Intermountain Rural Electric Association Spatial Electric Load Forecasting
(IREA SELF)

Phase 1
Urban Growth Simulator Application

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Disclaimer

Purpose

This project documentation was written for the sole purpose of completing a required element pursuant to a Masters of Science degree in Geographic Information Sciences at the University of Denver's Geography Department (DU). Intermountain REA and DU are not responsible or liable for any of the information presented in this document.

Audience

The intended audiences of this document are Intermountain REA, the University of Denver's Geography Department, and Duane Holt. This document will also be archived in the University of Denver's Geography Department for student and faculty review.

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Abstract

Intermountain Rural Electric Association (IREA) has embarked on a project to perform Spatial Electric Load Forecasting. This project is broken into two phases, the first being accurate prediction of urban growth that may require IREA to identify areas where new facilities are required and the second being the prediction of electrical load demands in the newly predicted urban growth. This paper covers the first phase of the project that predicts urban growth.

The requirements of the urban growth phase of the project are set to make the project repeatable and sharable among the electric utility community. This requires that the urban growth prediction be performed on single Windows based PC's running ESRI software and programmed in a common language that is also portable. Visual basic was used to create windows based forms that read, manipulate and write raster data files using ESRI ArcObjects.

The urban growth predictions were performed using similar methods as those found in the SLEUTH urban growth model developed by Dr. Keith Clarke at the University of California, Santa Barbara. The model is a cellular automata model meaning that cells are affected and changed based on the values of its neighboring cells. This model utilizes raster datasets of the same resolution and spatial extent for seed files in the urban growth model. These datasets represent current urban extents, areas where urban growth would be excluded, transportation data, and slope values for the study area. The SLEUTH model has three processing modes. First is the Calibration mode where coefficient factors affecting growth are determined from historical simulations. Second is a Self Modifying mode that adjusts the coefficients based on growth rates. Third is the prediction phase where urban growth is simulated.

There are five coefficients that affect growth prediction. They are Dispersion, Spread, Breed, Slope Resistance, and Road Gravity. There are four growth rules in the growth prediction. They are Spontaneous Growth, Breed Growth, Edge Growth, and Road Gravity Growth. Spontaneous growth uses the dispersion coefficient to randomly select cells to become urban. Breed growth uses the breed coefficient to determine if the spontaneously grown urban cells will become urban centers. Edge growth uses the spread coefficient to determine how much an urban center will expand. Road gravity

uses all the coefficients to determine how much growth will occur because of transportation in the proximity.

Calibration is the most time consuming process mode of the growth simulator. This paper presents a calibration method that attempts to save considerable time. This method, termed the High-Low Coefficient Determination, searches coefficient ranges by testing a high value and a low value in the range. The value with the better results determines the next range searched and thus the next values tested. Considerable application development changes were also made to increase the speed of calibration.

Growth prediction was not as accurate as expected. Various methods for checking the accuracy are presented in this paper. The accuracy problems are likely due to a rushed calibration process. Despite the accuracy concern, the simulator application has proven to be a useful tool that met the requirements of the project by being a Windows based urban growth prediction application programmed in a common programming language utilizing ESRI ArcGIS technology.

Table of Contents

Table of Figures

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Glossary and Acronyms

Breed – A coefficient in the growth simulation program that determines the probability that lone urban cells will become urban growth centers.

Calibration Mode – Processing mode that simulates growth with specified model coefficients in every combination to derive the best historical match of urban growth.

Coefficient Start Value – The initial (low) coefficient value used for the calibration process.

Coefficient Step Value – Value added to initial coefficients to search other coefficients in the calibration process.

Coefficient Stop Value – The maximum coefficient value used for the calibration process.

Control Year – A year where historical urban extent data exists and is used for comparison in the calibration mode.
Growth Mode – The processing mode that simulates future urban growth using the coefficient results from the calibration process.

Critical Slope – The maximum slope percentage that will allow urban growth to occur. For this project, the critical slope is 21%.

Diffusion – For this project, interchangeable with Dispersion. See Dispersion.

Dispersion – A coefficient in the growth simulation program that determines the probability of spontaneous growth.

Edge Growth – A growth rule in the growth simulation program that determines the amount of urban growth spread from an urban center.

Geographical Information Systems – In this document, refers to the software, hardware, and people that manage information pertaining to IREA's electric distribution facilities and consumers and their spatial locations to be referenced for mapping, locating, and managing those facilities and consumers.

GIS – Refers to a general term more specifically known as Geographical Information Systems.

IREA – Intermountain Rural Electric Association

LeeSallee – A key statistical result that measures the spatial correlation of simulated urban growth. This statistic is the intersected cells between simulated and actual urban cells divided by the union of simulated and actual urban cells. $S \cap A / S \cup A$ Results closer to 1 indicate a stronger spatial correlation.

PC – Pentium based Personal Computer

NLCD – National Land Cover Dataset maintained by the United States Environmental Protection Agency

Road Gravity – A coefficient value representing the probability of urban growth to occur along transportation routes.

Run – A process of growth cycles for a given number of iterations and number of years for a given set of coefficients.

Seed Year – The start year for calibration or growth processes. There must be a historical urban extent data set for this year.

SELF – Spatial Electric Load Forecasting

Slope Resistance – A coefficient value representing the resistance of urban growth to steeper slopes.

Spontaneous Growth – A growth rule in the growth simulation program that determines the probability that a randomly selected location will become urban.

Spread – The type of urban growth where small developed regions become urban centers. Also a coefficient in the growth simulation program that determines the probability that spread growth will occur.

Chapter 1- SELF Project Background

Introduction

Intermountain Rural Electric Association (IREA) has agreed to participate in a student project acting as the client for the project. The project is a partial requirement for the completion of a Masters of Science Degree in Geographical Information Science from the University of Denver's Geography Department in the School of Natural Sciences and Mathematics. This project and all rights, implicit or explicit, remain the property of the student and IREA jointly.

This project will allow IREA to perform forecasting of electric loads using spatial methods. The IREA Spatial Electric Load Forecasting (SELF) Project will be completed utilizing hardware, software and methods common to Geographic Information Sciences (GIS).

The project consists of two phases. The first phase attempts to predict urban expansion in the IREA territory. The second phase applies historical electric load trends on the predicted urban expansion. Load centers are determined to aid in the planning and procurement of future facility locations. This document covers phase 1, the Urban Growth Simulator Application

IREA Statistics

Intermountain REA is an electric distribution cooperative that operates in the suburban regions of the Denver Metropolitan area. They serve 138,000 customers over ten counties. IREA is the largest electric cooperative in Colorado and the 5th largest electric cooperative in the United States. IREA maintains 7,700 distribution line miles, 39 substations, 1,000 transmission line miles, and is a financial participant in one power generation plant. IREA serves a customer base ranging from dense urban service areas with 1000 customers per square mile to remote single customer areas with 1 customer per square mile. The customer base for IREA is broken down into 92% residential and 8% commercial. Service is provided to the customer base through overhead and underground distribution lines with 60% of the customers served though underground lines and 40% served through overhead lines. The densest population is generally served with underground lines so it is not surprising that only 35% of the distribution line miles are underground and 65% are overhead.

Technical Environment

Intermountain REA maintains records of facilities through CAD and GIS technologies. IREA has recently implemented a GIS that is comprised of ESRI software called ArcGIS. All facility spatial data are maintained in the GIS utilizing geodatabase and ESRI's SDE software for query access. The geodatabase is stored in Oracle on a network server. Client side workstations are PC based. The GIS technologies are overseen by a department of 2 GIS technicians and one GIS supervisor. The GIS department is overseen by the Planning department in the Engineering division of IREA.

Electric load data are the demand or amount of electricity required to serve customers over the whole system. Customer consumption data are the amount of electricity used by a single customer. Consumption data is a measure of actual usage whereas load data is a predictor of how much electricity is required to have available for service. Customer data and electric consumption data are maintained in the Information Services division of IREA. The data are stored in a relational database on a network server. The electric system's load data are maintained by the Planning department. The data are stored in Microsoft's SQL Server relational database on a network server.

Needs & Benefits

Intermountain REA has had difficulties in the past acquiring land for substations and transmission routes. This land is required to build new facilities so that the growing electric demands can be met. Opposition to these types of facilities is strong among the general public. While there is the desire to have reliable service, there is the "not in my back yard" attitude which blocks IREA's attempts to construct needed facilities. At one point, this problem reached a point of impasse requiring service moratoriums, condemnation hearings and many other expensive meetings and public hearings. It is the desire of IREA to never reach a similar point causing such negative impacts to the public and IREA as were seen previously. As a result, IREA has taken a progressive approach to the planning of new facilities.

The Intermountain REA Spatial Electric Load Forecasting (IREA SELF) project is one method to the progressive planning approach. The desired result of the project is the ability to predict future electric load needs with enough location precision to begin land procurement. This ability should be able to be performed for different time spans such as five, ten or even twenty year projections. It is also desirable that a project of this type be portable. Results from this project's methods will likely be valuable to other utilities; therefore it has been completed using standard software and flexible constraints to allow use in other locations.

There are many benefits to be realized from the SELF project. Land procurement at early stages of growth tends to be less expensive less contested. Planning facilities and land use around procured land with a defined use intent is less ambiguous for both IREA and land developers. Construction design and materials ordering can begin earlier resulting in fewer delays to providing service. The most important benefit is that the public is less likely to be combative about new facilities when the intended use of a property has been disclosed early on. This will result in better public relations and less litigation costs for IREA.

Project Components

The SELF project employs scientific methods and modeling to accurately project the urban growth of the Denver Metropolitan area particularly those in the IREA service territory. In addition the project applies electric load estimations to the predicted growth areas. As a last requirement of the project, the entire process has been completed with ESRI's ArcObjects and Microsoft's Visual Basic programming language. This allows sharing of the technology. The Urban Growth Simulator program has been constructed in a manner that allows varying levels of data input and output allowing other users flexibility based on their needs and resources.

The urban growth simulation phase of this project required a data precision fine enough to determine potential substation locations. IREA substations range in size from one acre to eight acres. A one acre substation will contain three single phase platform mounted transformers and two feeders. The largest substation contains three large pad mounted three phase transformers and twenty feeders. The average substation will contain two pad mounted three phase transformers and twelve feeders. This size substation requires approximately 5 acres of land. For this reason, the urban growth simulation uses a cell size of 150 meters square. That means that each cell is 2.25 hectares or about 5.5 acres.

The electric load forecasting phase of the project utilizes historical load data. Actual load data can be calculated from the kilowatt-hour meter reads of each customer. Each customer has a geographical location thereby pinpointing the load for each customer. Since customer densities vary across the IREA territory, the spatial precision of load data will also vary. Electrical load forecasting will be carried out in the second phase of the SELF project under a separate document.

Background

One of the goals of science is the description and prediction real phenomena. Often times these phenomena are too large and complex to explain completely. To overcome this complexity, the study is either reduced in scope or simplified with the use of a model. Much the same way a model airplane allows a child to observe and manipulate the aircraft facsimile; scientific models allow observation, description, and prediction of real world phenomena. Models are a collection of scientific deductions assembled precisely to mimic the attributes of a scientific theory.

Modeling is not a new concept to the electric utility. Many electric utilities will employ one or more models in daily operations. Typically these models are network based models. A network based model is a compilation of points and lines connected together with relationship to each other that describes the real world wires and equipment that make up an electric utility distribution system. The electric utility model typically contains a source and then expands outward, or downstream, in a radial fashion to the customer meters. Some utilities will have a looped network that feeds back onto itself, but that is not the practice at IREA.

The first phase of this project uses a model to simulate the urban growth. There are many factors that contribute to the expansion of urban development. While there are too many to list, the common factors include proximity to goods and services, transportation capacity, and desirable habitat. There are almost as many models for urban growth as there are factors contributing to it. Some models are descriptive in nature whereas some are mathematical representations.

Descriptive Urban Models

There are several models that try to describe the urban dynamics (Candau, June 2002). In the early 1800's, the VonThunen model was developed. This model is sometimes referred to as the Central Pole Theory where all urban is centered about a central point. The VonThunen model based land cost on agricultural markets. VonThunen observed that those with vegetable crop were more likely to pay higher rents closer to the city than those with ambulatory livestock who lived further from the city at lower rents. The model describes land closer to the city as being smaller in plot size and more expensive then land further from the city. While the model still holds some legitimacy, it did not account for transportation networks or physical geography.

In the middle 1920's, E. W. Burgess devised the Concentric Zone Theory to describe urban areas. The Concentric Zone Theory is based on industrialization and the workers of the industries. The urban area is divided into rings, or zones, from the center outward much like an archery target. Zone 1 contains the central business district. Zone 2, surrounding zone 1, is the multi-use zone of lower class housing mixed with industry. Surrounding zones 1 & 2 is zone 3 made up of residences for the factory working class. Further out is zone 4 comprised of middle class commuter residences. The last zone and furthest from the urban center is comprised of the upper class. This model also holds legitimacy but disregards physical geography.

In 1933, Walter Christaller developed the Central Place Theory. This is different than the Central Pole Theory. The Central Place Theory model states that there is a central community that is supported by surrounding smaller communities. The further out from the central community, the smaller the supporting communities. These supporting communities are part of the sphere of influence by the central community. Each smaller community also serves as its own central community with its own sphere of influence. Christaller noted that when all the communities were connected, the spheres of influence formed geometric shapes such as triangles and hexagons.

In 1939, Hoyt expands on the Concentric Zone Theory with the Sector Theory. This theory incorporates travel routes which extends portions of the zones outward along the routes. Where travel routes do not exist, certain zones won't exist. The result is segregated sectors of the zones. To further this expansion away from the central urban center, C. D. Harris and E. L. Ullman develop the Multiple Nuclei Theory. This theory states that the central business districts are dispersed throughout the urban area. These disperse business districts are influenced by worker proximity and product distribution. The results are a closer representation of current urban expansion.

Mathematical Urban Models

Urban Geography has always been interested in the expanding urban landscape. Older growth simulation methods were cumbersome and difficult to prove accuracy but GIS has renewed the interest and allows newer perspectives on growth simulation models (Aitken, Mitchell, & Staeheli, 2003). There are many methods and examples of urban growth simulation. Aitken lists the three main categories of model computations as Fractal, Agent-Based, and Cellular Automata (Aitken et al., 2003). Fractal modeling divides a region into smaller but similar regions based on a simple rule. The division occurs over and over many times to create a growing model. Agent based modeling relies on a single agent to act a certain way until some change is applied then as rules are applied the agent reacts to the change. Models can contain multiple types of agents with differing rules to simulate different scenarios. Cellular Automata models are cells that react depending on neighboring cells and the rules applied.

When referring to growth simulation though, this becomes more than just computations for modeling and steps into the realm of computational intelligence. Computational intelligence doesn't refer to computers with artificial intelligence but rather processes that run through iterations and automatically adjust variables based on iteration results, rules base decisions, and fault tolerances (Legates, Gopal, & Rogerson, 2003). Legates et al. go on to delineate the four most common methods. First is the neural network which is a non linear extension of a statistical model. A good example of this technology is discussed later with regard to electric load forecasting (Ghiassi, Zimbra, & Saidane, 2006). Second is genetic programming which simulates evolutionary process. Third is fuzzy logic which is capable of modeling nominal data and heuristic intuition. This was also indicated above in electric load forecasting (Chow, Zhu, & Tram, 1998). The fourth and most common approach to growth simulation is cellular automata (CA). This approach uses a regular grid and assigns classification to each cell. The cells then change their classification based on neighboring cells and applied rules.

