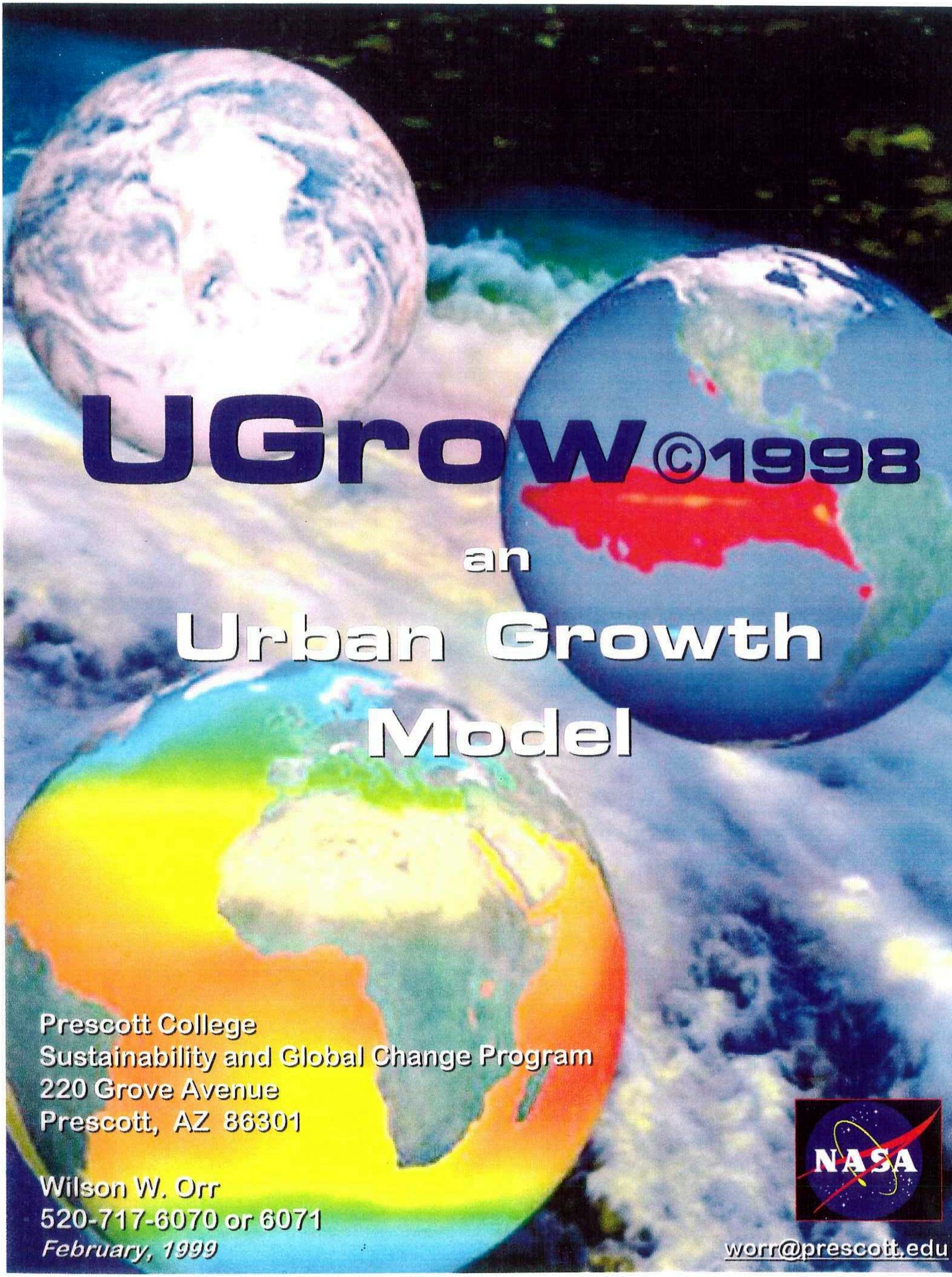

UGrow ©1998

an Urban Growth Model

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SUMMARY: AN URBAN GROWTH MODEL

Long-term community planning is a challenge *par excellence'*. An era of rapid urbanization - deemed "growth" or "sprawl" depending on one's point of view - places extraordinary pressures on local government planning capabilities. The NASA Program at Prescott College[1] is developing an integrated suite of GIS/3D/ remote sensing, modeling and presentation technologies to assist local governments in understanding and communicating the complexities of local issues, global changes and the long-term consequences of current decisions.

Ugrow©1998 is a PC-based system dynamics model for urban policy design and testing. This modeling approach is inherently cross-disciplinary and incorporates a variety of spatial and temporal factors including those internal to a community as well as external influences. The model integrates time-based simulation modeling with a spatially-oriented geographical information system (GIS) and other visualization technologies. The system dynamics modeling framework permits explicit assumptions, represented by equations, to be examined over time with computerized tracking of the inter-relationships among variables using feedback and delay loops. Ugrow©1998 is being developed to assist community decision makers in understanding the complex impacts of climate change and the interactions with current problems, e.g. sprawl, water management, public safety, infrastructure financing, etc. This model characterizes an urban area as the confluence of built, human, and natural environments and currently accounts for over 300 variables grouped into major sectors which are: *Quality of Life, Economic & Business, Housing, Population, Land Use, Transportation, Climate Change, Energy and Water.*

Typical of the variables are: *land use by type, population, employment, level of business activity, air quality, vehicle miles traveled, house hold energy use, school quality, acres of park lands, average vehicle energy use, tax rates, and attractiveness to inmigration.*

The model runs from 1950 to 2100 with a "built-in hold" at years 1990 and 2030 for policy interventions. There are presently 10 policy option categories which encourage/discourage efficiencies in, for instance: *housing density, energy consumption, transportation, land use/land cover, and business activity:* Each of these may be adjusted for "intensity," representing the strength with which the policy is implemented. The visual and simultaneous "running" of all the variables within the assigned temporal scale is designed for decision-makers, informed on local issues, but with limited time. Currently, the input variables are derived from national averages; therefore the model currently typifies a generic American community.

A Spatial Element of the model generates GIS-format maps of the "future community" based on specific zoning regulations used to implement the growth policies selected in the numerical element of the model. The zoning regulations may be programmed to change as a function of time to explore the results of changing public preferences in the character of their community.

Ugrow©1998 runs on one screen of the Environmental Planning Information Center, a portable 3-screen system (using 3 computers, driving 3 high intensity projectors) developed by working closely with local government agencies and city councils. The standard configuration runs Ugrow on the **right screen**, 2/3-dimensional GIS and remote sensed imagery on the **center screen** and decision support software, meeting agenda, or PowerPoint graphics on the **left screen**. Real-time "free fly" software is used on the center screen to vividly portray a variety of growth scenarios for a public audience. This integrated system helps clarify issues and improves the efficiency of public meetings, thus reducing the time spent on tangential issues or unlikely outcomes.

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SECTION 1. MODEL DESCRIPTION

NUMERICAL ELEMENT

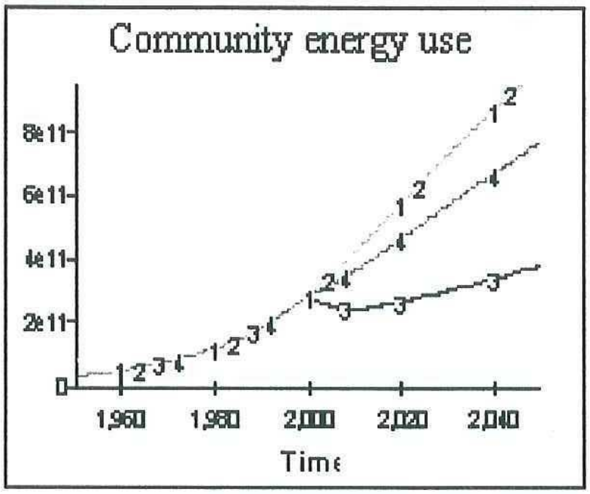
Ugrow©1998 is a system dynamics, PC-based model running over 300 equations, which define the basic interdisciplinary relationships among the economic, social and environmental sectors of a community. This model also quantifies local sustainability and couples a given locale to climate change via CO_2 emissions. A range of local climate change and variability impacts may be tested, primarily through a variety of weather/hydrologic scenarios which affect (for example) groundwater availability and storm damage to local infrastructure The model runs from 1950 to 2100 with pauses at years 1990 and 2030 (or any selected time) for policy. It is designed to test proposed policies and can be stopped at any year to produce the community status as a scenario responding to the proposed policy(s). The model characterizes an urban area as the confluence of built, human, and natural environments and projects variables grouped into major sectors such as: *Quality of Life, Economic & Business, Housing, Population, Land Use, Transportation, Climate Change Impacts, and Energy.* This modeling framework permits explicit assumptions, represented by equations, to be examined over time with computerized tracking of the interrelationships among variables using feedback loops and delays.

