quality prediction. It is unclear from the documentation what programming (and in what language) would be needed to customize the model to California.

3.3 Land Use Change Analysis System (LUCAS) (Michael Berry, Richard Flamm, Brett Hazen, Rhonda MacIntyre, and Karen Minser; University of Tennessee)

LUCAS uses the public-domain geographic information system (GIS) Geographic Resources Analysis Support System (GRASS) to estimate land cover change and the resulting impact to the environment. The LUCAS model contains three modules: the socioeconomic module, the landscape change module, and the impacts module. The socioeconomic module derives the probability of change from transportation networks, topographic information, ownership, land cover, and population density. The landscape change module then uses the output probabilities to assign land cover changes to the landscape. Finally, the impacts module assesses the impacts to the environment resulting from these changes (U.S. EPA 2000). The LUCAS model has been used in the Little Tennessee River Basin in Tennessee, and the Olympic Peninsula in Washington.

Assessment: This model requires the use of GRASS software, source code manipulation in C++, and needs to be run in a UNIX environment. It is also unclear from the documentation how many time steps are needed for input from Land Use/Land Cover (LULC), population density and other model predictor variables. This model would require training and experience to calibrate.

3.4 Slope, Land Use, Exclusion, Urban, Transportation, Hillshading (SLEUTH) (or Clarke Cellular Automata Urban Growth Model) (Keith Clarke, University of California, Santa Barbara)

The SLEUTH model simulates change from nonurban to urban, based on local factors (e.g., topography, existing urban, roads), temporal factors, and random factors. SLEUTH models four types of growth: (1) spontaneous, (2) diffusive, (3) organic, and (4) road-influenced. The model does not explicitly address population, policies, and economic impacts on land use change except in terms of growth around roads. Calibration of the SLEUTH model is based on historical patterns of land use change based upon the following five parameters: (1) dispersiveness of growth, (2) growth at new settlements (breeding), (3) outward expansion, (4) likelihood of development on slopes, and (5) promoting new settlements near transportation networks. The historical trends derived are then projected into the future. The model addresses any combination of user-defined land use categories. The SLEUTH model has been used to model urbanization in many metropolitan areas around the United States (including Santa Barbara and San Francisco) and to model land use change in the Chesapeake Bay watershed where satellite imagery (Landsat) was used to derive historical trends (U.S. EPA 2000; Goetz et al. 2003).

Assessment: As of 2000, the SLEUTH model needs to be run in a UNIX environment and might require modification of the C source code. The model would probably require significant guidance in the calibration phase; however, the ability to use land cover data sets derived from satellite imagery (which is widely available) is attractive.

3.5 UPLAN (Robert Johnston, University of California, Davis)

UPLAN models growth based on user-defined assumptions of land use suitability, projected growth demands (population change and various socioeconomic factors), land use controls, and current and future infrastructure. The model uses GIS grid layers to specify the parameters where the user specifies weights for "attraction grids" (locations for future development such as near highways), "exclusion grids" (locations where no development should occur), "general plan grids" (derived from maps of general plan land use for the areas of interest), and "existing urban grids." These grids are usually compiled from a combination of mapped information (e.g., the exclusion grid might be composed of hydrographic and topographic information). UPLAN currently models six land use categories but can be modified for any number and type. UPLAN is a policy- and scenario-based projective tool and has been used in the Sacramento, California and Espanola, New Mexico regions (U.S. EPA 2000).

Assessment: As acknowledged by the developer, the model is fairly simplistic and does not take into account interrelated factors of fiscal policies and other planning decisions. The GIS data sets required to run the model GIS are fairly common, although the compilation of the data would require an extensive effort.

3.6 UrbanSim (Paul Waddell, Michael Noth, and Alan Borning, University of Washington)

The UrbanSim model projects future land use based on interactions between factors such as land use plans, density constraints, urban growth bounds, development impact fees and policies, and environmentally sensitive lands (e.g., wetlands, high topographic slopes, floodplains). The model simulates land market and interactions of supply and demand with prices adjusting to short-term imbalances. In other words, the model tries to mimic real decisions that households and businesses make in response to policy about when and where they would like to move. The model requires extensive calibration to derive coefficients for several models: land price model, developer model, residential location model, employment location model, and mobility rate model (derived from external travel model). The UrbanSim model requires spatially explicit data for environmental and policy constraints, parcel data, business establishment data, household survey travel data, census STF3A, and Public Use Micro (PUMS) data. The model has been used in Honolulu, Hawaii; Eugene-Springfield, Oregon; the Greater Wasatch Front area (Salt Lake City, Utah); and Puget Sound (Seattle, Washington) (U.S. EPA 2000).