Modeling Considerations

David O'Sullivan, while reflecting on unnecessary high resolution grids for a rural area, writes about an extension to CA called CA gentrification (O'Sullivan, 2004). Rather than use regular grid cells, CA Gentrification uses located vertices that don't need to be regularly spaced but interact with each other based on proximity and applied rules. There are several considerations with urban growth modeling. First is scale as discussed (Jantz & Goetz, 2005). In this article, Jantz studies several different CA models and processes them at various scales to determine an optimum scale. The results show differing thresholds based on urban densities and do not clearly define a single optimum scale but rather show a researcher the impact of using an incorrect scale.

Growth simulation modeling is a very intensive process with a large resource demand. Among those resources is computer processing demands. There have been studies dedicated to determining the best method for minimizing computational requirements and determining the proper hardware required for such simulations. One such study appears in Geoinformatica (Dietzel & Clarke, 2006b). One recommendation put forth by this study is the need for researchers to publish the open source code so that others may be able to refine processes and gain usability as computer developments evolve. This ensures the original processes to be a valid source of knowledge into the future.

Arguably the most important consideration with urban growth simulation is the calibration process. This is mentioned in almost every article about the subject(Dietzel & Clarke, 2006a; Dietzel & Clarke, 2006b; Herold, Goldstein, & Clarke, 2003; Legates et al., 2003; O'Sullivan, 2004; OĞUZ, 2004). This is the process of setting some base parameters and running the calibration programs. Each time the programs are run, they apply multiple iterations and record results. The results are then used to determine the variables applied to the rules that govern the simulation.

One other consideration of urban growth simulation that is not as prominently documented is that of policy. Policies and plans such as zoning are difficult to apply to simulation models but many of these decisions are derived from them. Large multi-agency collaborations have utilized these simulation models (Margerum, 2005; White, Straatman, & Engelen, 2004) and set policy based on the predictions. The difficulty with these collaborations is the documentation of the plans set forth and the use of those plans in future simulations. If they are not clear, they are not likely to be followed (Margerum, 2005).

> This raises questions about whether existing models need to be amended for metropolitan settings to better address complex institutions and large numbers of decision-makers. Several studies have demonstrated the difficulty of collaboration at the metropolitan scale, and these issues would benefit from additional cross-case comparisons.(Margerum, 2005)

Specific Urban Growth Models

There are many specific models for urban growth simulation. These are listed in a doctoral thesis out of Texas A&M University and includes Christaller's central place theory, Alonso and Muth's land-use transition model, and Batty's diffusion limited aggregation (DLA) model (OĞUZ, 2004). For the IREA SELF project, the focus is on CA models. Roger White is considered the pioneer of CA model use for urban growth simulation (OĞUZ, 2004). Some of the CA models discussed in a writing by White include the LeefOmgevingsVerkenner (LOV) and BabyLOV which were used in a collaborative VISION project for the European Union (White et al., 2004). These models take into consideration the global supply and demand factors for a larger regional study. Dr. Keith Clarke is also at the forefront of CA use for urban simulation as noted on the Project Gigalopolis Website (Candau, 2007a). His Urban Growth Model (UGM) developed at the University Of California Santa Barbara Geography Department

(UCSB) has been adopted and combined with Land Cover Deltatron (LCD) by the USGS. The combined efforts of the USGS and the UCSB department of Geography have made this a publicly downloadable program coined SLEUTH. This is an acronym for the components required to run the program namely Slope, Land use, Exclusion, Urban extent, Transportation, and Hillshade (OĞUZ, 2004). The SLEUTH model processes simulated growth and compares that simulation to actual data from control years. Based on results, coefficients are derived that allow growth simulation into the future. The optional part of the program is land cover change analysis. The SLEUTH model has proven to be successful both on the local and regional scales (Herold et al., 2003; Jantz & Goetz, 2005; OĞUZ, 2004) and is an appropriate approach for the IREA SELF project.

Spatial Electric Load Forecasting

Electric load forecasting is important to distribution companies and their planning efforts. This forecasting allows distribution planners to protect, maintain, and add facilities based on the amount of load required. In addition to load requirements, the geographic distribution of the load is also required for planners (Chow et al., 1998). Spatial electric load forecasting has been attempted for decades.

Three large projects are considered the milestones in load growth applications and are listed by Lee Willis in a short publication simply titled ‘Spatial Load Forecasting’ (Willis, Engel, & Buri, 1995). In the 1960’s, Arizona Public Service performed load growth analysis using land use information and bell curve showing concentric dispersion from the city focal point of downtown Phoenix. Through the 1970’s, Westinghouse created two programs that were utilized by several utilities. These programs predicted load growth using polynomial trend curves and multi-variate regression. While these programs were fast, they had some accuracy issues and they lacked any strong geographic component. Houston Light and Power (HL&P) was experimenting with different methods at the same time that Westinghouse was developing their programs. HL&P settled on a land use grid method. They added multi-dimensional pattern recognition to analyze constraints. This method is the basis for most load growth simulations today.

There are other methods such as dynamic neural networks mentioned in an article published in the ‘Electric Power Systems Research Journal’ (Ghiassi et al., 2006). The method evidenced in this writing also applied weather and seasonal variables with a very high degree of accuracy but it did not contain a geographic component. Other load forecasting methods include trend analysis with an attempt to overcome the day-to-day changes of the electric network (Willis, Tram, & Rackliffe, 1992). In this article, Lee Willis removes the network switching configuration by coupling feeders that have been switched and grouping feeders of similar type and location together. An interesting step in this example was to set a horizon limit to the load growth at a specified time frame. This helped improve the accuracy of the trend analysis even though the horizon estimate was not accurate. Fuzzy logic is another method for predicting spatial load forecasting. Applying multi-objective decision rules to fuzzy models allows for more accuracy as shown in an article published in the ‘IEEE Transaction on Power Systems’ journal (Chow et al., 1998). This method is comprised of memberships, rules that govern interaction between memberships, and multi-objective decisions that constrain and direct the rules governing membership relations.

A paper written by Jessica (Noonan) Valenti and presented at the 2006 Electric and Gas Users Group meeting lists three main components that feed into spatial electric load forecasting models used today (Noonan). First is the historical load data. This is usually a compilation of substation meter data and customer usage. Second is a load classification schema. This refers to the type of customer and their usage such as industrial, light commercial and residential. Third is land use information. Most of the spatial load forecasting models are grid based to a resolution of quarter sections or approximately 2600 feet x 2600 feet. One problem posed in another paper by Lee Willis (Willis, Finley, & Buri, 1995)is that this resolution in rural areas where a customer base is very sparse might cause models to infer more growth than is likely. To improve accuracy, Willis suggests using road frontage versus property area to determine development probabilities. In any case, the key feature to successful spatial load forecasting is land use information.

> Land-use simulation is the only realistic choice for long-range distribution planning studies, where accuracy and multi-scenario planning capability are necessary. (Willis, Finley et al., 1995)

Project Scope

The scope of the IREA SELF project focuses on the geographic area that IREA services. Portability is an important component of the project so consideration has been given to allow for other geographic regions to be applied. Precision is another scope consideration. While remaining open ended for portability purposes, the SELF project focuses on the scale and precision required by IREA.

Spatial

The IREA territory covers portions of 10 different counties adjacent to the Denver Metropolitan area. Reference the territory maps in Appendix A. The territory can be generally described as areas to the East, South and West of Denver. The counties served are Adams, Arapahoe, Douglas, Elbert, El Paso, Teller, Fremont, Park, Jefferson, and Clear Creek. There are four operating districts for IREA. They include the Strasburg District, Conifer District, Woodland Park District and Sedalia District. The Strasburg district serves the currently rural portions of Adams and Arapahoe counties. The Sedalia district serves Douglas and westerly portions of Elbert counties. The Woodland Park district serves small portions of Fremont and El Paso counties. That district also serves Teller County and the part of Park County known as South Park. The Conifer District serves a small portion of Clear Creek County, the mountainous portions of Jefferson County and the eastern portions of Park County.

Due to the geography of the Colorado Front Range, IREA has two distinct geographic regions within the service territory. The Mountains region is serviced by the Conifer and Woodland Park operating districts while the Plains region is served by the Sedalia and Strasburg operating districts. The two distinct regions also share different service attributes with the plains region being more urban based with high service density and the mountains region being more rural based with more sparse service density. Fortunately, there is a good correlation between the service boundaries, served counties and geographic regions. Of the counties served, Jefferson County is the only one that participates in both mountain and plains geography but IREA does not serve the plains portion of Jefferson County. The good boundary line correlations are beneficial for data compilation as well as growth model calibration.

This project phase focuses on Douglas County. Douglas County contains both extremes of the population density within the IREA service territory. While Douglas County is considered a plains region in the service territory, the county does include some mountainous areas. Because of the variety of population density and terrain, Douglas County serves as good pilot region for the SELF project.

Precision

As mentioned above, the average substation occupies about 5 acres of land. For that reason, the urban growth simulation uses raster data with a pixel size of 150 meters by 150 meters. Source data was collected at a 10 meter by 10 meter resolution for raster data and vector data was rasterized to the same resolution. Once collected, the source data was aggregated to the 150 meter by 150 meter resolution for the working data.

Project Data-Urban Growth Simulation Phase

The data for the IREA SELF project is in the UTM Zone 13 North projection utilizing Meter units.

The IREA SELF project involves 2 phases requiring data. The first phase for urban growth simulation requires several raster data sets. The second phase for load classification also requires a raster data set. It is required that all data sets are in the same resolution, same projection and cover the same extents with the same origin.

Since it is the intent of the SELF project to closely approximate the SLEUTH urban growth model for the urban growth simulation phase, the requirements for the corresponding data were derived from those delineated on the Project Gigalopolis website (Candau, 2007a). In the SLEUTH urban growth model, the datasets are Slope, Land Cover, Exclusion, Urban Extent, Transportation and Hillshade. For the SELF project, the Urban Growth Simulator is written so that the Urban Extent and Land Cover data are classified with the same code values. Land cover data is not used in the simulator but used to create the working datasets within the simulator. For these two reasons, the data for the Urban Growth Simulator program can be run with Slope, Exclusion, Urban Extent, and Transportation datasets. Examples of these data sets can be seen in Figure 1. Actual images of the data sets can be seen in Appendix B.

Slope

The slope data required for the SELF project is a raster data set derived from digital elevation models (DEM). DEM data can be downloaded from the USGS National Map website (United States Geological Survey, 2007). This data set was projected to UTM Zone 13 North NAD 1983 coordinate system. The DEM data is then converted to slope data using the slope analysis tools in ArcGIS. The output was set to Percent versus Degree. The source DEM and slope data produced are in a 10 meter by 10 meter resolution. For the project, the slope data needed to be aggregated to a 150 meter by 150 meter resolution using the average slope value for the larger cell size.

The resultant raster file is in the ESRI Grid format containing continuous data. The data are 32bit floating point precision.

Land Use / Urban Extent

The land use data acquired for the SELF project was a raster data set created by the U.S. Environmental Protection Agency (EPA). It is derived from vector digitized and remotely sensed digitization of distinct land use classes. The raster dataset is classified by various land uses such as urban, forested, and agriculture lands. This data is downloadable from the US EPA website for National Land Cover Data (United State Environmental Protection Agency). The data was classified according to the 2001 NLCD classification scheme also found on the EPA website. In effect, Urban would be any value between and including 21 through 29. Other values indicate other types of land cover. There were a couple problems with this data. First is availability. Currently, the NLCD data is only available for 1990 and 2001. The Urban Growth Simulator program requires at least three control year datasets to derive a statistical solution. This means that the NLCD data would need to be interpolated to create a third dataset. This would still result in only an 11 year data span limiting the historical range to analyze. Second is the data consistency. Both NLCD datasets were compiled using different standards and different source information. The inconsistent lineage results in differences in the data that may affect growth calibration. As flexibility is one of the requirements for the SELF project, the NLCD data can be used and will provide a solution but a different approach was used to create land use data for the SELF project. A highly detailed data source that is available from most county governments is the parcel data maintained by the assessor's department. A common field in this data is the year that a structure was built on the parcel. Raster files can be created from selected parcels that have a given year built value or older. This can be repeated by adding more years to the selection set and building another raster dataset. For the SELF project, the seed year was 1980 and control files were made for 5 year intervals through 2005.

The source land cover data is a raster dataset derived from Douglas County Parcel data. The raster datasets are in a 10 meter by 10 meter resolution. The resultant datasets from the parcels was classified to urban and not urban coded values. Urban cells were coded with a value of 23 but could have been any integer value ranging from 21 to 24, non-urban were coded to a value of 1 but could be any other integer value greater than 0 and less than 100 that doesn't fall within the urban range, and the no data value was set to 0. For the project, the land cover data needs to be aggregated to a 150 meter by 150 meter resolution using the maximum land cover value for the larger cell size. This means that if a 10 meter cell centroid was in a parcel with a year built value it received an urban status and upon aggregation, if a 150 meter cell contained any urban it was set to urban. The resultant raster file is in the ESRI Grid format containing continuous data. The data are unsigned 8 bit integer precision. The tabled values are 23 for urban, 1 for non-urban and 0 for no data. There are several raster files in this data set. One for the seed year and the rest for control years used in the calibration processes.

Exclusion

The exclusion data set is also a raster data set. This data are derived from vector digitized data. These data delineate areas resistant to urbanization. The values range from 1 to 100 and a no data value of 0. Any value over 100 is considered 100. An excluded area with a value of 100 is completely resistant to change such as bodies of water whereas areas with values of 1 are not resistant to change. An unclassified wetland may be classified a 30 whereas a dedicated open space may be classified an 80.

For the SELF project, the sources of this data were Colorado Department of Transportation's Federal Lands shape file, Douglas County's Water Bodies shape file, and Douglas County's Open Spaces shape file. Raster data sets were created for each shape file with a value of 100 within the boundaries in the shape files, a value of 1 for areas outside the boundaries, and a value of 0 for no data. The resulting raster datasets were then combined using map algebra and adding the values together. The resulting raster dataset was then classified with any value 100 or greater becoming 100, any value greater than 0 and less than 100 becoming a 1, and all no data values becoming a 0. This data is also in the ESRI Grid format containing continuous data. The data are unsigned 8 bit integer precision.