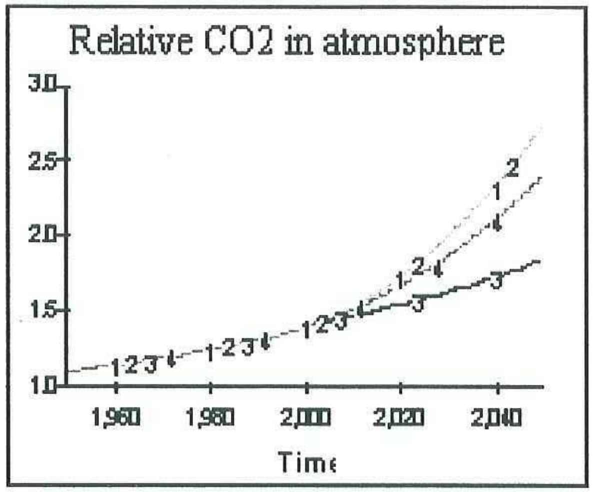
The model produces a variety of future scenarios based on changes in local development policy, input conditions or external variables. There are presently ten policy option categories which encourage/discourage efficiencies in, for instance: *housing density, energy consumption, transportation, land use/land cover, and business activity:* Each of these may be adjusted for "intensity," representing the strength with which the policy is implemented. The visual and simultaneous running of all the variables within the assigned temporal scale is designed for decision-makers, informed on local issues, but with limited time to understand the complex impacts of climate change and the interactions with current problems, e.g. sprawl, public safety, infrastructure financing, etc. The input variables are derived from national averages; therefore the model currently typifies a generic American community.

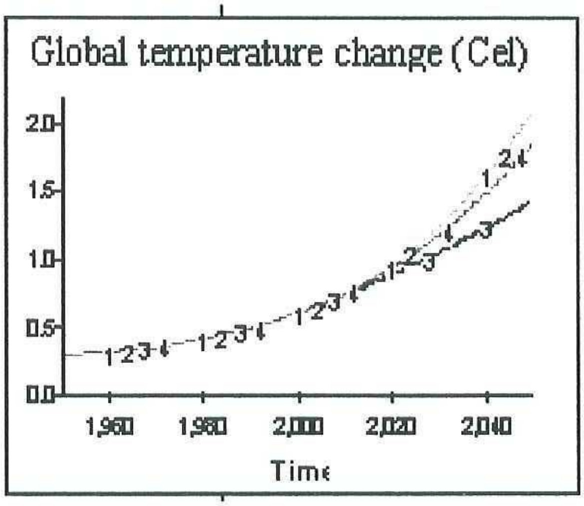
The ecological footprint component of the model serves both as a single metric for sustainability and, by quantifying the resources consumed by a community, a measure of a community's economic competitiveness. The latter is becoming increasingly important to a region's long-term economic vitality as corporate trends begin to favor more efficient production using fewer resources and lowered CO_2 emissions.

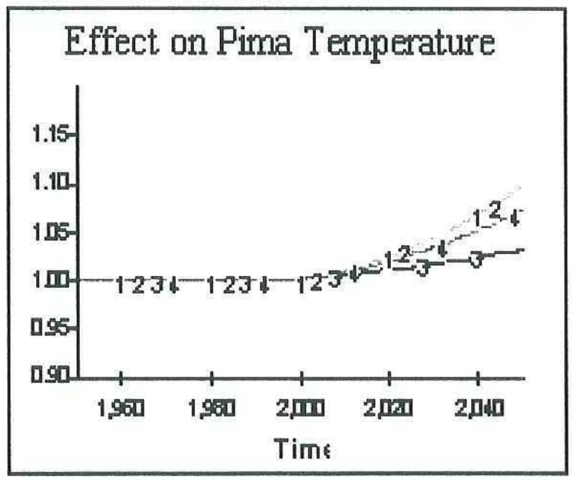
The model is interactive with global climate change via community CO_2 emissions. ***Figure 1,*** shows three scenarios (responding to 3 different policy assumptions) coupling local energy use to global CO_2 and temperature, and displaying the impacts on Pima County (Tucson, Arizona) temperature, precipitation and groundwater.

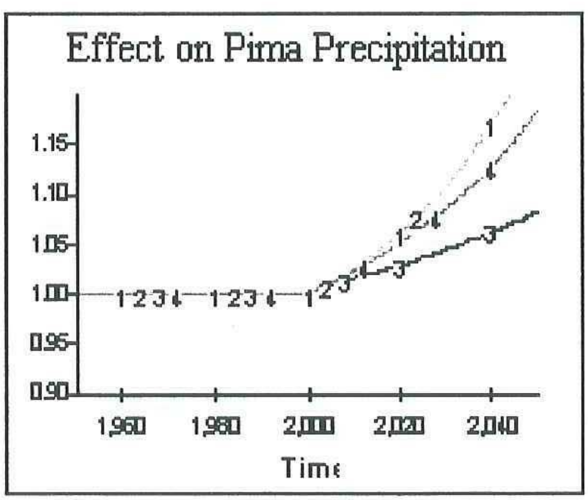
Global Change -- Climate Change











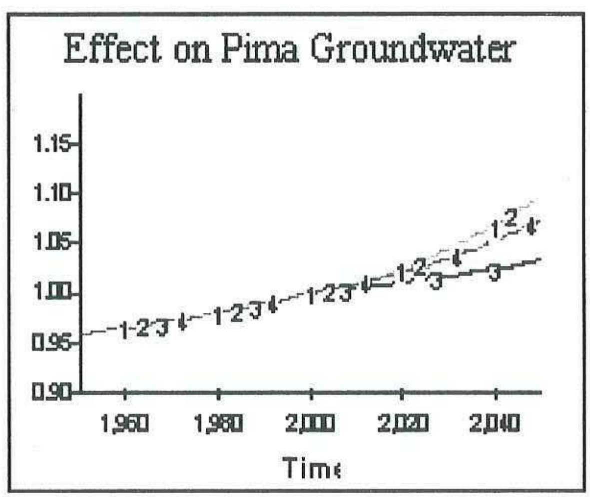


Figure 1. These are screen captures are typical of the current model and shows a base run (1), and a third run (3) with increased efficiency, reduced consumption, and higher land use densities.
The following screen captures, **Figures 2-7,** are better detailed and reveal some of the model's versatility, again with line 1 showing the business as usual outcomes and line 2 showing an altered future base on policy changes favoring sustainabiltiy with reduced emissions and pollutants.