Assessment: The UrbanSim model is highly sophisticated, but the data requirements are extensive and might not be available for many locations in California. In addition, the calibration process would probably require extensive expert guidance. This model also requires the use of an external econometric model (as of 2000, although future plans were to include this internally) and travel plan model.

3.7 What if? (Richard Klosterman, Community Analysis and Planning Systems, Inc.)

The What if? model projects future development using three modules: the suitability module, the growth module, and the allocation module. The suitability module applies standard weights and ratings based on user-defined land use criteria. The growth module projects residential, industrial, commercial, preservation, and locally oriented uses into equivalent future land uses based on projected growth for each land-use type for up to four future time periods. The allocation module then allocates the predicted land uses to the landscape based upon land use suitability, demand, infrastructure, and land use plans and controls. The model requires fairly detailed local growth information (e.g., number of households, density of housing type, vacancy rates, regional employment, density of employees per industrial/commercial type, average sq. ft. floor space per employee, industrial/commercial floor area). The What if? model has been used to model three counties in Ohio (U.S. EPA 2000).

Assessment: The What if? model requires a lot of specific local information on socioeconomic factors, but much of this may be available through the latest census. However, assembly of the data would require a fairly extensive effort. In addition, assignment of weights would probably require guidance from the developer to achieve believable results.

3.8 Conversion of Land Use and Its Effects (CLUE) (A. Veldkamp and L. Fresco, Wageningen University, The Netherlands)

The CLUE model projects land cover into the future and can be run at the local, regional, or national scales (user-defined scale). The model is composed of three different modules: (1) the regional biophysical module, (2) the regional land-use objectives module, and (3) the local land-use allocation module. The specifics of each module were not provided in the documentation, but the model addresses 10 different land use types and considers a variety of biophysical (e.g., land suitability for crops, climate, effects of past land use, impacts of pests/weeds, disease) and human variables (e.g., population size, density, and growth, technological level, level of affluence, political structures, economic conditions, and attitudes and values). The CLUE model has been used in Costa Rica, China, Java, Ecuador, and Honduras (Agarwal et al. 2002).

Assessment: This model appears to more suited to developing countries than to the United States. This assessment is based on the limited consideration of institutional and economic variables as well as the human variables considered (e.g., political structures, technological level).

3.9 NELUP (Natural Environment Research Council [NERC]-Economic and Social Research Council (ESRC]: NERC/ESRC Land Use Programme [NELUP]) (J. R. O'Callaghan, University of Newcastle, Newcastle upon Tyne, UK).

The NELUP model predicts patterns of agriculture and forestry land use under various scenarios. The model consists of three modules: (1) the regional agricultural economic model, (2) the hydrological model, and (3) the ecological model. The agricultural/economic model overtly models the choices of farmers, while the actions of others are taken into account through technology or policy constraints. The ecological model runs at a 1-km cell size, and the economic model treats the entire catchment as a single farm but accounts for land use variation using land cover data. Therefore, the model uses land cover data to link the socioeconomic data with the ecological models. The variables considered in the model include soils, weather, parish census data, input/output farm data, species, and land cover. The NELUP model has been used in the River Tyne catchment in northern England (Agarwal et al. 2002).

Assessment: Although this model was developed for northern England, it should be fairly easy to use in California because of the availability of the data sets needed as inputs. However, the model may be too simplistic for the overall project needs.

3.10 Modeling Farmland Conversion with New GIS Data (Nicolai Kuminoff and Daniel Sumner, University of California Agricultural Issues Center)

The analysis conducted by Kuminoff and Sumner does not explicitly predict agricultural land use change in the future, but the variables examined and relationships derived from their analysis could be used to predict farmland conversion given certain socioeconomic assumptions and in conjunction with urban projection data from other models. The Kuminoff/Sumner model utilizes spatial data from the California Department of Conservation Farmland Mapping and Monitoring Program (FMMP) over two time periods: 1988–1992, and 1992–1998. The model considers three types of conversion: (1) agricultural to urban; (2) all conversion out of agriculture (e.g., agricultural to urban, agricultural to idled farmland, and agricultural to wetlands and wildlife habitat); and (3) all conversion to urban (includes all types of nonurban lands to urban). The dependent variable used in their analysis was average acres of farmland converted per year in the county, and the independent variables examined include conversion pressure along urban edge, change in farm income, change in prices of agricultural land available for development, population growth, stock of agricultural land in each county, zoning and development restrictions, and time period. The results of their analysis suggest that urban factors, not low farm income, have been the primary cause of recent farmland conversion in California, and that urban edge effects are an important determinant (Kuminoff and Sumner 2001).