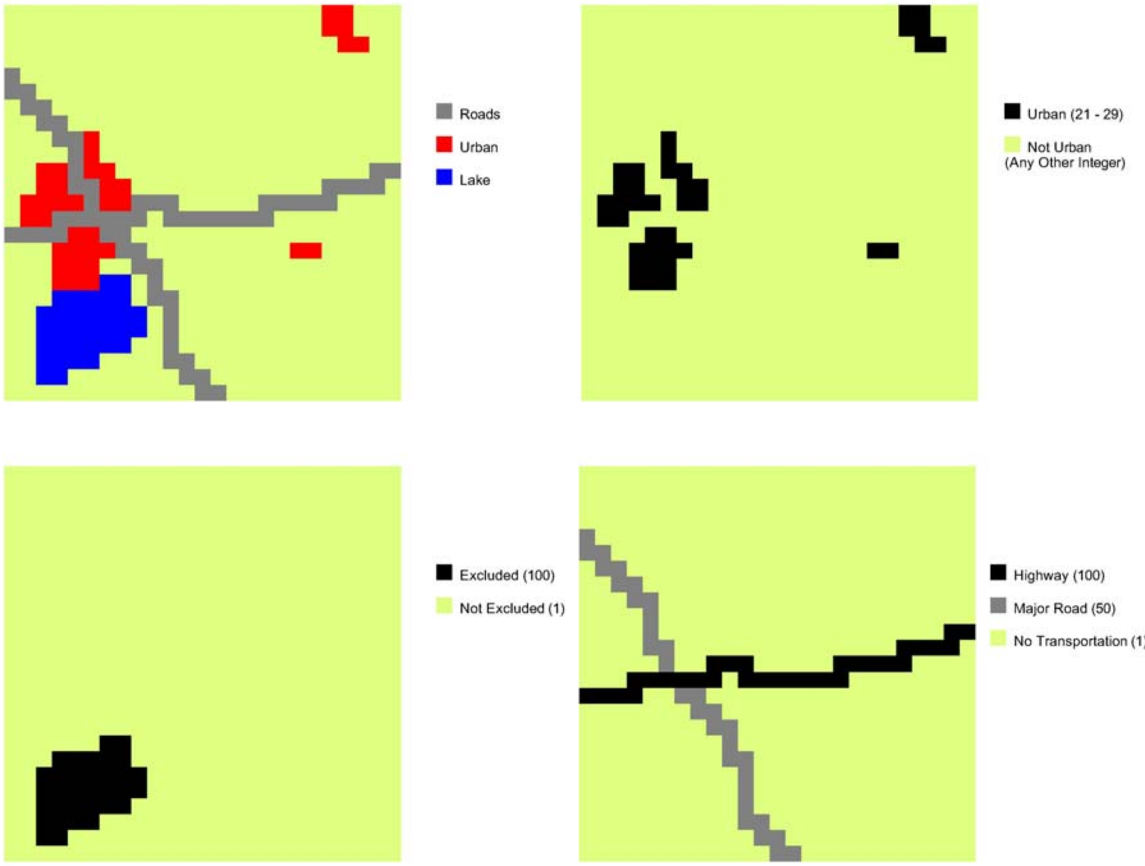


Figure 1 – Dataset examples from top left clockwise;
Existing land cover, Urban extent, Transportation, and Exclusion

Transportation

Transportation data are vector data converted to raster that include road information. The pixels have values representing the weighted value of a road, such as 100 for a highway and 10 for a residential road. Transportation is a key component of urban growth so it is prudent to include as much transportation information as possible.

For the SELF project, the source for transportation data was the Colorado Department of Transportation. They maintain several different road shape files, each containing a different class of road. In these shape files, there is field that indicates when the road was built. Even though this data was not consistent, the majority of the data had a posted year built value and was suitable to create historical road datasets.

In the SELF project, it was assumed that urban growth was only influenced by highways and major roads. Residential roads were only present when urban development had already occurred yet major roads and highways often traverse ground available for development. Two shape files from the Department of Transportation were converted to raster datasets. The two raster datasets are then added together with map algebra and then reclassified. If the two datasets had overlapping values, the higher value was saved. The values in the resulting raster dataset are 100 for highways, 50 for major roads, 1 for non transportation and 0 for no data. There were multiple datasets made for the control transportation years. All transportation datasets are in the ESRI Grid Format containing continuous data. The data are unsigned 8 bit integer precision.

Hillshade

The hillshade data are DEM data used as a backdrop for the resultant data to provide spatial reference. The source for these data is the same as the slope data and will be processed with hillshade techniques common to GIS.

Urban Growth Simulation Methods

The SELF Urban Growth Simulator closely assimilates the SLEUTH model methods. The SLEUTH model makes the assumption that future urban growth can be predicted based on and mimicking historical urban growth patterns for the region being studied. The SLEUTH model uses cellular automata to analyze and predict the probabilities that a cell will become urban. Cellular automata use neighboring cells and rules to determine the probabilities that a focus cell will change. In the case of the SLEUTH model, there are multiple layers of grids and the neighboring cells of each layer are analyzed for the same focus cell location in each layer. To predict urban growth, the SLEUTH model first needs to be calibrated. This is an iterative process of trying many variables and analyzing the results to determine which variables create the best fit to known historical data. The SELF Urban Growth Simulator follows much of the same methods as the SLEUTH model.

Calibration Coefficients

The SELF Urban Growth Simulator uses five variables or coefficients in determining growth patterns. The ranges for each of these variables are 1 through 100. The first coefficient is *Dispersion*. This coefficient determines the propensity of spontaneous urban growth throughout the study area. The second coefficient is *Breed*. This coefficient determines if the newly urbanized cells from the spontaneous growth will become urban growth centers or not. The third coefficient is *Spread*. This coefficient is determines how much an existing urban center will spread outward from the center. This is also known as edge growth. The fourth coefficient is *Slope*. This coefficient is a factor in how resistant urban growth is at certain slope values throughout the growth cycles. This is factored in for every cells determination of being available for urbanization or not. The fifth coefficient is *Road Gravity*. This coefficient determines the probability that urban growth will be drawn towards transportations routes.

Calibration Rules

There are four rules in the SELF urban growth simulator. Each rule is applied for each growth cycle which represents 1 year of growth in the model. The Urban Growth Simulator needs to know which cells are grown by which rule so each rule will create cells with different coded values depending on the type of growth that occurred. For instance, Spontaneous growth cells will have a value of 26, Breed growth cells will have a value of 27, Spread growth cells will have a value of 28 and Road Gravity growth cells will have a value of 29. At the end of each growth cycle, statistics are gathered and all new growth for that cycle will be recoded with a value of 25.

The first rule is the *Spontaneous Growth* rule. This rule randomly selects cells across the raster. If the selected cell is available for urbanization then the simulator will make that cell urban. The dispersion coefficient is used in this rule of growth. This value determines how many cells will be selected for urbanization in a growth cycle but is limited to no more than 50% of the image diagonal if the dispersion value were set to 100.

$$dispersionvalue = (dispersion * 0.005) * \sqrt{rasterwidth^2 + rasterheight^2}$$

```
do until dispersionvalue
  select cell @ random column, random row
    if cell can be urban
      urbanize cell
    endif
loop
```

Figure 2 – Pseudo Code for Spontaneous Growth

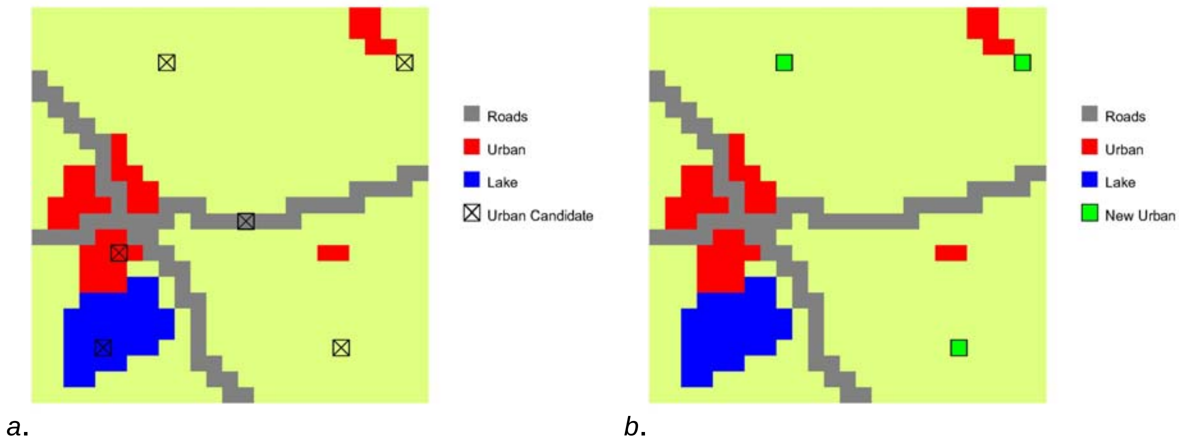
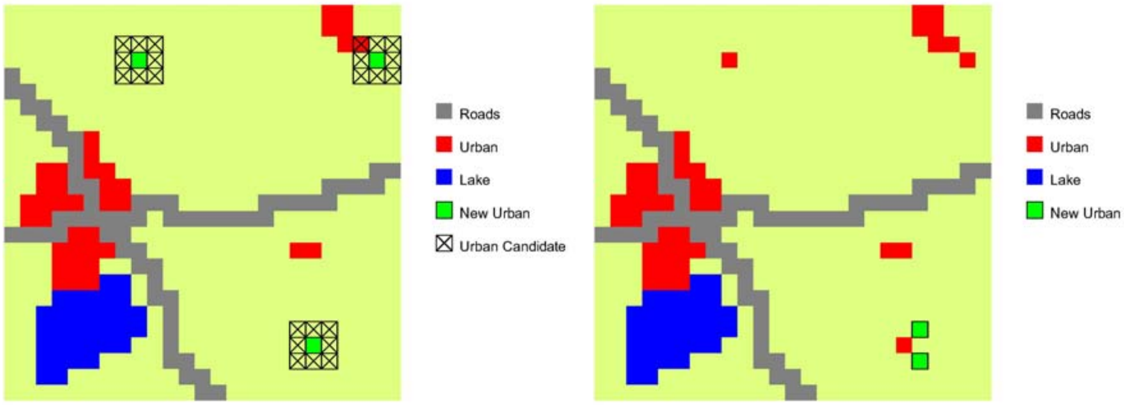


Figure 3 – Spontaneous Growth;
a. Randomly select cells
b. Urbanize if possible

The second rule is the ***Breed Growth*** rule. This rule selects new cells from spontaneous growth within the current growth cycle and randomly decides whether or not the cells will become new spreading urban centers. The randomness in this growth rule is weighted by the breed coefficient. A random number is generated between 1 and 100. If that number is less that the breed coefficient, then two random neighbors of the spontaneous growth cell will become urban.

```
if random(1,100) < breed coefficient
  search neighbors
    if at least two neighbors available
      urbanize two at random
```

Figure 4 – Pseudo Code for Breed Growth



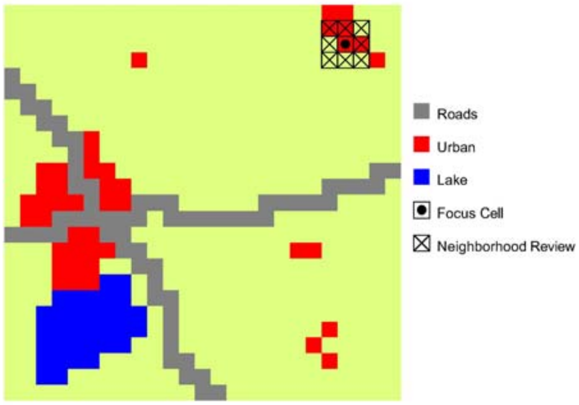
a *b*

Figure 5 – Breed Growth;
a. Select spontaneous growth cells
b. Randomly urbanize two neighbors

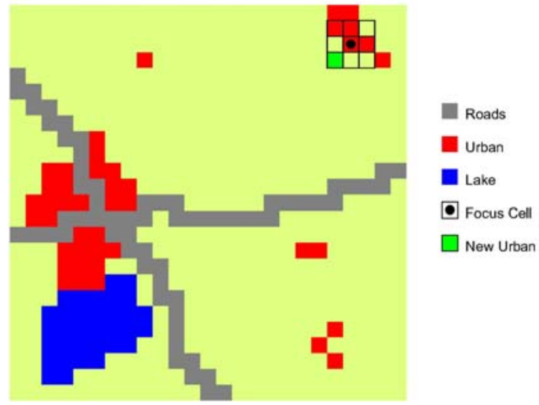
The third growth rule is Spread Growth. This growth rule determines the amount of urban growth along urban cluster edges. In the SLEUTH model this is also known as Edge Growth. The spread coefficient is used in the spread growth to weight the randomness of urbanizing a neighbor of an urban cell along the edges of urban clusters. The raster data set is scanned for urban cells. When an urban cell is found, a random number is generated between 1 and 100 and if that number is less that the spread coefficient, it is selected for spread growth. If the cell is selected for spread growth, its neighbors are searched. If there are at least 2 urban neighbors and less than 8 urban neighbors, then one of the non-urban neighbors will be urbanized.

```
if cell is urban
  if random(1,100) < spread coefficient
    search neighbors
      if 2 < urban neighbors
        if 2 < available neighbors > 8
          urbanize 1 available neighbor
```

Figure 6 – Pseudo Code for Spread Growth



a.



b.

Figure 7 – Spread Growth;
a. Search neighbors of urban cell for 1-7 urban cells then search for 1-7 available cells
b. Randomly urbanize one available neighbor

The fourth growth rule is *Road Gravity Growth*. This growth rule determines how much transportation influences urban growth. This growth rule uses the road gravity coefficient, the dispersion coefficient and the breed coefficient. The raster dataset is scanned to find urban cells. Once an urban cell is found, a random number between 1 and 100 is generated and, if less than the breed coefficient, then the cell is promoted to the road search processes. The road gravity coefficient is used to generate a road gravity value. This value is a percentage of 1/16 of the image size. That is to say if the road gravity coefficient is 100, the road gravity value would be 1/16 the image size. Using this road gravity value, neighborhoods of increasing size are searched for transportation cells. Once a transportation cell is found, then the road is walked a distance that is a factor of the road type found, the road gravity coefficient, and the dispersion coefficient. At the end of the walk, the neighborhood is searched for a cell to urbanize. If there is a new cell urbanized, then its neighbors are searched to urbanize two more cells.

```
road gravity value = (road gravity coefficient / 100)*((raster width* raster height) / 16)
if cell is urban
  if random(1,100) < breed coefficient
    search increasing neighborhoods (i.e. 3x3 then 5x5 then 7x7 and so on)
    if transportation found
      walk distance = (transportation cell value / road gravity coefficient) * dispersion coefficient
      travel the walk distance along road
      urbanize 1 available neighbor
      if urbanized
        urbanize 2 neighbors of the new urbanized cell
```