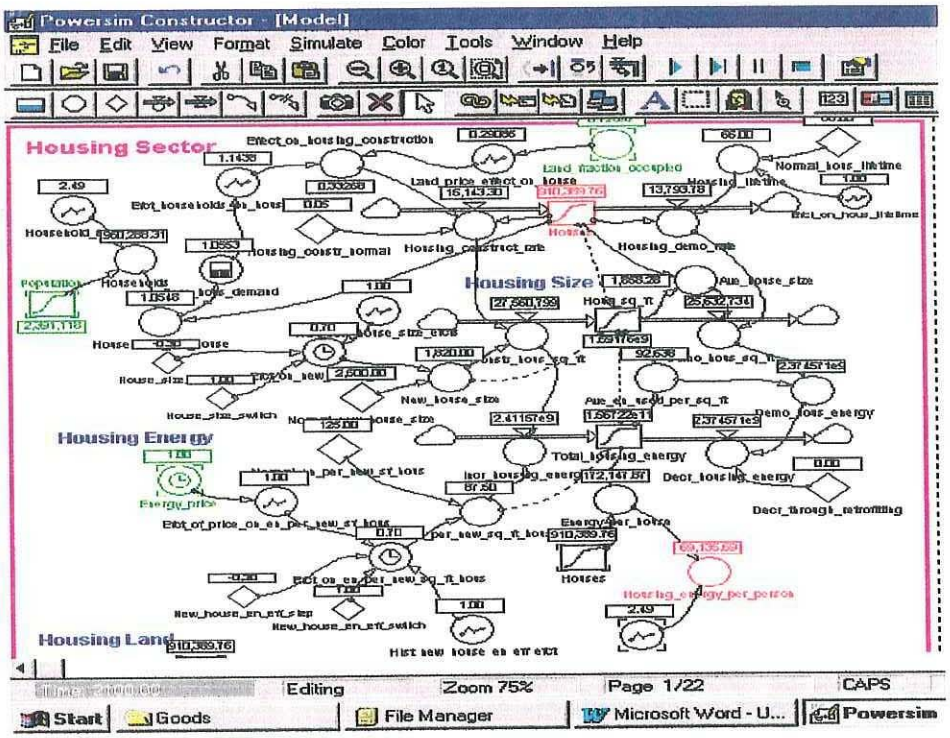


Figure 2. Equations for calculating the Housing Sector effects.