Assessment: As mentioned above, although this model does not explicitly predict agricultural conversion to urban lands in the future, the variables examined and relationships derived most likely could be used in conjunction with existing urban models to predict agricultural losses in the future.

3.11 The Use of Cluster Analysis in Distinguishing Farmland Prone to Residential Development: A Case Study of Sterling, Massachusetts (Delphis F. Lavia, Jr., Clarke University, and Daniel R. Page, University of Massachusetts)

The study was conducted to demonstrate the use of cluster analysis as a tool for identifying farms prone to residential development. The study utilized k-means nonhierarchical cluster analysis on 84 farms in two groups: (1) those farms likely to be converted, and (2) those not likely to be converted. The factors examined included farm size, farm slope, distance to nearest city center, and distance to nearest highway. Discriminant analysis determined that the classification into the two groups was 98.8% accurate. The authors noted that while additional variables might be considered in other regions (e.g., proximity of farm to local mountain ranges and other recreational resources, distance to water body, scenic value), the variables used in this study are appropriate because they influence land value. This study was conducted on 84 farms in Sterling, Massachusetts (Lavia and Page 2000).

Assessment: As with the Kuminoff/Sumner study, this analysis did not explicitly model farmland conversion into the future. However, the methods used in this study could also be used to predict loss of farmland in the future under different urbanization modeling scenarios.

Table 1. Comparison Land Use/Land Cover Model Examined

Name	Cost	Spatial Extent/ Resolution	Temporal Extent/ Resolution	Factors Considered	Software Required	Expertise Required	Inputs Needed	Outputs Provided	Rural Land Use Classes Considered
CURBA	Free	38 counties in CA/1 ha	User defined (output to specific times: 2020, 2060, 2100)	Transportation infrastructure, local zoning, city/county master plans	ArcView, SAS or SPSS	Minimal	Land Use/Land Cover, GAP, topography, transportation network, hydrography, jurisdictional bounds, wetlands, population and employment levels, FEMA floodplains	Urban/Non-Urban or 10-urban density classes in update	Agricultural, forest, wetlands, water, preservation, park land
GSM	Free	User defined	User defined/user defined	Transportation infrastructure, local zoning, city/county master plans, local fiscal policies, subdivision regs., environmental regs.	ArcInfo and relational database management system	Must be customized by skilled programmer	User defined (but minimum of land use/land cover and management areas)	Residential, commercial, mixed use, industrial, other	Agricultural, forest, wetlands, water, preservation, park land
LUCAS	Free	User defined (up to 90 meter cell size)	User defined time steps (default: 100 yrs/5 yr. Intervals)	Transportation infrastructure, local zoning, city/county master plans	UNIX, GRASS, C++	Calibration requires expertise and C++ programming	Transportation network, topography, ownership, land cover, population density	Residential, commercial	Agricultural, forest, wetlands, water, preservation, park land
SLEUTH	Free	User defined	User defined/ annual	Transportation infrastructure, local zoning, city/county master plans, local fiscal policies	UNIX, gnu C compiler	Calibration requires expertise	Topography, excluded areas, transportation network, seed, background	Residential, commercial, mixed use, industrial, other	Agricultural, forest, wetlands, water, preservation, park land
UPLAN	Free	User defined	User defined/user defined	Transportation infrastructure, local zoning, city/county master plans, local fiscal policies	ArcView	Use of GIS and avenue programming	Various demographic and socioeconomic, regional and local plans, transportation network, hydrography, topography, land use/land cover	Residential, commercial, mixed use, industrial, other	Agricultural, forest, wetlands, water, preservation, park land
UrbanSim	Free	User defined	User defined/ user defined	Transportation infrastructure, local zoning, city/county master plans, local fiscal policies	Java, econometric software, transportation model	Statistics, expertise in calibration	Parcels, business establishments, Census data, topography, wetlands, floodplains, general plans, zones used in travel modeling, travel impedance from travel models	Residential, commercial, mixed use, industrial, other	Agricultural, forest, wetlands, water, preservation, park land