Figure 8 – Pseudo Code for Road Gravity Growth

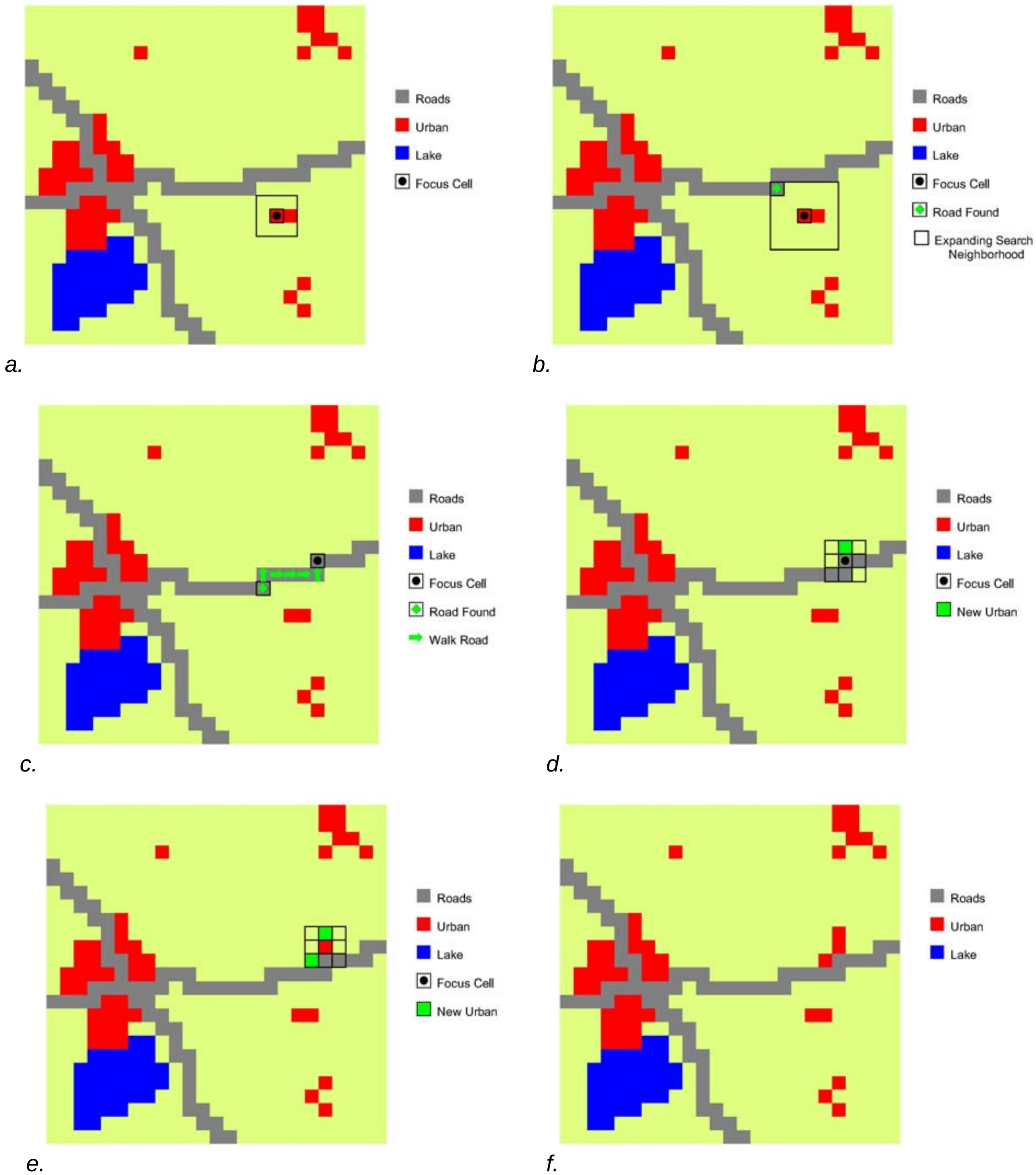


Figure 9 – Road Gravity Growth;
a. Locate urban cell and search neighborhood for road
b. Search increasing neighborhood sizes for road
c. Walk along the found road
d. Urbanize a neighbor at the end of the walk
e. Urbanize two neighbors of the newly urbanized cell
f. End of growth cycle land cover after all growth rules are applied

There is no specific rule that uses Slope directly. Slope rather is a factor of the availability for a cell to urbanize that is applied in all rules when determining if a cell can be urbanized. Slope is a factor that affects urbanization in a variable manner. First, there is a maximum slope that can be built upon. The maximum slope for the Urban Growth Simulator is set to 21% but can be easily modified by changing the code in the "CanUrban" function. Second, as more land is available to urbanize, less steep slopes will develop first. As less land is available, steeper slopes will be developed. This is modeled by finding a value that is equivalent to the difference between the critical slope and the cell's slope value. This difference is then divided by the maximum slope and then raised to the power of the slope coefficient divided by 50, half of the highest slope coefficient possible. The resulting value is then compared to a randomly generated number between 0 and 1 and if lower than the random number, the cell can be urbanized.

```
Slope Exponent = Slope Coefficient / 50
Slope Value = (21 – Focus cell slope value) / 21
Look Up Value = Slope Value^Slope Exponent
If Random(0, 1) > Look Up Vaalue Then
Available = False
End If
```

Figure 10 – Pseudo Code show how slope is used to determine a cell's ability to become urban

Calibration Process

The calibration process for any cellular automata model often requires the most work. This is the case with the SELF Urban Growth Simulator. The calibration process consists of runs, iterations and growth years. A growth year consists of one cycle of simulated growth. Iteration consists of a given number of years to grow. A run consists of a given number of iterations processed against one combination of coefficients.

To gain the best simulation from the program, the best combination of the five coefficient values needs to be discovered. The sure method for achieving this is to try each combination and review the statistics for each combination. Unfortunately, to accomplish this would require too much time as there are 100^5 or 10 billion combinations. This means that a systematic approach is required to filter out the majority of combinations. The SLEUTH model discusses a ‘Brute Force’ calibration on the Project Gigalopolis Website (Candau, 2007a). This brute force calibration discusses performing some calibration steps at a reduced resolution of data. It was determined by Candau though that the SLEUTH model could not accept a reduced resolution dataset as that greatly influenced the results specifically in the spread growth (Candau, 2007b). The other difficulty with the brute force calibration is that it searches an increasing number of coefficient combinations as it progresses through the calibration process. The brute force calibration is often run on multiple machines, as many as a dozen or two, to complete the process in a timely manner (Candau, 2007b). Based on the scalability requirements of the SELF project and that an electric utility is not likely to have a bank of machines waiting to process growth simulations, the brute force methods would not work for the SELF project.

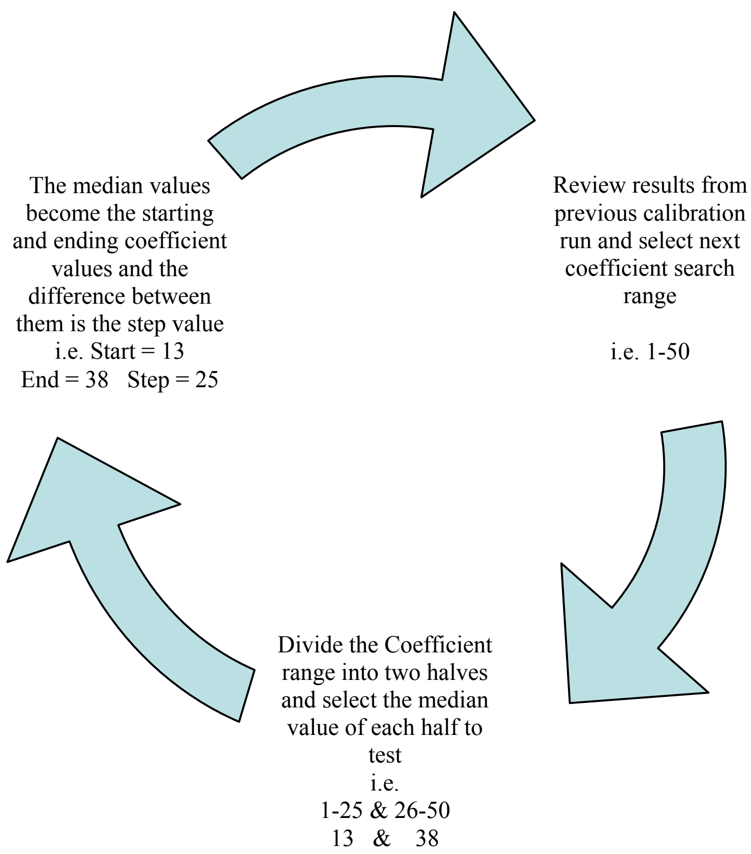


Figure 11 – Cycle of Coefficient Determination;

For the SELF project, a method of searching the coefficient ranges was developed. This method can be termed 'High-Low' calibration. Using this method (Figure 11), a range of numbers is searched by picking a start value that is approximately the median of the lower half of the search range and an end value that is the median of the upper half of the search range. The step would be the difference between the two. For example, to search a range from 1 to 100, the start value would be 25, the end value would be 75 and the step value would be 50. Once the calibration runs are complete, the statistics are reviewed and a smaller search range is selected. For instance, if the previous example showed better statistics for values of 75, then the search range would become 51 to 100, the start value would be 63, the end value would be 88 and the step value would be 25. This progresses to smaller and smaller search ranges and step values until the final coefficient is determined. The idea of this method is to minimize the number of step values for a calibration run. This process will require many more calibration runs but the time to finish each will be exponentially shorter. For example, a calibration that has two steps for each coefficient requires 32 or 2^5 coefficient combinations and will take slightly more than a day to process. A calibration run that has four steps for each coefficient will require 1024 or 4^5 coefficient combinations and about a month to run. Figure 12 is a guide to search ranges and step values.

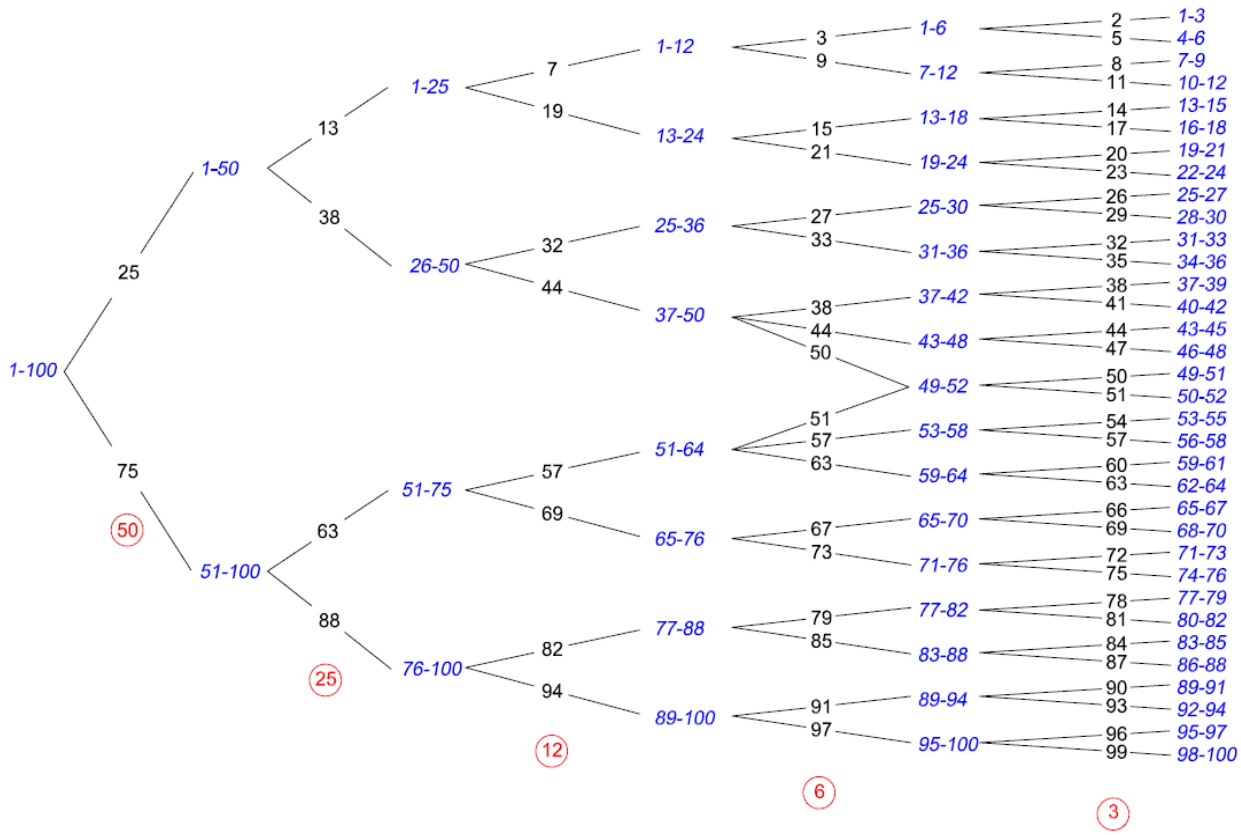


Figure 12 – High-Low Coefficient Determination;
The blue italicized numbers are the search ranges.
The black numbers along the lines are the start and end values for the search range to the left.
The red circle numbers are the step values for the start and end values in that level of the tree.

Searching large ranges of coefficient values does not require a large number of iterations. The goal is to just determine the high or low portion of the range to search further. As the search ranges and step values get smaller, the number of iterations should increase to provide a better averaging of the coefficient results. It would be good practice to use three or four iterations when searching a range of 1-100 and increase the number of iterations by one or two for each smaller range searched. When searching the smallest ranges, the number of iterations should be nine or ten.

Selecting coefficients does not have to always step to the next level of smaller ranges. If a given coefficient does not provide a good solution from a calibration run, a broader range of the same step level can be searched while the other coefficients progress to smaller search ranges. For example, if all coefficients were searching ranges at a level where the step value is twelve and the spread coefficient doesn't produce a good solution, the next calibration might have all coefficients searching a range with a step value of six. The spread coefficient would be searching two ranges at the level where the step value is twelve. This will increase the number of coefficient combinations to be searched but not exponentially.

Once final values are determined for the five coefficients, the SELF Urban Growth Simulator needs to run the self modification process. This process runs a given number of years for 100 iterations. Each iteration starts with the final coefficients from the previous calibration process. As the self modification process runs, the coefficient values are modified depending on the amount of urbanization in a growth cycle. If the amount of urbanization in a given cycle is more than a maximum growth level set by the user, the coefficient values will increase by one tenth. If the amount of urbanization in a given cycle falls below a minimum growth level set by the user, the coefficient values will decrease by one tenth. In effect, this causes the model to react to boom or bust scenarios that develop causing a fluctuating growth pattern and eliminating linear effects of static coefficients. The final coefficient values are recorded after each iteration and then averaged across all iterations to produce a new set of seed coefficients to be used in the growth simulation.

Urban Growth Simulation Interface

The SELF Urban Growth Simulator required a user interface. This was provided with Visual Basic. The interface allows entry of seed data files, coefficients, processing modes, control data and results output options. These settings can all be set from one form that is organized with tabbed panels. Below the tabbed panels is the area where processing modes and timeframes are configured.