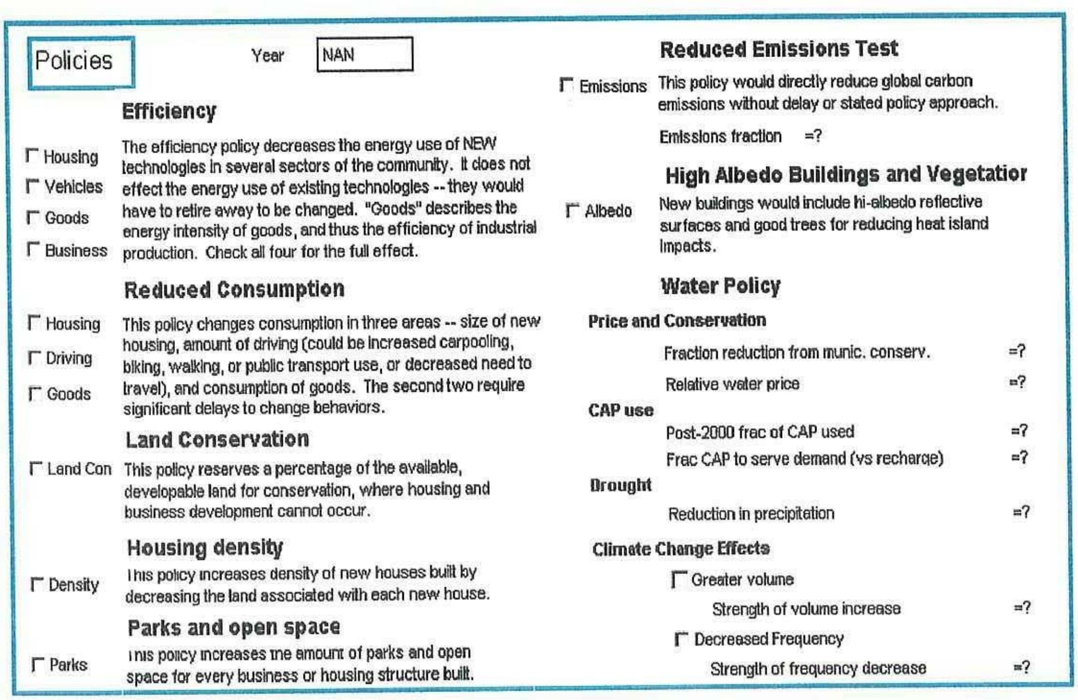


Figure 3. Policy choice and intensity menu

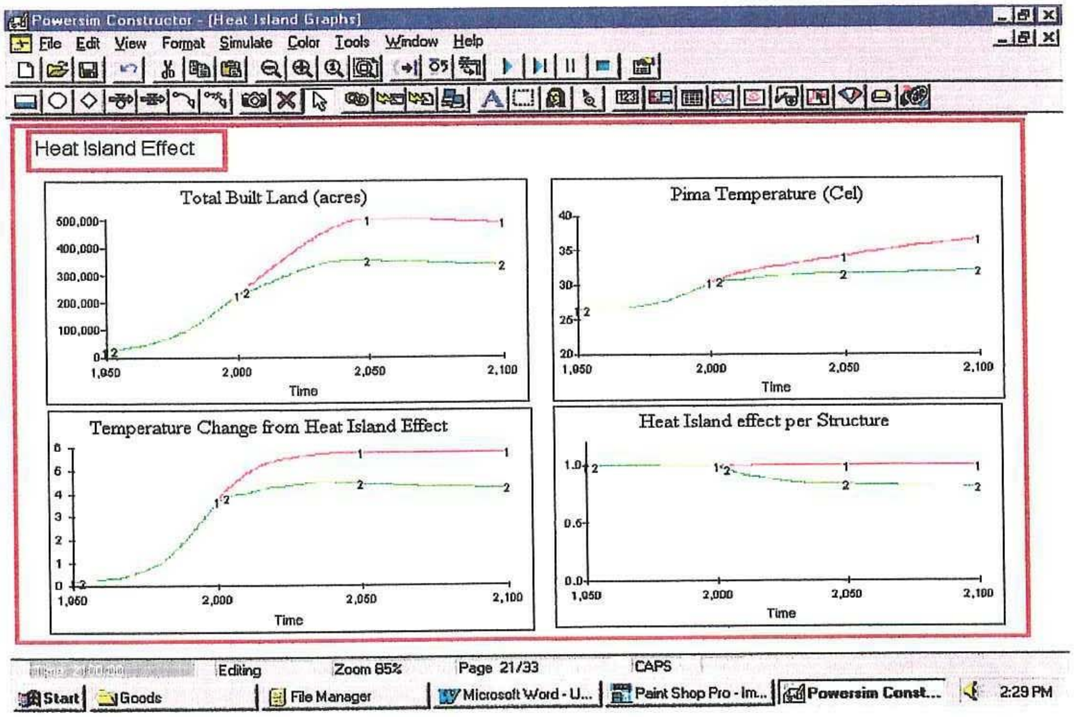


Figure 4. Urban heat island effect

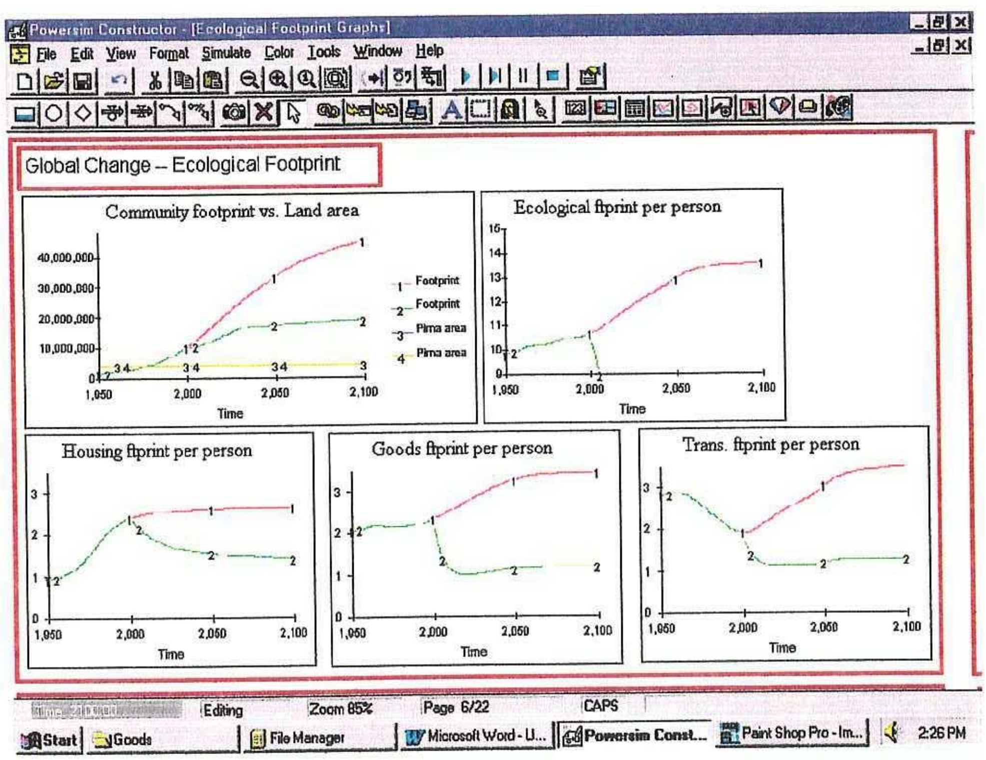


Figure 5. Components of the Ecological Footprint

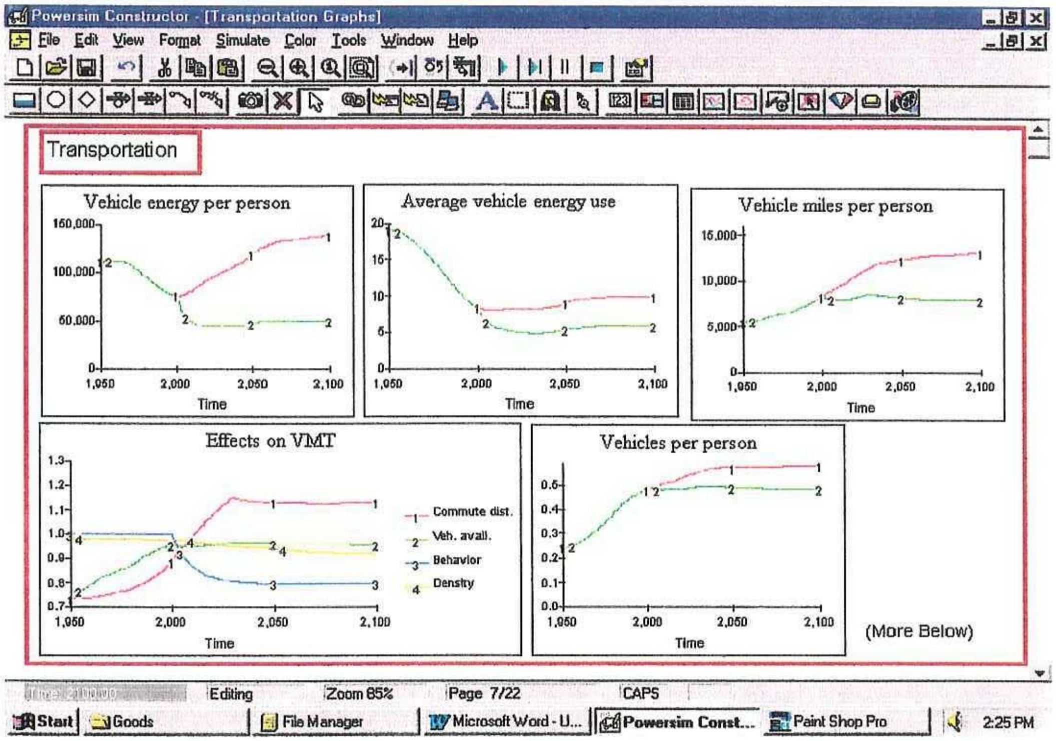


Figure 6. Transportation effects

Figure 7. Effect of Combined Heat Island / Global Climate Change

Spatial Element

The Spatial Element of the model uses the basic output of the numerical element to generate GIS-format maps of the "future community." The spatial element, however, bases its growth on the specific zoning regulations used to implement the growth policies selected in the numerical element of the model. The zoning regulations may be programmed to change as a function of time to explore the results of changing public preferences in the urban character.

Parcel, building permit or other accurate and high resolution GIS information (from any standard format) is overlaid on Landsat or other remote sensed imagery for to create the base map for the future scenarios. These data layers, in turn, are draped over a digital elevation model of comparable resolution to build community scenarios showing growth by type, location and year. The user may select the future time intervals for the maps - out to the year 2100.

Screen captures from this process are shown in Figures 8-12 below:

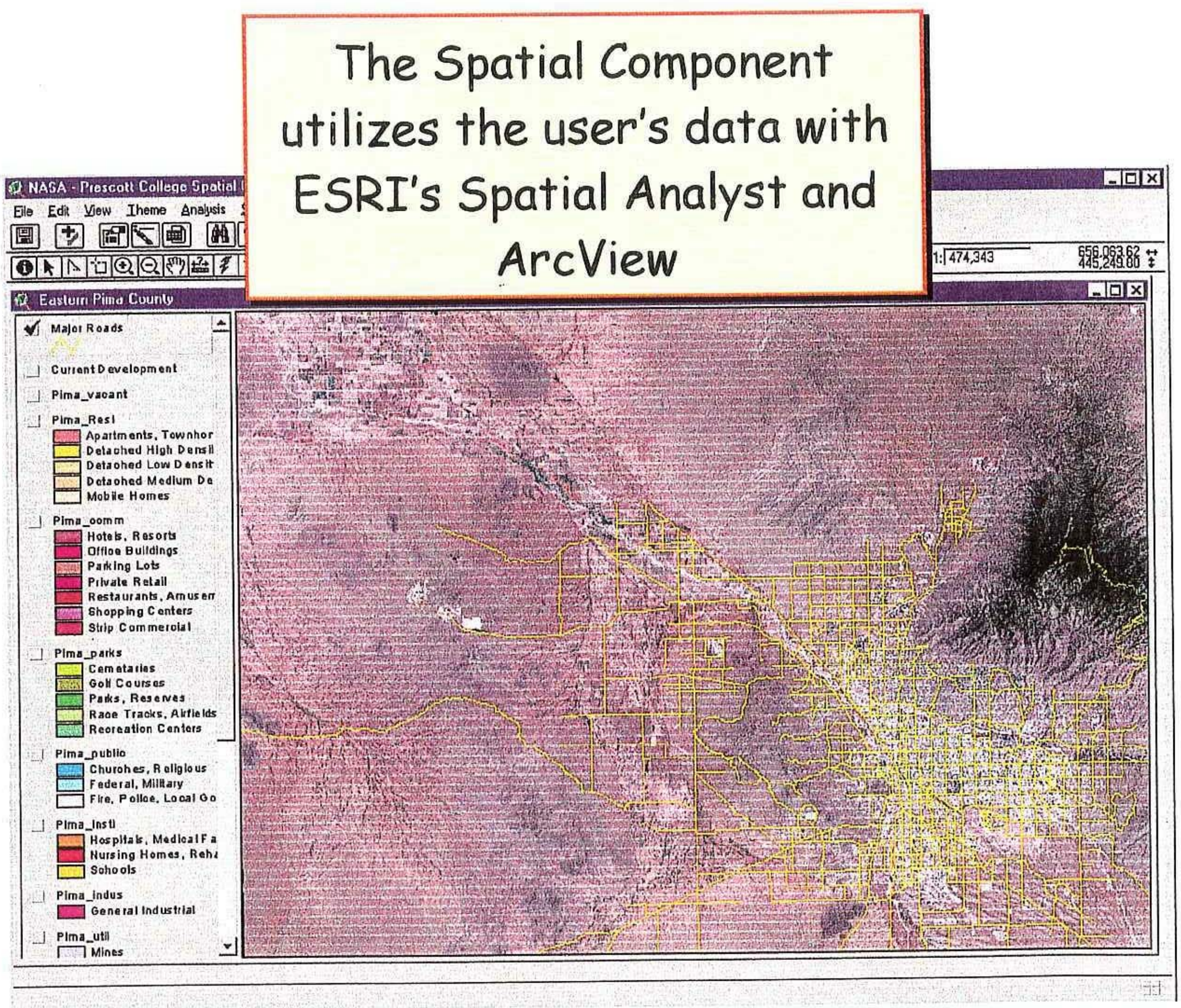


Figure 8. Spatial Element – GIS road data overlaid on Landsat, Tucson, AZ.