Table 1. Comparison Land Use/Land Cover Model Examined

Name	Cost	Spatial Extent/ Resolution	Temporal Extent/ Resolution	Factors Considered	Software Required	Expertise Required	Inputs Needed	Outputs Provided	Rural Land Use Classes Considered
What if?	$250-$2,500*	User defined	User defined, but 4 time periods	Transportation infrastructure, local zoning, city/county master plans	GIS	Minimal	Natural features, infrastructure plans, land use/land cover, comprehensive plans or zoning, various socioeconomic, census, and employment data, alternative development scenarios, land use classifications	Residential, commercial, mixed use, industrial, other	Agricultural, forest, wetlands, water, preservation, park land
CLUE	Free	User defined	User defined/annual	Land suitability for crops, climate, effects of past land use, impacts of pests/weeds, disease, population size, density, and growth, technological level, level of affluence, political structures, economic conditions, and attitudes and values	Unknown, but assumed at least GIS	Unknown	Land suitability for crops, climate, effects of past land use, impacts of pests/weeds, disease, population size, density, and growth, technological level, level of affluence, political structures, economic conditions, and attitudes and values	10 land use types (assumed)	10 land use types (assumed)
NELUP	Free	User defined/ 1-km cell size	User defined/annual	Soils, meteorological, parish census data, input/output farm data, species, and land cover	Unknown, but assumed at least GIS	Unknown	Soils, meteorological, parish census data, input/output farm data, species, and land cover	Unknown, but agricultural and forest land use at a minimum	Unknown, but agricultural and forest at minimum

*$250 is the University rate, while a single-user license for the public was $2,500, as of 2000.

4. Conclusions

4.1 Models excluded

We reviewed 39 of the leading land-use/land-cover change models being used to predict future development and several studies that examined the factors involved in farmland conversion. Only 11 of the 39 models examined met the criteria established for use in the broader PIER project.

The rationale for exclusion was based on several factors. Eight of the 28 models were excluded based on cost, which ranged from approximately $7,500 to $200,000 (which included a consulting fee in some cases).[1] However, in all but one case, these models also failed in at least one other category, or a more current version was available.[2] Twelve of the models were excluded, because they were deemed not suitable for the project needs. Those needs included:

- models that evaluate the labor market (e.g., job forecasting) and transportation planning issues;
- models designed to optimize different development plans on community desires and/or public policy (e.g., master plans and economic policies);
- models that examine environmental impacts associated with alternative land use plans;
- models that examine select land uses; and
- models that predict sites suitable for shifting agriculture.

In addition, many of these models (especially those examining transportation issues) require output from external models as inputs (e.g., transportation models, air quality models, and socioeconomic models). Finally, nine of the models were rejected because of spatial and/or temporal scale issues: their inability to project land use change into the future (e.g., not a predictive model or unable to project to year 2100); a time step that is inappropriate for PIER purposes (e.g., single time output); or a spatial scale too coarse for use in the PIER project (1 km × 1 km).

Lastly, one of the project needs is to address conversion of nonagricultural lands into agricultural production (e.g., land use conversion to vineyard). Although none of the models that were examined specifically predict this land use change, it might be possible to use the cluster analysis method outlined in Lavia and Page (2000) in conjunction with other socioeconomic and environmental parameters (such as those highlighted in Kuminoff and Sumner 2001) to predict potential land use change into agricultural production.

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[1] The cost was not available for many of the models.

[2] CUF-1 and CUF-2 (J. Landis, University of California, Berkeley) were prior versions of the CURBA model and the SAM IM model (Planning Technologies, LLC, Albuquerque, New Mexico) required consulting services estimated at $30,000 to $100,000 and is based on the Landis model.

4.2 Recommendations

Although all the models listed in Section 3 would be appropriate for inclusion into the PIER project (based on the criteria from Section 2), we recommend the use of the CURBA model (or the updated version in progress) developed by John Landis at the University of California, Berkeley, as the most appropriate for the project needs. This assessment is based mainly on the time and effort that would be required to use alternative models in California. Many of the other models are very sophisticated and might in some cases provide a more accurate prediction of future land use change at a specific location; however, all of the models examined require extensive inputs (e.g., transportation networks, population and employment levels, city/county master plans) that would need to be collected from individual communities and processed for incorporation into the model. Because the spatial extent of the project covers the entire state of California, the effort needed to assemble these input data sets would be substantial for use in this study. In addition, most of the models require extensive calibration to provide defensible results. Although the effort required for calibration is specific to the individual model, direct involvement by the model developer and/or training of a PIER staff member would be needed. The CURBA model has been run previously for 39 urban counties in California, so all input data sets have already been assembled and calibrated. Even though additional counties may need to be incorporated, the amount of effort needed is small compared to other models. In addition, the CURBA model has been run to the year 2100 and the output data is in a format that is consistent with the PIER project needs. The updated version of the CURBA model will include 10 urban density classes that would be optimal for use in the PIER project, though the current urban/nonurban classification is suitable for the PIER project needs.

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