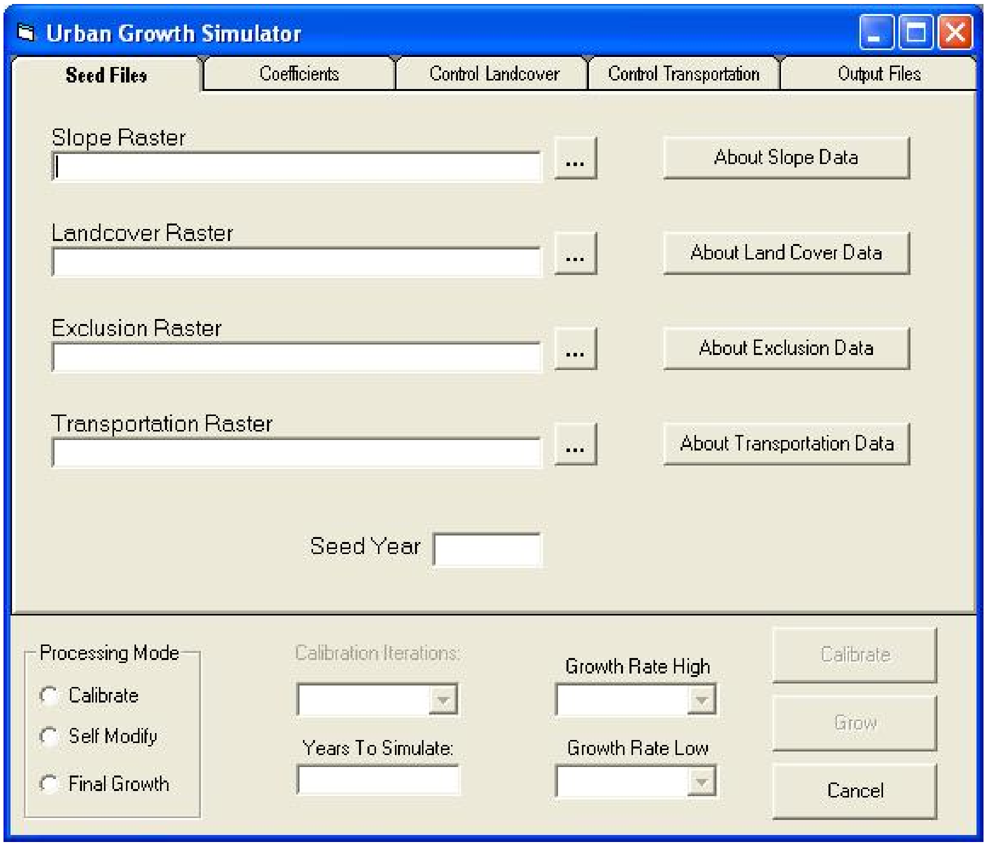


Figure 13 - Seed Files Panel

The first panel, pictured in Figure 13, is used to enter the seed files for both calibration and growth simulations. The file location for each data set must be entered on this panel. The ellipses (…) button opens the ArcObjects data dialog box that is filtering for raster data sets. Help for each dataset can be retrieved with the "About" buttons. The seed year is the year at which calibration and growth simulation starts. This year will be the first growth cycle so entering the year 1980 would mean that the growth starts on January 1st of 1980. That is, if you set the seed year to 1980 and you want the growth cycle to include growth for 1990, there would be 11 cycles to include growth all the way through December of 1990.

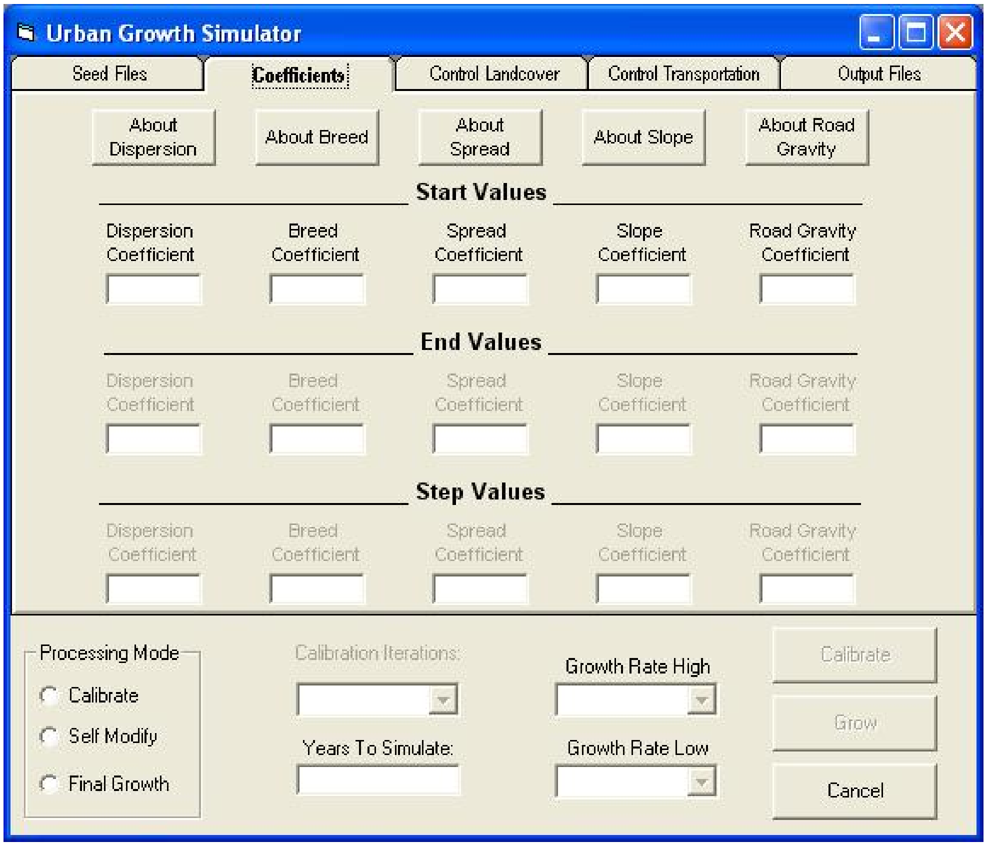


Figure 14 - Coefficients Panel

The second panel, pictured in Figure 14, is used to enter the coefficients. Across the top of the panel are help buttons that explain the different coefficients. The top row of entry boxes is for the starting coefficient values. Depending on the processing mode, the second and third rows of coefficient entry boxes may be enabled. The second row of entry boxes is for the ending or maximum value of each coefficient. The third row of entry boxes is for the step value of each coefficient. Rather than entering the number of increments, this value is the additive number for stepping through coefficient values. That is to say, if the start value was 25 and the end value was 75 and the evaluation was to include 5 values in this range, the step value would be 10. End and step values are only enabled when the simulator is in the 'Calibration' processing mode. The end values are populated by the growth simulator with ending values at the end of the 'Self Modify' processing mode.

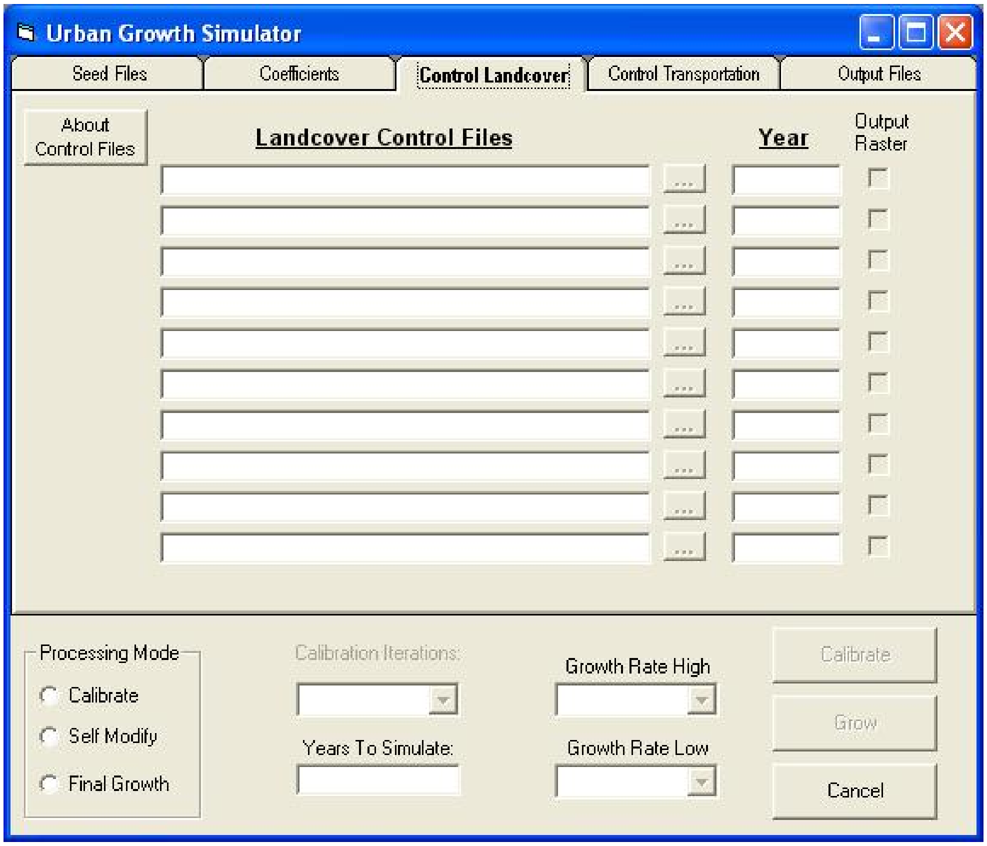


Figure 15 – Land Cover Control Panel

The third panel, pictured in Figure 15, is used to enter the control data for land cover / urban extent. The controls on this panel are only enabled in the 'Calibration' processing mode. The entry boxes and ellipses buttons operate the same as on the first panel. The entry boxes to the right of the ellipses button are for the year. Like the seed year entry box on the first panel, these year entry boxes are considered the first of the year. The output check boxes indicate whether or not raster files are generated after the control year growth cycle has been completed. This option is available to allow visual analysis but is not required for calibration to complete. Checking the boxes causes the Urban Growth Simulator to utilize ArcObjects to write out raster files and adds time to the calibration process.

The fourth panel, pictured in Figure 16, is used to enter the transportation control files. This panel operates the same as the third panel. Like the third panel, the year boxes indicate the first of the year so the transportation control files will be loaded into memory prior to running that year's growth cycle.

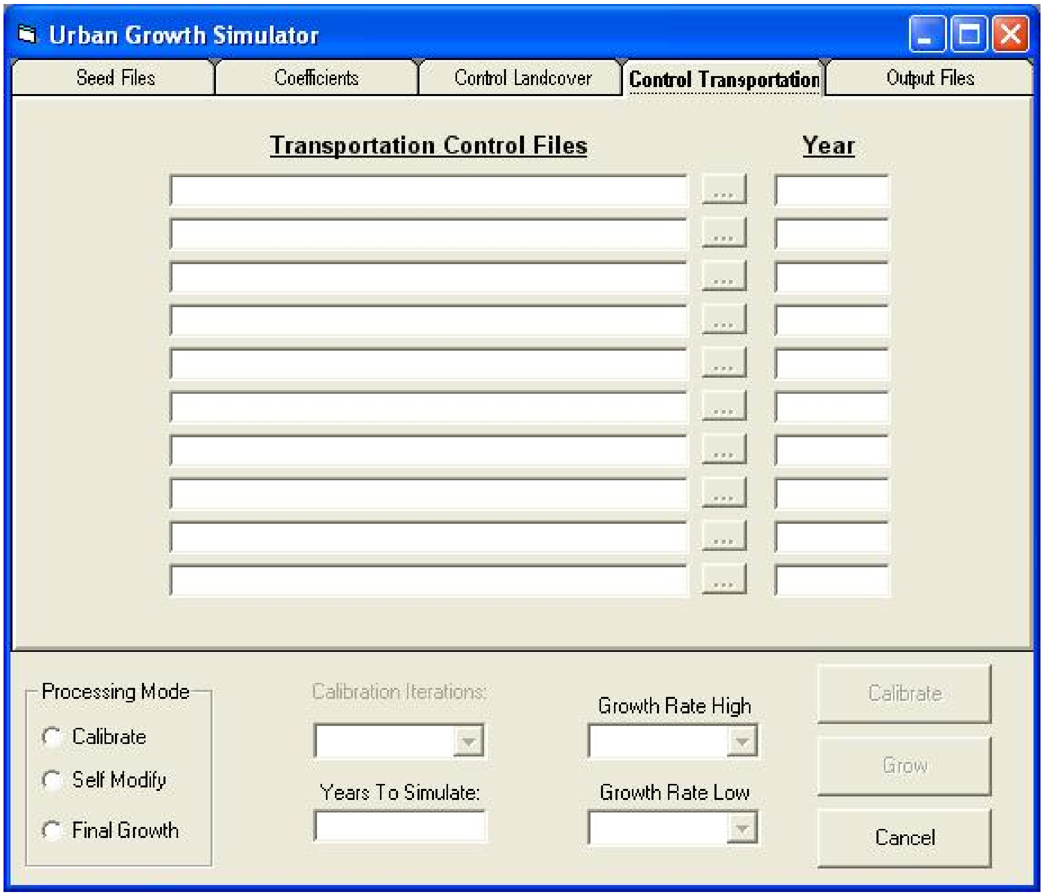


Figure 16 – Transportation Control Panel

The fifth panel, pictured in Figure 17, is used to select directories for raster file output and statistics logs. The entry boxes on this panel are looking for directories as opposed to files in the other panels. The ellipses buttons will open the ArcObjects data dialog with the filter set to directories. Even if no output files are configured, both directory entry boxes must be completed. There is no requirement that these directories be different and in fact can be the same directory. Project organization would be better if these were separate directories though. The raster files that are output are ESRI grid files and contain their own directory structure which may get cluttered if combined with the statistics files. At the bottom of this panel is a help button that explains miscellaneous information and best practices.

The lower portion of the form contains the controls that set the processing modes and study timeframes. The three modes that the program runs in are ‘Calibration’, Self Modify’ and ‘Final Growth’. If the program is set to ‘Calibration’ mode, the user must specify the number of iterations and the number of years to simulate. In the ‘Self Modify’ processing mode, the iterations are automatically set to 100 but the user must specify the number of years to simulate. In addition, the user must also select the upper growth limits and lower growth limits which will control the boom and bust scenarios and cause coefficient modification. In the ‘Final Growth’ processing mode, there are no iterations but the user must specify the number of years to simulate. The Calibrate button is used to start the ‘Calibration’ and ‘Self Modify’ processing mode simulations. The Grow button is used to start the ‘Final Growth’ processing mode.

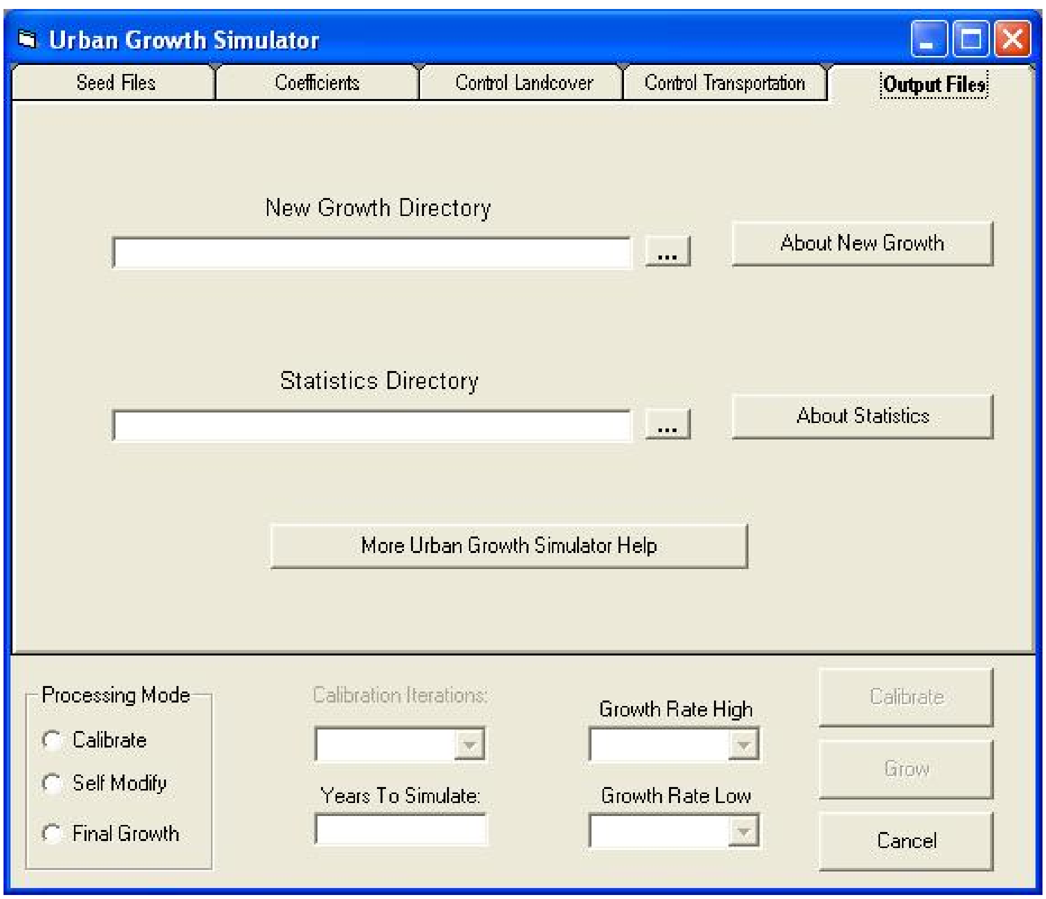


Figure 17 – Output Panel

Urban Growth Simulation Output

The SELF Urban Growth Simulator program outputs raster data as well as statistical data about the simulations. The program interface has options that allow the output raster data to be generated or suppressed. This is used to manage processing time during the calibration process. Raster data output is not required for the calibration process to reach a solution but may be desirable to verify reasonableness of the statistical solutions. All other output is required by the program. See Figure 18 for the program process flow.