The Spatial Component allows for several variables when setting up a model run.

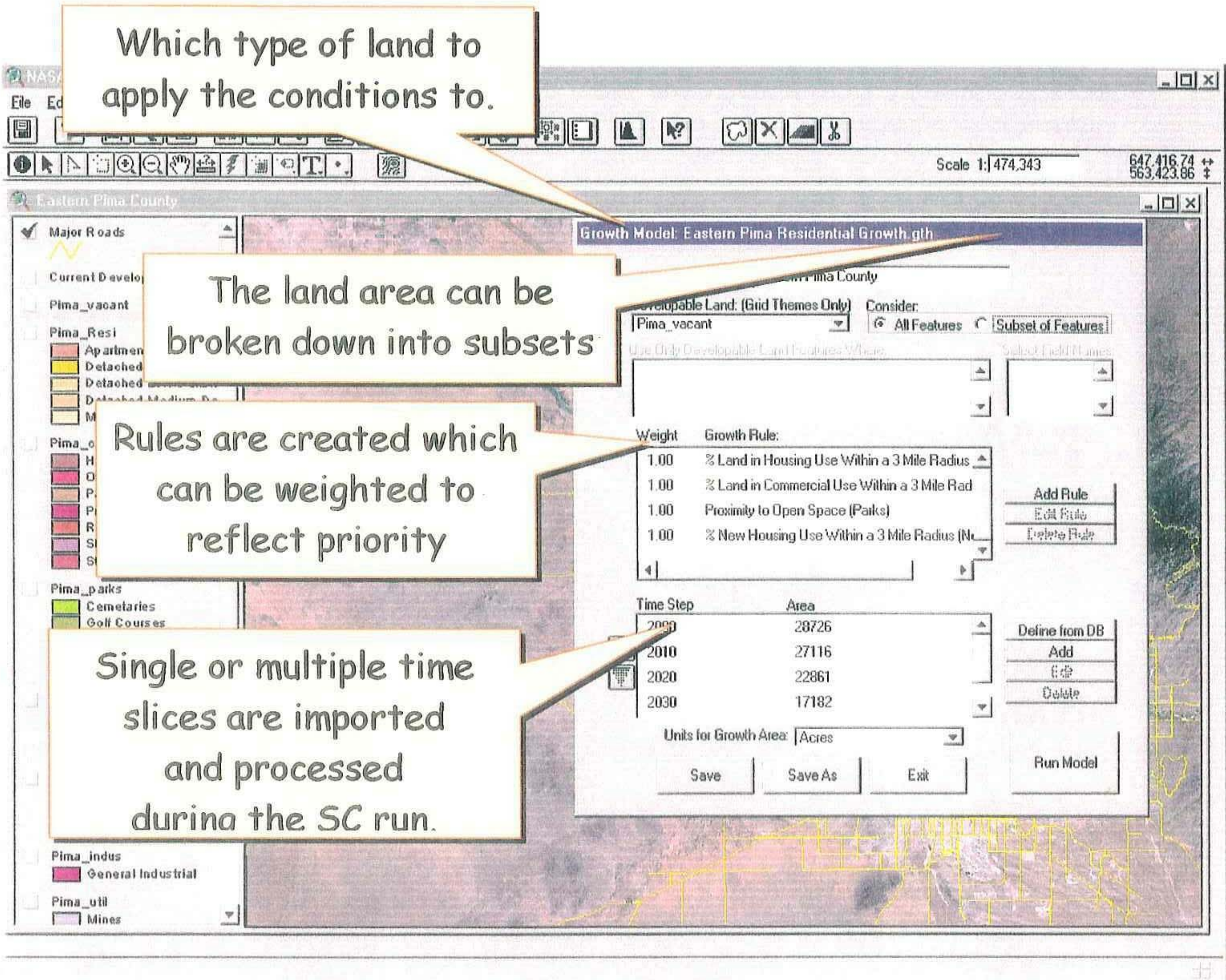


Figure 9. Spatial Element – Selecting Zoning categories.

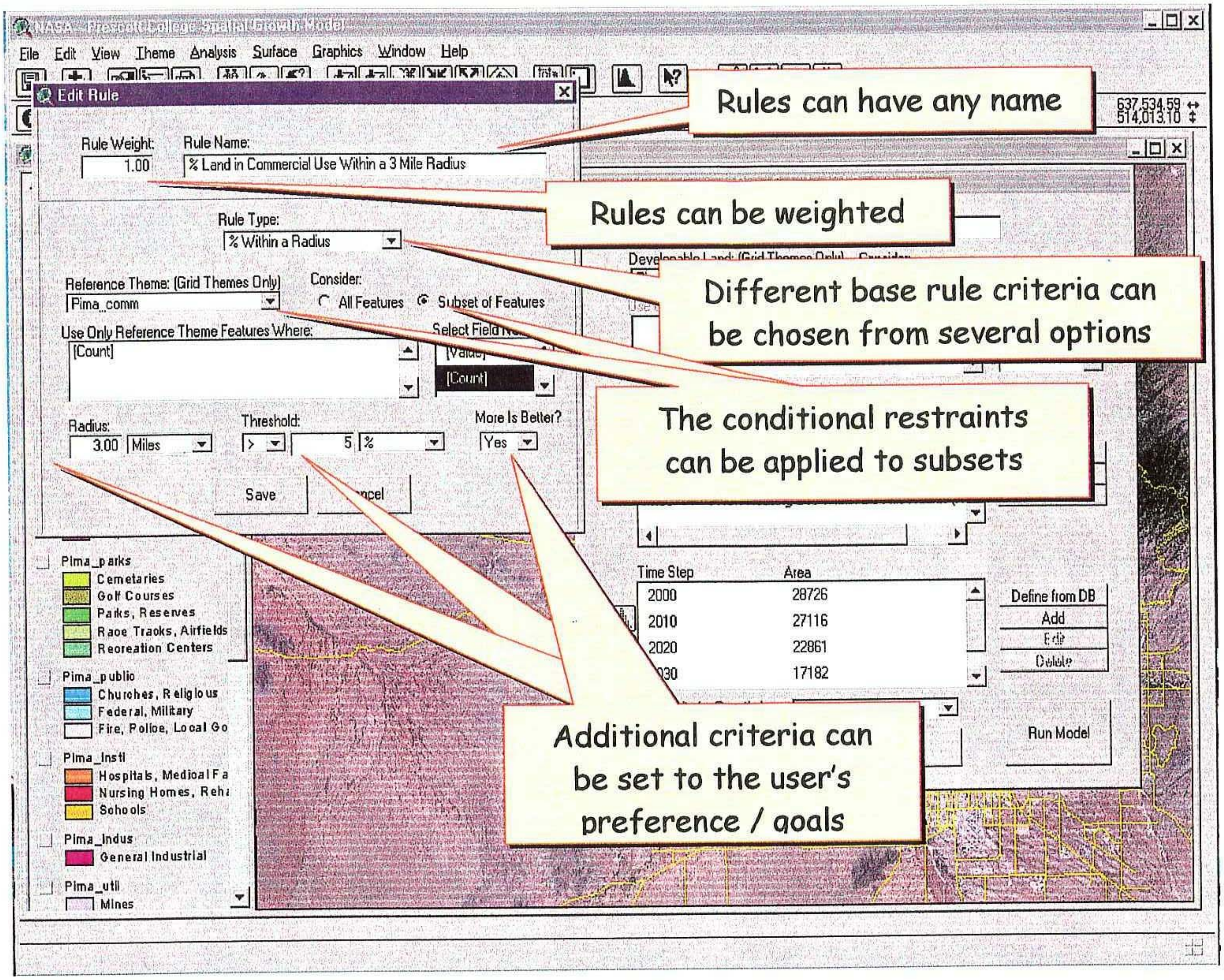


Figure 10. Spatial Element – Defining the specifics for zoning implementation.

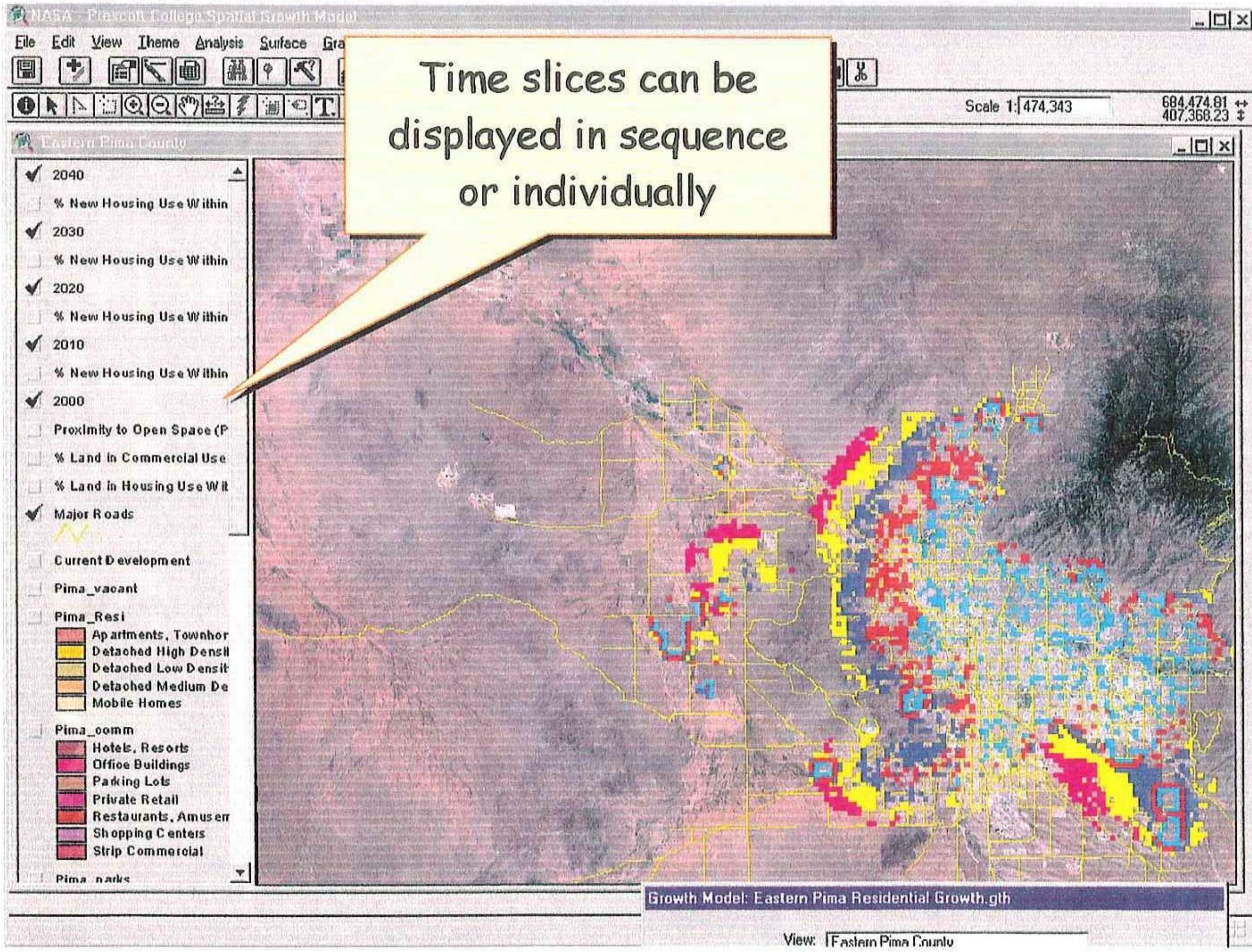


Figure 11. The results of the model are displayed on the base data; these results can be saved for comparison with other runs.

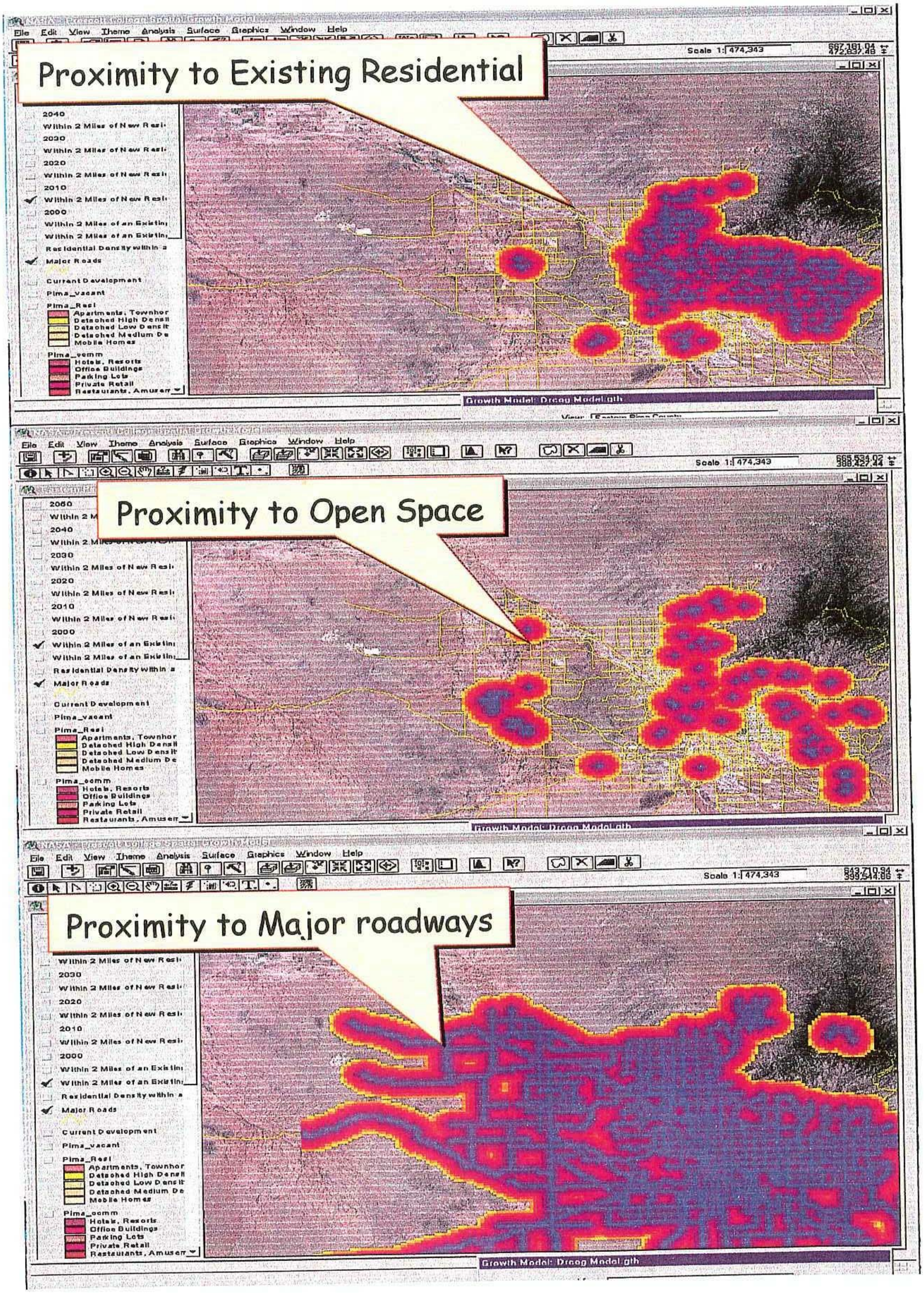


Figure 12. Display of underlying rule criteria.

SECTION 2. ADAPTATION METHODOLOGY

The basic Ugrow©1998 model uses urban data derived from national averages and interrelates the sectors of a community such as population changes and vehicle miles traveled, the accompanying traffic congestion and air quality based on these national averages. Accordingly, the Beta version of the model "thinks" it is the average American community and provides a valuable reference (to national averages) for a community which has built its own adapted version. The conversion of this model to a given community or region for growth impact assessment is reasonably straightforward as the basic Ugrow©1998 model already contains the cross-sectoral equations relating community growth, housing, transportation, land use, economic activity, energy, and quality of life.