Raster Data

The raster data files are essentially copies of the seed Land Cover / Urban Extent raster data. Examples can be seen in Appendix C. The only difference between the seed and output raster data are that there will be several cells that have a value of 25 representing new growth. The program interface allows the user the option to output the raster data for each land cover control file year. These files will be output each time the selected control file year is reached. This includes each iteration as well as each coefficient set run. The files are automatically named as to which run, iteration and year generated the data and are saved in ESRI Grid format. For example, a file name of r3_i6_y1995 would be the output raster for the 3rd iteration of the 1995 growth cycle using the 3rd set of coefficients. If a control file year is selected to be output, there will be a raster file for that growth cycle for all iterations and runs. The output raster file is created by copying the seed raster file and then for each newly grown cell from all growth cycles, those cells with a value of 25, are assigned to the copied raster file.

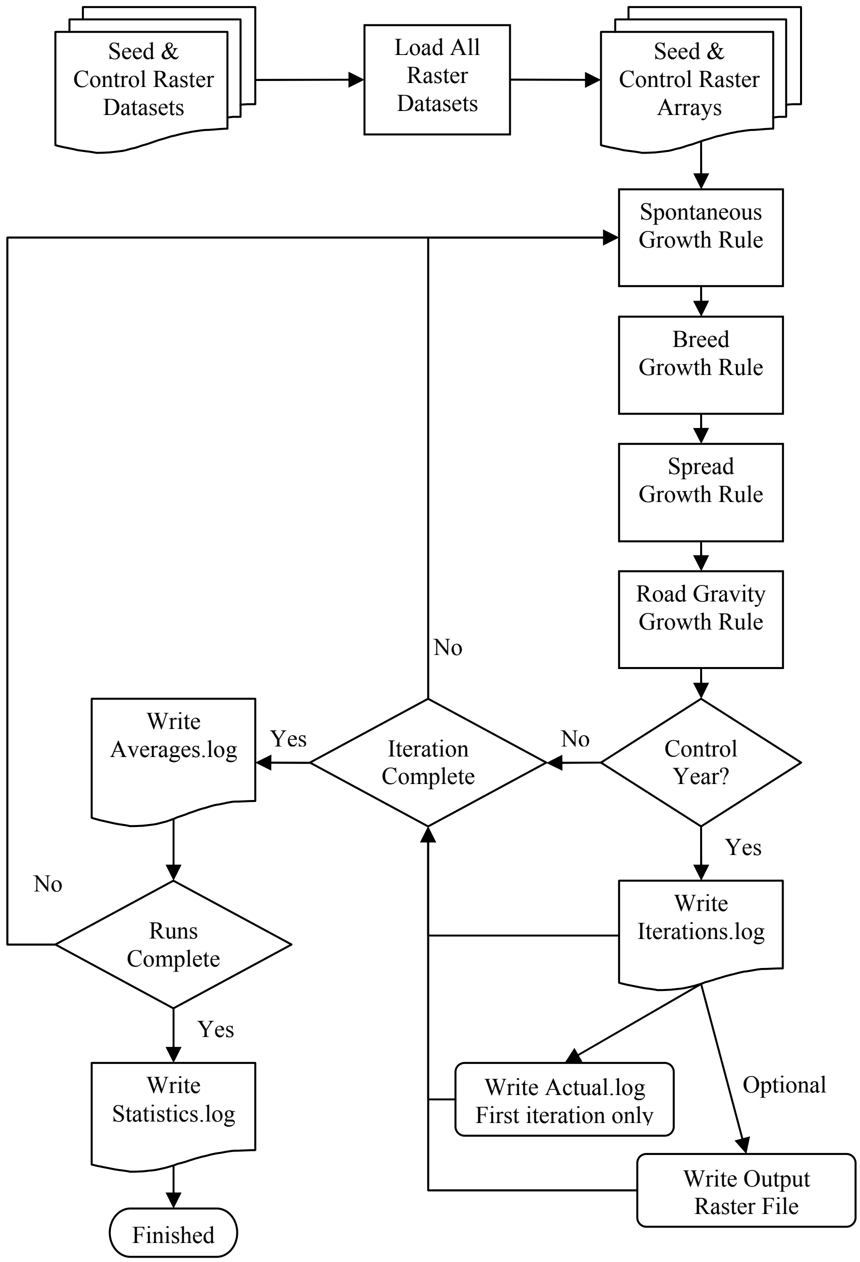


Figure 18 – Calibration Process Program Flow

Statistical Logs

The SELF urban Growth Simulator generates 5 log files used for statistical analysis. Examples can be seen in Appendix D. All of the files except the "Errors.log" file have the same column headings but may not have data in all of the columns.

Each column contains either the growth cycle information, the coefficients for the run, or the statistical metrics.

<u>Iterations.log</u>

The first file generated is the "Iterations.log" file. This file contains statistics for each growth cycle. Most of the values in this file are simple counts for the statistical metrics. Each row is one growth cycle from one iteration from one coefficient set run. There will be a row for each control growth cycle processed.

<u>Actuals.log</u>

The second file generated is the 'Actuals.log" file. This file is identical to the iterations.log file except that is contains the statistical metric counts for the control year raster data. Therefore, all columns related to growth cycles and coefficients will be empty.

<u>Averages.log</u>

The third file generated is the Averages.log file. This file is the average of the values in the iterations.log file for each iteration. That is, all iterations for a control year in a given coefficient set run are averaged for all statistical and growth cycle metrics.

<u>Statistics.log</u>

The fourth file generated is the Statistics.log file. This file contains the calculated statistics between the actuals.log file and the averages.log file. The R-square is calculated for most of the statistical metrics. Each row of this file is for one coefficient set run. This file is used to determine the best coefficient set to promote forward to the self modifying growth process.

<u>Errors.log</u>

An additional file that is sometimes created is the errors.log file. This file is only generated if the growth simulator encounters an error that is not reported to the user. Most errors such as coefficient entry or file selection will be presented to the user for correction. Some errors though occur during the growth cycle processing when there is no user involvement. The most critical of these errors is a divide by 0. Normally this type of error would crash the simulator, but they are being monitored and adjustments made to values so the division can occur without error. When this occurs, there is a message written to the errors.log file as to what caused the error and what values were changed. In these cases, the processing for that growth cycle, iteration or run may need to be ignored when evaluating the statistics.

Statistical Metrics

There are several statistical metrics that are tabulated and calculated from the SELF Urban Growth Simulator. Each metric account for some geographical perspective of the simulated growth whether it is clusters of growth or latitudinal and longitudinal correlation. Each metric will be explained below in the order that they appear in the statistical log files.

Run

This is the run number for a given coefficient set. It is a sequential number assigned as each coefficient set is analyzed.

Year

This is the year represented by the current growth cycle.

Iteration (MC)

This is labeled MC in the statistical logs referring to the Monte Carlo iteration process. This is the iteration number of the current run.

Spontaneous Growth (SnG)

This metric is found in the iterations and averages log files. In the iteration log file, each row contains a count for the number of cells that were urbanized under the spontaneous growth rule. In the averages log file, this value is the average across iterations for a given run.

Breed Growth (SpG)

This metric is found in the iterations and averages log files. In the iteration log file, each row contains a count for the number of cells that were urbanized under the breed growth rule. In the averages log file, this value is the average across iterations for a given run.

Edge Growth (EdG)

This metric is found in the iterations and averages log files. In the iteration log file, each row contains a count for the number of cells that were urbanized under the edge growth rule. In the averages log file, this value is the average across iterations for a given run.

Road Gravity (RdG)

This metric is found in the iterations and averages log files. In the iteration log file, each row contains a count for the number of cells that were urbanized under the road gravity growth rule. In the averages log file, this value is the average across iterations for a given run.

Total Grown Cells (GrwPix)

This metric is found in the iterations and averages log files. In the iteration log file, each row contains a count for the total number of cells that were urbanized under all growth rules. In the averages log file, this value is the average across iterations for a given run.

Population (Pop)

Population is simply a count of all urban cells that were not existing urban cells in the seed year. In the iterations and actual log files, this is a pure count whereas in the averages log file this is an average of all iterations for a given run. In the statistics log file, this metric is the r-square value between the actual urban cells and the simulated urban cells.

Area

Area is the population value multiplied by the area of each cell. In the averages file, this is the average of all iterations for a given run rather than a calculation of the averaged population multiplied by the area of a cell. Although both values would be the same, it is important to note how the value was derived. In the statistics log file, this metric is the r-square value between the actual urban area and the simulated urban area.

Compare

Compare is a metric that only appears in the statistics log file. This metric is R-square value of simulated and actual urban cells. In the statistics file, the population, area, and compare should all have the same value as they are all based on urban cell counts.

Clusters

A cluster is defined as 3 or more urban cells within a neighborhood whether or not it was existing at seed year or newly grown after. The clusters are counted for the iterations and actual log files. The averages log file contains the average cluster count for iterations within a given coefficient set run. The statistics log file contains the clusters R-square value for actual and simulated growth.

Perimeter

The Perimeter is the total length around each and every cluster. This is measured by the cell width or height for each cell along the edge of a cluster. In the iterations and actual log files, this is the measured length whereas in the averages log file this is the average of all iterations for a given run. In the statistic log file, this is R-square of the cluster perimeters in the actual growth compared to the cluster perimeters in the simulated growth.

Cluster Size (Clst_Size)

The cluster size is the average size of clusters in the iterations and actual log files. This number is then averaged again in the averages log file and the statistics log file contains the R-square value for the actual and simulated average cluster size.

Latitude (Lat)

This metric counts the number of newly urbanized cells in each row of the raster file and then averages the value for the number of rows. This is then averaged across iterations for the averages log file. The statistics log file contains the R-square value for simulated latitude compared to the actual latitude.

Longitude (Lon)

This metric counts the number of newly urbanized cells in each column of the raster file and then averages the value for the number of columns. This is then averaged across iterations for the averages log file. The statistics log file contains the R-square value for simulated longitude compared to the actual longitude.

Slope

The slope metric is the average slope value for newly urbanized cells in the iterations and actual log files. This value is again averaged across iterations for a given coefficient set run in the averages log file. The statistics log file contains the R-square value for simulated average slope compared to the actual average slope.

% Urban

This metric is the number of newly urbanized cells divided by the total number of available cells. As with the other metrics, the averages log file contains the average % urban for all iteration in a given coefficient run and the statistics log file contains the R-square values.

Intersect (IntSect)

This metric is the count of newly urbanized cells in simulated growth that are coincident with newly urbanized cells in the control year files. The number is averaged for all iterations within a coefficient set run in the averages log file. The statistics log file contains the averaged value from the last control year in the averages log file. A formula for this would be Actual $\cap$ Simulated.

Union

This metric is the count of newly urbanized cells in simulated growth combined with the newly urbanized cells in the control year files. The number is averaged for all iterations within a coefficient set run in the averages log file. The statistics log file contains the averaged value from the last control year in the averages log file. A formula for this would be Actual $\cup$ Simulated.

LeeSalee

This metric is the measure of the spatial correlation from the coefficient set solutions. It is calculated by dividing the intersect value by the union value. A formula for this would be (Actual $\cap$ Simulated) / (Actual $\cup$ Simulated).

Dispersion (Diff)

This is the dispersion coefficient value for the statistical row in all log files except the actual log file.

Spread (Sprd)

This is the spread coefficient value for the statistical row in all log files except the actual log file.

Breed (Brd)

This is the breed coefficient value for the statistical row in all log files except the actual log file.

Slope Resistance (SlRs)

This is the slope coefficient value for the statistical row in all log files except the actual log file.

Road Gravity (RdGr)

This is the dispersion coefficient value for the statistical row in all log files except the actual log file.

Urban Growth Simulation Development

The SELF Urban Growth Simulator was developed using common programming language found on windows based machines. Development of the application went through a couple different variations until the final product was completed. These variations were due to processing times that were unacceptable.

ArcObjects

A key requirement for this project is compatibility with ESRI ArcGIS. For that reason, ArcObjects was utilized to read and write to the raster data input and output files. The input and output raster data is in the ESRI Grid format containing continuous data. The data values are all 8 bit unsigned integers except for the slope data set which in 32 bit floating point precision.

Specific ArcObjects interfaces that were utilized for the raster data sets were IRaster and IRasterdataset. To be able to locate and write to the raster datasets, the iGXDialog, IWorspaceFactory and IRasterWorkspace interfaces were utilized. Writing to specific raster cells utilized the IPoint, Ipnt, IPixelBlock, and IRasterEdit interfaces. Early development efforts utilized the IRawPixels interface but the code was more complicated and less timely results were received. The IRawPixels method of writing raster data was abandoned.

The early development efforts utilized ArcObjects to manipulate the raster data at all stages of the growth process. While this processing method achieved the results of input and output of growth simulated raster data, the processing times were unacceptable. A calibration run that consisted of 128 coefficient sets would require roughly 14 months of processing raster data sets containing 100,000 cells. The code was re-architected to utilize multidimensional arrays to handle most of the growth processes. ArcObjects was used to read raster data sets into memory and to write output raster data when required. In effect, each raster dataset that is specified by the user in the entry forms is read with ArcObjects and the cell values are loaded into two dimensional arrays where the first dimension is X and the second dimension is Y. The X refers to the column number and the Y refers to the row number. This initial loading of the raster data takes between one and two hours for raster data with 100,000 cells on a standard 3 GHz Windows XP PC with 1GB of RAM. After modifying the code to utilize arrays, a calibration run that consists of 128 coefficient sets require roughly 48 hours to process.

VBA vs. Visual Basic

Due to the fact that ArcObjects were used, an object based program was required for development of the SELF Urban Growth Simulator application. Initial testing and early development was completed using Visual Basic for Applications (VBA). This was the most convenient way to monitor changes to cells and determine the most efficient methods of changing them. VBA is integrated within ArcGIS so, when testing, results could immediately be seen by visually reviewing the raster data inside ArcMap. The core components of the growth processes were completed using VBA but were then converted to Visual Basic for the final stages of development. This was done for the sake of speed. In VBA, there is a significant amount of computing resource overhead because ArcMap needs to be running. By converting to Visual Basic, the resources for ArcMap are not required and are available to the Urban Growth Simulator . Visual Basic also allows code to be compiled for even more efficient run time. The reason for programming in Visual Basic is to build a workable application utilizing the simplest form of coding knowing that conversion to other languages such as C and .NET Studio languages will only improve the application by making use of the advanced resources

Specific Coding Challenges

Other than processing time, there were two specific challenges in writing code for the Urban Growth Simulator.

Walking the Road

The first challenge was the Road Gravity growth rule. The other growth rules required the use of a 3x3 cell neighborhood. The road gravity rule required a varying size neighborhood. The road gravity rule also required navigation along a path.

The method used to solve the varying sized neighborhood was to scan the top row, then the bottom row, then the right column, and then the left column of the neighborhood no matter the dimensions. The search for roads would start with a 3x3 neighborhood and then expand in size by 2 rows and two columns for each try such as 5x5, 7x7 and so on.

The method used to solve the traversing the road once a transportation cell was found was to use the 3x3 neighborhood cell like a compass and remember the direction last traveled. Once the code determines a direction to "walk", the cells closest to that direction are searched first for the next transportation cell. For example, if the direction of travel for the last step was northwest, the first cell of the neighborhood searched would be the upper left cell. If a transportation cell was not found then the next two cells searched would be the top (North) cell and the left (West) cell. If a transportation cell was not found, then the search moves to the upper right (Northeast) cell and the lower left (Southwest) cell. The progressing around the neighborhood continues until the last cell to search is the cell in the opposite direction of the direction of travel. This situation would indicate a dead end in the road and the program would begin to retrace the walk backward until the required number of steps has been reached. If a transportation cell was found in any of the neighborhood cells, that cell would indicate the new direction of travel and become the focus cell. For example if the transportation cell was found in the top cell of the neighborhood, the new direction of travel would be North and the top cell would become the focus cell and one step in the required steps to walk. See Figure 19 for priority of neighborhood cell search while traversing a path.

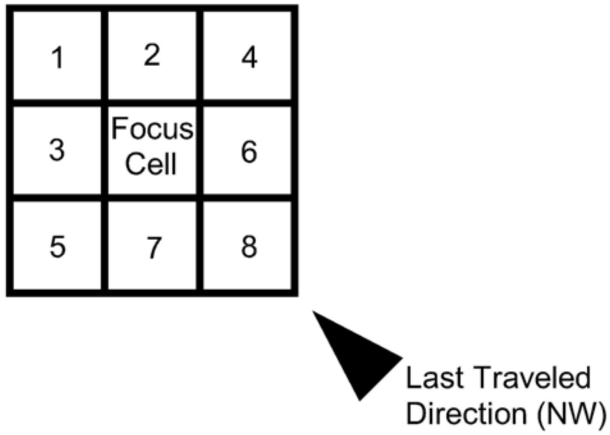


Figure 19 – Directional Priority of Neighborhood Transportation Cell Search

<u>*Counting the Clusters*</u>

The second challenge was summarizing urban clusters in the grown raster datasets. There are numerous papers that discuss methods for locating clusters of data in remote sensed imagery. Most of these methods though deal with edge detection. They use a zonal statistic or zonal filter to exaggerate and edge such as a high pass filter. The information required by the Urban Growth Simulator statistics is the number of clusters, the size of these clusters and the perimeter of these clusters. The methods mentioned in the papers work well for continuous data but the nature of cluster information in the Urban Growth Simulator is more discrete than continuous. Either it is a cluster or it isn't.

With regard to the Urban Growth Simulator , a cluster is defined as two or more adjacent urban cells. To locate clusters in the grown raster datasets, the datasets were scanned cell by cell. When an urban cell is located, the 3x3 neighborhood around the cell is reviewed for other urban cells. If found the focus cell is assigned a cluster number in an array used specifically for storing cluster values. The cluster number assigned is determined by an index that increases each time a new cluster is found. In addition, there is a cluster counter that increments for each new cluster. Because the raster dataset is scanned row by row, it is a given that a scanned urban cell will be part of a previously discovered cluster. When this occurs, the neighborhood is scanned and the focus cell will receive the highest cluster value found among the neighbors. It is possible for more that one cluster value to be in the neighborhood. When this occurs, all cells in the raster dataset with the lower cluster values will be changed to the higher cluster value. The cluster counter will be reduced by the number of clusters combined with the higher cluster value. At the end of processing the cluster counter will reflect the number of grown clusters.

As cluster values are assigned, the total number of cells within a cluster is kept. In the case above where lower cluster valued cells receive higher cluster values, the number of cells for the lower cluster value are added to the number of cell for the higher cluster value. The number of cells for the lower cluster values is then set to 0. At the end of processing, the number of cells for all clusters is multiplied by the cell size, summed and the sums are averaged. This becomes the cluster size statistic.

Determining the cluster perimeters also occurred while scanning the raster datasets. The rule for this was if a focus cell was urban and between 2 and 7 of its neighbors were urban than the cell width was added to the cluster value perimeter. This results in a perimeter that is orthogonal in nature. For example, if the focus cell is urban and only the northwest cell is not urban than the focus cell will receive a perimeter value. The west cell has already received the perimeter value as it was the previous focus cell. The north cell will receive the perimeter value when it becomes the focus cell in the next row scan. The west, center, and north cells have received perimeter values indicating the distance across the west cell, the distance to the center of the focus cell from the west cell, the distance from the center of the focus cell to the north cell, and the distance across the north cell. See Figure 20. A running total of all perimeter values are kept and this becomes the cluster perimeter statistic.

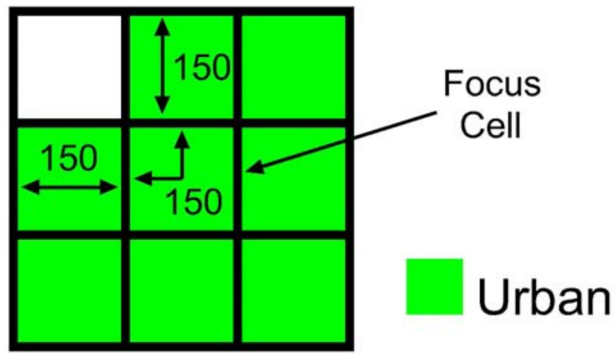


Figure 20 – Cluster Perimeter Measurment

<u>Chapter 3 – SELF Project Urban Growth Simulation Findings</u>

Results

Previous Study

The Colorado Front Range was studied with the SLEUTH model by the United States Geological Survey. This is cited on the Project Gigalopolis website (Candau, 2007a). According to the website, the final coefficients from this study were 11 for Diffusion, 41 for Spread, 35 for Breed, 1 for Slope and 91 for Road Gravity. Prior to running the Urban Growth Simulator to determine the SELF coefficients, the coefficients from the previous study were processed to determine their statistical values for the SELF project study area. The results, see Figure 21, showed a fairly low spatial correlation (LeeSalee) factor of 0.1946. This is likely due to the vast difference in extent of study area. The Colorado Front Range consists of several major urban centers in a mostly north-south straight line tucked up against the Rocky Mountains on the west and agricultural plains on the east. The Colorado Front Range is 160 miles long by roughly 50 miles wide. The SELF project area is more even in dimension being 35 miles east to west by 30 miles north to south. Proportions of slope changes, excluded areas, and transportation network between the two projects vary greatly and therefore should calibrate differently.

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope
1	0.8797	0.8797	0.8797	0.7707	0.6148	0.9773	0.8726	0.8914	0.2385
	%Urban	**IntSect**	**Union**	**LeeSalee**	**Diff**	**Sprd**	**Brd**	**SlRs**	**RdGr**
	0.8384	173958750	893986875	0.1946	11	41	35	1	91

Figure 21 – Previous Study Coefficient Results for SELF Study Area

Coefficient Determination Process

The coefficient calibration for the SELF project took nine different calibration runs and nearly three solid weeks of CPU processing time. After each calibration run, the statistics were reviewed and the next set of coefficient ranges to search were determined. There are many differing opinions on how coefficient determination is performed and which statistical metrics are most important (Candau, June 2002). For the SELF project, three different methods were utilized. This was done by importing the statistical log files into Microsoft Excel and sorting the values in various ways. An output similar to the sheet pictured in Figure 22 was completed for each calibration run.

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
7	0.9772	0.9772	0.9772	0.2629	0.9712	0.9966	0.9743	0.9814	0.0061	0.9679	119877188	553955625	0.2164	4	21	24	40	62
27	0.9795	0.9795	0.9795	0.5725	0.9793	0.9953	0.9778	0.9837	0.0058	0.9669	111192188	518675625	0.2144	4	19	24	42	64
21	0.9772	0.9772	0.9772	0.2166	0.9788	0.9947	0.9735	0.9817	0.0054	0.9657	115723125	540441562	0.2141	4	21	22	40	64
														4	21	24	40	64

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
18	0.9835	0.9835	0.9835	0.6624	0.9827	0.9963	0.9795	0.9862	0.0068	0.9727	110697188	525588750	0.2106	6	19	22	40	64
10	0.9835	0.9835	0.9835	0.6087	0.9832	0.9939	0.9799	0.9864	0.0057	0.9727	111341250	529475625	0.2103	6	19	22	42	62
														6	19	22	40	62

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
3	0.9797	0.9797	0.9797	0.8703	0.9837	0.9942	0.976	0.9832	0.0127	0.9703	109358438	512370000	0.2134	4	19	24	40	62
18	0.9835	0.9835	0.9835	0.6624	0.9827	0.9963	0.9795	0.9862	0.0068	0.9727	110697188	525588750	0.2106	6	19	22	40	64
17	0.9814	0.9814	0.9814	0.6501	0.9805	0.9933	0.9779	0.9855	0.0081	0.975	107460000	507597188	0.2117	4	19	22	40	64
														4	19	22	40	64

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
3	0.9797	0.9797	0.9797	0.8703	0.9837	0.9942	0.976	0.9832	0.0127	0.9703	109358438	512370000	0.2134	4	19	24	40	62
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
10	0.9835	0.9835	0.9835	0.6087	0.9832	0.9939	0.9799	0.9864	0.0057	0.9727	111341250	529475625	0.2103	6	19	22	42	62
														6	19	22	40	62

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
29	0.9779	0.9779	0.9779	0.0846	0.9777	0.9968	0.9746	0.9821	0.0065	0.9657	115419375	546086250	0.2114	4	21	22	42	64
25	0.9809	0.9809	0.9809	0.6116	0.9795	0.9967	0.9789	0.986	0.0051	0.975	108570938	507290625	0.214	4	19	22	42	64
7	0.9772	0.9772	0.9772	0.2629	0.9712	0.9966	0.9743	0.9814	0.0061	0.9679	119877188	553955625	0.2164	4	21	24	40	62
														4	21	22	42	64

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
20	0.9828	0.9828	0.9828	0.2981	0.9785	0.9929	0.9804	0.9867	0.009	0.9707	114080625	540078750	0.2112	6	19	24	40	64
11	0.9804	0.9804	0.9804	0.4195	0.9818	0.994	0.9802	0.9865	0.0047	0.9757	109454062	518504062	0.2111	4	19	24	42	62
														6	19	24	40	62

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
26	0.9828	0.9828	0.9828	0.2472	0.9797	0.9949	0.98	0.9871	0.0056	0.9727	110224688	526350938	0.2094	6	19	22	42	64
20	0.9828	0.9828	0.9828	0.2981	0.9785	0.9929	0.9804	0.9867	0.009	0.9707	114080625	540078750	0.2112	6	19	24	40	64
														6	19	22	40	64

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
8	0.9796	0.9796	0.9796	0.2106	0.9694	0.9961	0.976	0.9842	0.0228	0.9704	121348125	571530938	0.2123	6	21	24	40	62
1	0.9797	0.9797	0.9797	0.6338	0.9793	0.9945	0.9771	0.9851	0.0154	0.9713	108149062	505822500	0.2138	4	19	22	40	62
3	0.9797	0.9797	0.9797	0.8703	0.9837	0.9942	0.976	0.9832	0.0127	0.9703	109358438	512370000	0.2134	4	19	24	40	62
														4	19	24	40	62

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SIRs	RdGr
12	0.9815	0.9815	0.9815	0.4528	0.977	0.9941	0.9786	0.9854	0.0046	0.9763	111889688	533908125	0.2096	6	19	24	42	62
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
11	0.9804	0.9804	0.9804	0.4195	0.9818	0.994	0.9802	0.9865	0.0047	0.9757	109454062	518504062	0.2111	4	19	24	42	62
														6	19	24	42	62

Run Frequency in top 3

Run	Freq.	Diff	Sprd	Brd	SIRs	RdGr
2	5	6	19	22	40	62
3	3	4	19	24	40	62
7	2	4	21	24	40	62
10	2	6	19	22	42	62
11	2	4	19	24	42	62
18	2	6	19	22	40	64
20	2	6	19	24	40	64
1	1					
8	1					
12	1					
17	1					
21	1					
25	1					
26	1					
27	1					
29	1					

Solution

Diff	Sprd	Brd	SIRs	RdGr	
1	22	19	38	59	Start
3	24	21	41	61	End
2	2	2	3	2	Step
2	2	2	2	2	32 Runs

LeeSalee was lower, re-evaluating calibration 6

Figure 22 –Calibration Run Evaluation Sheet

This first step on the calibration sheet was to sort the data rows in the Statistics.log file by each metric. Then the top three rows for that metric are copied to the evaluation sheet. Below the coefficient values for the three rows in each metric is a summary of the coefficients that performed best for that metric (See A in Figure 23).

Bold black numbers indicate that a coefficient value was consistent for the top three runs of a given metric. The red numbers are showing the majority coefficient. See Figure 23.

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
7	0.9772	0.9772	0.9772	0.2629	0.9712	0.9966	0.9743	0.9814	0.0061	0.9679	119877188	553955625	0.2164	4	21	24	40	62
27	0.9795	0.9795	0.9795	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0058	0.9669	111192188	518675625	0.2144	4	19	24	42	64
21	0.9772	0.9772	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	115723125	540441562	0.2141	4	21	22	40	64
														4	**21**	**24**	**40**	**64**

Top 3 Runs for Area metric

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	[illegible]	0.2098	6	19	22	40	62
18	0.9835	0.9835	0.9835	0.6624	0.9827	0.9963	0.9795	0.9862	0.0068	0.9727	110697188	525588750	0.2106	6	19	22	40	64
10	0.9835	0.9835	0.9835	0.6087	0.9832	0.9939	0.9799	0.9864	0.0057	0.9727	111341250	529475625	0.2103	6	19	22	42	62
														6	**19**	**22**	**40**	**62**

A

Figure 23 – "Top 3" coefficient runs for each metric

The second step is to determine the frequency of a run's occurrence in "Top 3" sets determined in step 1. Once the frequency is determined, the runs are ranked from highest to lowest frequency of occurrence. The coefficient values are recorded for all runs the appeared more than once in the "Top 3" sets. See Figure 24.