Community research and data acquisition

Local research and interviews within each community are essential to acquire accurate data and modify the basic equations to accommodate the dynamics of the specific community. Each community will have its own drivers of growth, economic vitality and social well-being. Additionally, each community will have its unique priorities and dominant issues.[2] These fundamental relationships must be researched at the community level in collaboration with the supporting agencies and interviews with local stakeholders. Excellent data already exists for many communities which permits the adaptation process to focus on building the algorithms representative of the cross-sectoral and external inter-dependencies of the community. In addition to an intensive local interview and research process the modeling team will review the available literature in urban modeling and gather case studies of similar urban areas which may help to relate cross-sectoral (horizontal) responses to a variety of policy options.

Contact process

The first meeting will convene the modeling team with local agency personnel for detailed data collection, research methodology review, resource person identification and individual stakeholder suggestions. This event, assembling the Project Team for a community, will include people with particular expertise in local priorities and process, urban development issues, data management, and/or simulation modeling and other diverse and expert backgrounds (e.g., government, business, university, environmental policy).

The second local meeting will incorporate the broadly based, at-large, stakeholder group into the Project Team with an open discussion of the overall methodology, timing, products and their utilization for an ongoing local integrated assessment process. The overall philosophy of the project and some sample growth scenarios will be presented and the local project "personalized" to the community based on the feedback received. The practical experience of the local team is an essential ingredient in developing a reasonably accurate version of the model for local use.

Model adaptation

Accurate model building is an iterative process requiring successive visits of the modeling team to each community. Local information acquired by the modeling team will be incorporated into the model and the model rerun for the Project Team, including the at-large stakeholders. This cycle should occur approximately every six weeks, (excepting the year end holiday season). Decisions by this team will guide and shape both the model – and the modeling process - by refining the goals, adding to the data base, improving the cross-sectoral algorithms and evaluating the GIS outputs. The group will review the causal factors for local development patterns, *differentiate between growth and sprawl,* and again test the effects of various policies on the development dynamics. These review meetings will be dynamic as equations, variables, new impact scenarios and policies can be changed by the modeling team – and the model rerun on the spot. This flexible, user-friendly, and rapid rerun capability of the system dynamics model efficiently utilizes the resources of this project by minimizing the model building and assessment process development time. The on-the-fly and what-if scenario generation capability rapidly assists the Project Team in refining and building confidence in the model's accuracy.

Model Validation

An investigation of the local urban sectoral interrelationships is an essential first step toward building confidence in a local model version which accurately represents local conditions in the equations. Combining literature review knowledge with historical patterns of local growth (and the judgements of the local Project Team) will build confidence in the model's equations. Essential information, for example, is how developers respond to different property tax policies and impact fees, how vehicle driving patterns change as a function of congestion, and how air quality alters inmigration patterns, local health, and the tourism economy.

A second validation step is to compare the outputs of the model to the historical record. This "hindcasting" helps calibrate the model and builds confidence in the ability of the model to capture future behavior. Preliminary data acquisitions indicate that time-series data such as population, housing starts, household size, number of businesses, tax rates, land use types and other variables are readily available in most communities. The range of these values and the driving forces of growth will likely require different algorithms and calibration methods for each locale.

Third, social and system dynamics scientists have developed a further suite of tests to build confidence in system dynamics models[3]. Primarily through collaboration with decision makers in the pilot communities, we can test the behavior of the model against the understandings of experienced people. However, the testing of extreme conditions, dimensional consistency, parameter sensitivity and other characteristics of the model are essential to validate the equations in the model.

Quantifying the relationship between sprawl, which integrates issues of population demographics, land use, transportation, economic development, open space preservation, air quality and other community factors, is a continual objective of this program. Although its definition and driving forces are expected to show some commonality among American communities, the modeling team will search for the community-specific factors which characterize and force sprawl for a given region.

SECTION 3. INTEGRATION WITH GIS/3D AND DECISION SUPPORT SYSTEMS (DSS)

This activity further develops the linkage coupling the model's outputs to a spatially-oriented GIS. This capability will generate a variety of GIS maps representative of the future community as a result of current/future policy choices and external impacts. Thus, a variety of future commercial, residential, open space, parks, civic, transportation and land use scenarios are produced in response to a range of community development policies. This feature will clarify, visually and dynamically, possible future scenarios for the community and be ideally suited for use with public audiences.

Also utilized is a DSS (*MeetingWorks)* for guiding and recording the public process of debating local issue(s). Assembling a diverse set of participants offers a collective and diverse experience base for developing strategies and action plans rapidly collecting ideas and recording them to one of the system screens. This separates the ideas from their owners, thus **assertive thoughts dominate rather than assertive participants**. This technology offers protection for minority viewpoints through anonymous collection, organization and display of ideas. With fewer and less intense conflicts the participants remain more focused on the assessment topics – and meeting time is simply invested more efficiently. Changes resulting from real time modeling results may be rapidly incorporated into the electronic agenda, thus producing the meeting's minutes with increased efficiency, opinion weighing and issue balancing. The advantages of surfacing minority opinions, improved meeting efficiency and the real-time creation of an electronic record indicate DSS technology can facilitate in-depth debate even under tight time pressures while balancing the perspectives and opinions of all participants.

This work element also tests the capability to digitize visual images of a community, construct a three dimensional (3D) model of a given area and modify it to represent the particular future growth scenario under consideration. This will require integration of the model's output variables into a few which can be interpreted by the software to mean "this community is in decline," "basically unchanged," or "this community is prospering." The software will modify the 3D images of the future accordingly.

Finally, this objective integrates the model, GIS, 3D, and DSS into a three screen, computer-driven system which produces a given model run on one screen and generates GIS/3D images representing the predicted scenario on a second screen. The third screen is used for supplemental imagery or DSS software to record and manage the responses to given policy choices or CCAV impacts and the portrayed community future scenario.

This integrated system dynamically illustrates current issues, response policies and scenarios, long term impacts on the economic, social and evnvironmental essence of the community and, doing so in real time, gives public audiences the opportunity to interact effectively while creating an electronic public meeting record. The capability to do this instantaneously for a variety of issues encourages the *conisderation of a wide range of response strategies. The visual presentation of impacts/responses helps the general public understand the complexities of growth management.*

SECTION 4. TYPICAL WORK PROGRAM *(THIS ONE FOR THE SANTA BARBARA/SOUTH COAST GROWTH MODEL)*

Phase 1 - Building the Model

NOTE: THE WORK PROGRAM HAS BEEN REVISED IN ACCORDANCE WITH THE MEETING ON JANUARY 19, 1999, REQUESTING ACCELERATED DEVELOPMENT OF THE GROWTH, TRANSPORTATION, AND AIR QUALITY ELEMENTS TO SUPPORT THE EVALUATION OF A REGIONAL GROWTH BOUNDARY PROPOSAL.

Stage 1 – February to April, 1999 – Background

The Project Team will meet with key South Coast personnel to research urban growth issues, driving forces and the specific characteristics of the South Coast community. This group will be critical in identifying local data resources and knowledgeable persons who can provide rapid responses to the modeling team's requests. This meeting will clarify the priority issues attendant the proposed urban growth boundary (UGB) for the Santa Barbara regional community. These issues may be either *forcing* or *fallout* issues from the initiative and will provoke the necessary discussion of related impacts on the economy, transportation, air quality and land use.

The Team will clarify which elements of the model will be deferred to Phase 2 in order to concentrate on the growth functions.

The team will review the available literature in urban modeling with a focus on *growth boundaries*, gather data from the sources identified in the initial meeting, interview local stakeholders, and identify local concerns and attitudes regarding growth limits and the interrelationships with transportation, air quality and other impacts. The team will gather relevant case studies of other urban areas (e.g., Boulder, Portland, Atlanta), to assess the results of a range of public and private policies in the growth boundary domain. A thorough understanding of the Santa Barbara community and its shaping forces is essential to this task.

Stage 1 deliverables:

- Summary of other urban models
- Urban case histories – growth boundary impacts/options
- Priority growth boundary issues for the South Coast
- South Coast data summary
- Elemental relationships among growth, transportation, air quality and land use

Stage 2 – May to August, 1999 – Model the growth function

This effort will begin with a one-day event with the modeling advisory team identified in Stage 1. The modeling team will present an initial model constructed during the prior effort. This is a *Critical Design Review* and will determine the modeling team's

focus for the balance of Stage 2. Essential judgements regarding the accuracy with which the model interconnects growth and the related issues are critical at this review. A focused discussion will center on improving the accuracy with which the model characterizes and couples growth with related sectors for the South Coast Region.

Stage 2 deliverables:

- Written report of modifications to the SCRAM and a listing of the assumptions relating the model's growth components.
- Recommendations to improve the value to the community of future work.
- A determination of the specific focus question for the next stage of modeling

Stage 3 – September to December, 1999 – Model use/ refinement

RESPONDING TO THE FOCUS ON THE UGB QUESTION THE MODEL WILL BE UTILIZED IN SEVERAL PUBLIC MEETINGS AS PART OF THIS PHASE. THE CONTINUED REFINEMENT OF THE MODEL WILL ADD TO ITS VALUE FOR PUBLIC USE, HOWEVER, THE EMPHASIS REMAINS ON ASSISTING THE COMMUNITY WITH THE UGB QUESTION, NOT DEVELOPING OTHER MODEL FUNCTIONALITY.

> **THE WORK EFFORT DEFINED BELOW WILL BE REVISED BY THE PROJECT TEAM DURING STAGE 2 TO BEST UTILIZE THE SCRAM FOR THE UGB PUBLIC EFFORT; A SIGNIFICANT PORTION OF THE WORK BELOW MAY BE MOVED TO STAGE 4.**

The following is an iterative process with the modeling team conferring frequently with the Santa Barbara team, acquiring additional data and revising the model to improve its performance.

The advisory group and the modeling team will meet to review the results from the last month of modeling work, revisit goals, share data, study GIS output, and chart the direction for the next stage of modeling. The group will postulate causes for historical patterns of development and test the effects of various policies on the development dynamics. To do so, the group will select assumptions, study data, gather new information, brainstorm theories, and improve their understanding of how this system operates. This process is highly iterative as the model is calibrated to the South Coast region and represents the bulk of the work effort.

A final Year One project review meeting will be scheduled for November, open to all interested parties where the methodology, data sets, and model assumptions will be summarized. Several model "runs" will demonstrate a range of future South Coast scenarios based on various policy choices.

THE FOLLOWING ORIGINAL DELIVERABLES MAY BE SUPERCEDED BY A PUBLIC MEETING PROCESS USING THE GROWTH FUNCTIONS OF THE MODEL TO COMMUNICATE UGB ISSUES.

The deliverables for this phase are:

A. Research, identify and test the drivers of urban sprawl for the South Coast Region.

B. Calibrate the South Coast Regional Assessment Model (SCRAM) by verifying its ability to:
   - Explain past growth dynamics
   - Generate a range of future scenarios for the region
   - Researching the effects of policies and actions

C. Test the model using drivers from other community experiences.

D. Couple the model to a GIS-based spatial visualization model
   - Modify the GIS interface for the South Coast region
   - Develop the South Coast GIS library
   - Test the linkage and output imagery

E. The above constitute an elemental and functional growth model for the South Coast region capable of producing GIS map outputs and community indicators representing the consequences of current policy decisions.

Phase 2 - Using the Model

THE PUBLIC MEETING EXPERIENCE OF PHASE 1, TO UNDERSTAND AND COMMUNICATE THE RESULTS OF A PROPOSED UGB, WILL PROVIDE AN EXCELLENT BACKGROUND FOR THIS PHASE. HOWEVER, DEFERRED WORK IN BROADENING AND CALIBRATING THE MODEL TO THE SANTA BARBARA COMMUNITY WILL BE RESUMED AND COMPLETED DURING THIS PHASE. THIS WILL FINISH THE ITERATIVE MODEL BUILDING EFFORT WITH A TRANSFER OF THE MODEL TO THE LOCAL COMMUNITY FOR CONTINUAL USE.

Stage 4 – January to June 30, 2000 – Model validation
and workshop design

With the core modeling completed, the second year's effort will continue to develop the overall tool by refining the decision support system (DSS) and incorporating the computer visualization technologies. The 2 and 3-dimensional visualization component will utilize digital imagery for selected areas of the existing community and alter these in accordance with the model's output. Thus, a given policy may produce an image of a prosperous community – or one in economic decline. This Digital Visual Preference Survey concept will be tested through a workshop process to help community leaders and decision makers better utilize the model.

Further refinement of the variables used and their relationships will improve the accuracy of the model and the confidence with which it can be used operationally.

This is a continuation of the iterative process to continue upgrading the model.

Several workshops/focus groups will be conducted to refine the public process and facilitation methodology for use of the model for specific issues. The number and extent of this activity will be determined as the final elements of Stage 3 are evaluated.

Primary Deliverables:

- Integrated decision support system
- Visualization component
- Interactive multi-stakeholder policy-testing workshop (number of these TBD)
- Improved consensus among workshop participants on the effects of various policies evaluated across community sectors.

Stage 5 – July 7 to December 31, 2000

Refine the model with final data collection, user interviews, and core model changes. Review the facilitation methodology used in the final Phase 1 workshops and revise the community design workshop accordingly. The entire project team will select a relevant and manageable local issue for a "live" public, community design workshop. The modeling team will support this event, but it will be facilitated by the local/ regional personnel who will be using the model. The model, GIS/3D visualization, and DSS will be utilized for this program which will introduce the technology and process to the general community. Press coverage of some portion of this will be arranged and press packets prepared.

This program will obviously place Santa Barbara in a leadership position to share technological planning tools and public process methodologies with other regional communities. The project team will assist in designing this process, defining any continuing maintenance or revision process, and discuss and modifications or future development options based on experience with other communities. The final activity will include at least one training session to insure a cadre of local/regional personnel have become competent in the use of the model and have the ability to make future refinements to the basic algorithms in accordance with changes in the local drivers of growth, business activity, societal expectations, environmental conditions and other community variables.

Primary Deliverables:

- Final community workshops
- Tested policies for the region
- A local cadre of trained model users
- Action lists emerging from the workshop for future work to be done locally
- Refined and improved model, software, and workshop

TYPICAL LOCAL DATA NEEDED FOR MODEL ADAPTATION

These data, annually, for as far back as possible to help establish trends, are a minimum. Additional data will be helpful and would be discussed with the local project team and the modeling team.

1. **Spatial**
   - Parcel data or land use data (*very important*)
     - (broken up by housing, business, public, infrastructure, et al.)
   - Undeveloped land
   - Geographic boundary of interest
   - Building permits issued

2. **Social**
   - Population (*very important*)
   - Average age
   - Birth fraction
   - Death fraction
   - Immigration rate
   - Emigration rate
   - Average household income

3. **Housing**
   - Number of housing units (*very important*)
   - Land used by housing
   - Units by type -- single family, multi family, apartment
   - Density/Land per house
   - People per house
   - Housing price

4. **Economic**
   - Number of business structures
   - Land used by businesses
   - Number of people employed/jobs available

5. **Vehicle use**
   - Vehicle miles traveled per person
   - Cars per person
   - Average commute time

6. **Environment**
   - Air quality
   - Water price
   - Water use per person
   - Congestion

7. **Public**
   - Property tax rates
   - Cost of providing infrastructure to a new house
   - Public transportation use

REFERENCES

[1] NASA/Ames Multi-year Grant #98-204
[2] Peirce, N, Fighting Sprawl: A New Civil Rights Issue, County News, National Association of County officials, November 23, 1998.
[3] Forrester, Jay W., and Peter M. Senge. Tests for Building Confidence in System Dynamics Models. TIMS Studies in the Management Sciences. 1980. 14, pp. 209 – 228.