Run Frequency in top 3

Run	Freq.	Diff	Sprd	Brd	SlRs	RdGr
2	5	6	19	22	40	62
3	3	4	19	24	40	62
7	2	4	21	24	40	62
10	2	6	19	22	42	62
11	2	4	19	24	42	62
18	2	6	19	22	40	64
20	2	6	19	24	40	64
1	1					
8	1					
12	1					
17	1					
21	1					
25	1					
26	1					
27	1					
29	1					

Figure 24 –Run Frequency in Top 3 sets

The third step is the evaluation of the coefficient summaries and the statistics found for each metric. The most weight was placed on the first metric of LeeSalee which is the measure of spatial correlation. This metric best represents the accuracy of the model but other metrics may reveal answers to help fine tune the coefficients. For example, cluster size is related to the spread coefficient and increasing the spread coefficient will likely increase the cluster sizes. In addition to the coefficient summaries, reviewing the run frequency will also indicate which coefficient run sets are creating the best statistics for the most metrics across the model. When the spatial correlation LeeSalee doesn't produce clear and firm summaries, the run frequency is a good backup for coefficient determination. Once the best coefficients are determined for the calibration, the next search ranges are determined and recorded. If the solutions for the current calibration are not as good as previous calibrations, then the previous calibrations are evaluated again for better solutions. See Figure 25.

Solution Diff	Sprd	Brd	SlRs	RdGr		
1	22	19	38	59	Start	
3	24	21	41	61	End	
2	2	2	3	2	Step	
2	2	2	2	2	32	Runs

LeeSalee was lower, re-evaluating calibration 6

Figure 25 – Solution for next calibration to search new coefficient set ranges

After nine calibration runs, the final coefficient set was acquired. All summary sheets for these calibration runs can be reviewed in Appendix E. The final coefficient values determined were 1 for Diffusion, 24 for Spread, 19 for Breed, 41 for Slope and 61 for Road Gravity. Statistically, this coefficient set produced the best spatial correlation of all coefficient sets tested to historical growth data with a LeeSalee value of 0.2205 or 22% of perfect spatial correlation.

Visual Check

In addition to review of the statistical data produced by the Urban Growth Simulator, visual checks of the output raster files were made. These visual checks helped reveal coefficients that were set incorrectly such as too much road gravity or not enough spread. These visual checks were made a couple different times throughout the calibration process. Figure 26 is an example of a visual check made for the coefficient set of Diffusion = 2, Spread = 23, Breed = 23, Slope = 44 and Road Gravity = 60.

The visual check required a raster dataset that showed the actual growth that occurred during the study timeframe. This was achieved by subtracting the seed rater dataset from the most recent control raster data set. The results are a raster dataset with values of 0 for no growth and values of 22 where actual new growth occurred.

The next step was to compare the simulated growth with the actual growth. The simulated growth raster dataset is one of the datasets output from the Urban Growth Simulator processes. The comparison was done by subtracting the actual growth dataset just created from the simulated growth raster datasets. The simulated growth raster datasets have values of 1 for no growth, 23 for existing growth, and 25 for simulated growth. The table below shows the results and classification. See Figure 26 for the map.

	No Growth		Existing Urban		Simulated Growth	
Simulated Growth	1		23		25	
Actual Growth	0	22	0	22	0	22
No Growth BothSets	1					
Act. Growth No Simulated Growth		-21				
Exist. Growth Both Sets			23			
No Growth BothSets				1		
Simulated Growth No Act. Growth					25	
Matched Growth in Both Sets						3

0 = No Growth
22 = Growth

Table 1 –Visual Check Classification – Simulated raster dataset minus Actual raster dataset

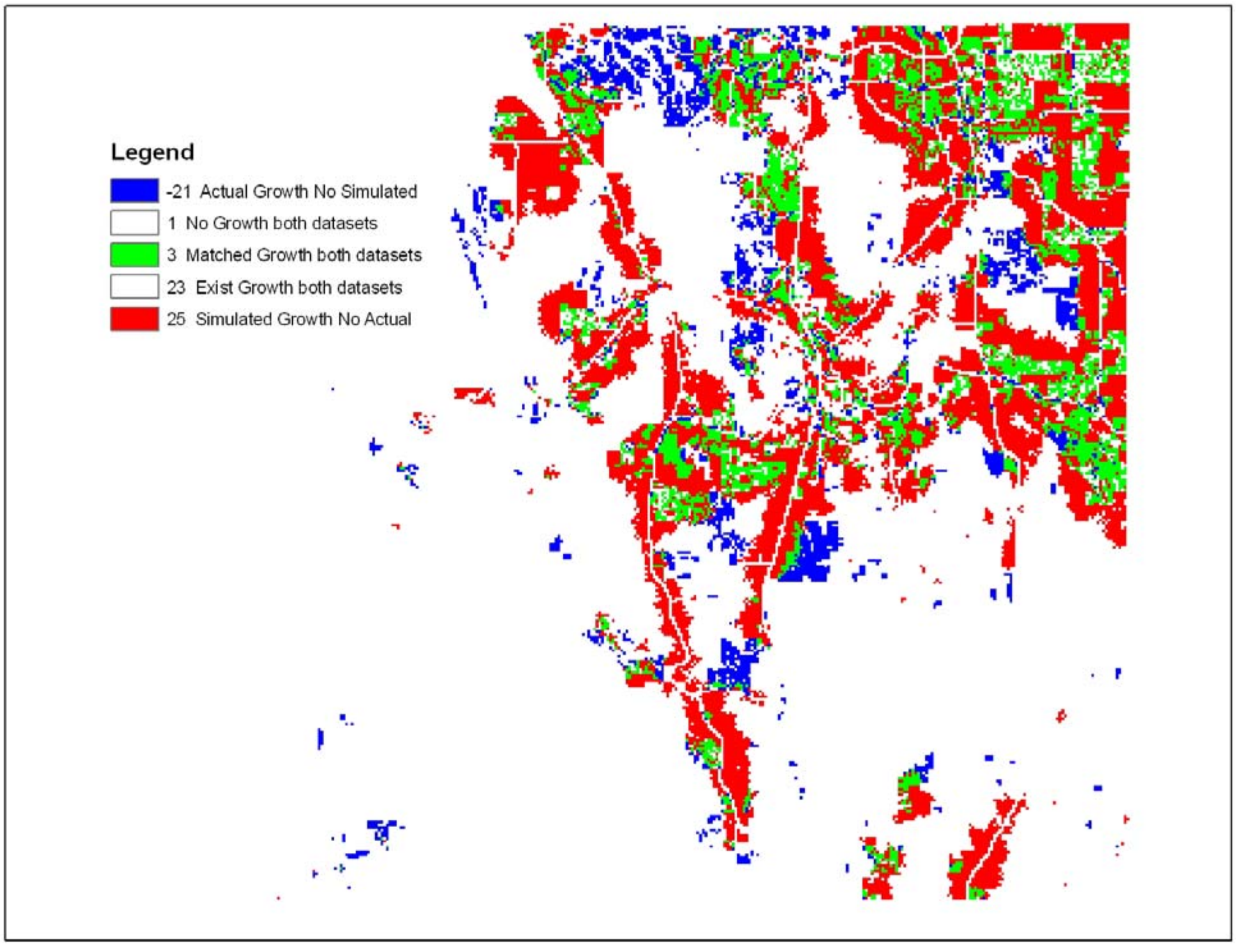


Figure 26 –Visual Check Classification – *Simulated raster dataset minus Actual raster dataset*

The map in Figure 26 indicates there is considerable simulated growth occurring along roadways. Based on the rules for Road growth, this could be a result of a road gravity coefficient or breed coefficient being set too high. Other areas of concern are the large regions of actual growth that was not simulated. Through cardinal knowledge, it is known that these areas are large planned developments with more than 1000 residences. Such "blooms" of development are difficult to model through the coefficients used in the Urban Growth Simulator.

Error matrices

As a final check of the coefficient determination results, error matrices were performed on the results to determine the producer and user errors. This was performed by selecting 550 random sample points in the study area that are collocated with cells that could become urban. That means that none of the random sample points were placed in areas of exclusion, transportation or existing urban cells. The actual and simulated values for the cells at the random points were recorded in five year increments for the years 1985, 1990, 1995, and 2000. The values were summarized by recording the totals for actual growth matching simulated growth, actual no growth matching simulated no growth, actual growth where no simulated growth occurred, and simulated growth where no actual growth occurred. These values are then divided by the number of matched, correctly predicted, cells to determine overall, producers, and user's accuracy percentages. In addition, the percentage of omission error, commission error and map accuracy for urban and non-urban are calculated. See Figure 27.

1985		Simulated Urban	Simulated Not Urban	Actual Totals	Correct Cells
Actual	Urban	**4**	10	14	4
	Not Urban	45	**491**	536	491
	Simulated Totals	49	501	550	495

Overall Accuracy **90.00%**		Producers Accuracy	Users Accuracy	Omission Error	Comission Error
	Urban	28.57%	8.16%	71.43%	321.43%
K_{hat} **0.09099**	Non Urban	91.60%	98.00%	8.40%	1.87%

	Map Accuracy
Urban	20.29%
Non Urban	90.69%

1990		Simulated Urban	Simulated Not Urban	Actual Totals	Correct Cells
Actual	Urban	**12**	15	27	12
	Not Urban	77	**446**	523	446
	Simulated Totals	89	461	550	458

Overall Accuracy **83.27%**		Producers Accuracy	Users Accuracy	Omission Error	Comission Error
	Urban	44.44%	13.48%	55.56%	285.19%
K_{hat} **0.14229**	Non Urban	85.28%	96.75%	14.72%	2.87%

	Map Accuracy
Urban	22.69%
Non Urban	85.04%

1995		Simulated Urban	Simulated Not Urban	Actual Totals	Correct Cells
Actual	Urban	**23**	19	42	23
	Not Urban	112	**396**	508	396
	Simulated Totals	135	415	550	419

Overall Accuracy **76.18%**		Producers Accuracy	Users Accuracy	Omission Error	Comission Error
	Urban	54.76%	17.04%	45.24%	266.67%
K_{hat} **0.16231**	Non Urban	77.95%	95.42%	22.05%	3.74%

	Map Accuracy
Urban	24.28%
Non Urban	79.50%

2000		Simulated Urban	Simulated Not Urban	Actual Totals	Correct Cells
Actual	Urban	**34**	0	34	34
	Not Urban	168	**348**	516	348
	Simulated Totals	202	348	550	382

Overall Accuracy **69.45%**		Producers Accuracy	Users Accuracy	Omission Error	Comission Error
	Urban	100.00%	16.83%	0.00%	494.12%
K_{hat} **0.20389**	Non Urban	67.44%	100.00%	32.56%	0.00%

	Map Accuracy
Urban	16.83%
Non Urban	75.44%

Figure 27 –Error matrix for the calibration control years 1985, 1990, 1995, & 2000

The overall accuracy decreases as the time passes in the calibration process. The decrease in accuracy is almost linear being roughly 7% every 5 years or approximately a decrease in accuracy of 42% over 30 years. The producers accuracy is a measure of how many matched cells in each category of urban vs. non-urban occur divide by the number of actual cells in each category or how close the match is to actual. Conversely, the users accuracy is a measure of how many matched cells in each category of urban vs. non-urban occur divide by the number of simulated cells in each category or how close the match is to the simulation.

Producer Accuracy = Matched Cells / Total Actual Cells
User Accuracy = Matched Cells / Total Simulated Cells
i.e. 1985
Producer Accuracy = 4 / 14 = 28.57% in urban category
User Accuracy = 4 / 49 = 8.16% in urban category

Figure 28 –Producer and User Accuracy formulae

The omission errors and commission errors are a measure of the incorrectly simulated cells divided by the actual cells. Omission errors are cells that were not correctly simulated and commission errors are cells that were incorrectly simulated. The map accuracy is a measure of the actual totals divided by sum of actual totals and incorrectly simulated cells.

Omission Error = Not Simulated When Actual / Total Actual Cells
Commission Error = Not Simulated When Actual / Total Actual Cells
Map Accuracy = ________________Total Actual Cells________________________
(Total Actual Cells + Not Simulated When Actual + Not Simulated When Actual)
i.e. 1985
Omission Error = 10 / 14 = 71.43% in urban category
Commission Error = 45 / 14 = 321.41% in urban category
Map Accuracy = 14 / (14 + 10 + 45) = 20.29% in urban category

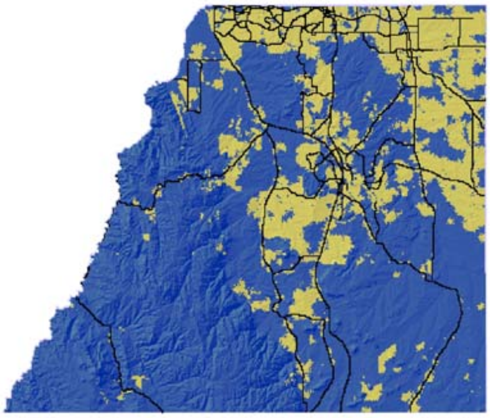
Figure 29 –Omission, Commission, and Map Accuracy formulae

It is apparent that simulation creating urban cells improves through 1995 but then drops of by 2000. A 100% producer's accuracy in urban and 100% user's accuracy in non-urban simulation indicates that all simulated non-urban cells are also non-urban in the actual growth but low urban users accuracy indicates a large amount of urban simulation that is not present in the actual growth. The Urban Growth Simulator determined coefficients are too strong and are predicting too much growth even though the coefficient set had the strongest spatial correlation from the calibration process.

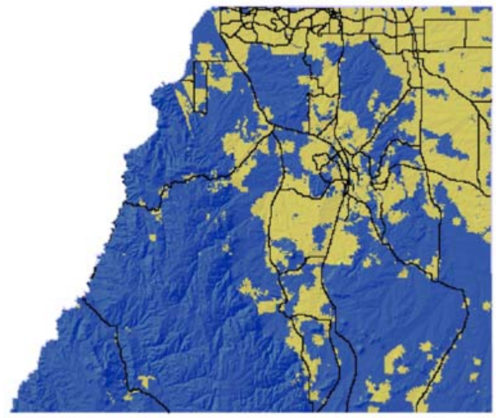
Predicted Growth

It is typical for an electric utility work plan to list projects for the short range, medium range and long range time frame. Usually these time frames are 5 years for short range projects, 10 years for medium range projects and 20 years for long range projects. These plans are often revised every 10 years. The minimum growth prediction for one of these work plan studies would then be 20 years but since the 20 years projects are meant to be proactive and serve into the future and are not reactive to past growth, the growth prediction should extend beyond the work plan study time frame.

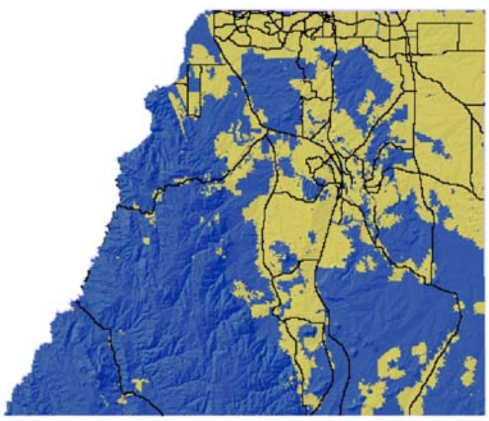
Growth prediction from the Urban Growth Simulator uses the determined coefficients and runs the same growth rules used in the calibration process. Every cycle or growth year will be output as a raster dataset. Growth prediction was run using the determined coefficients and predicting 30 years of growth in Douglas County. See Figure 30.



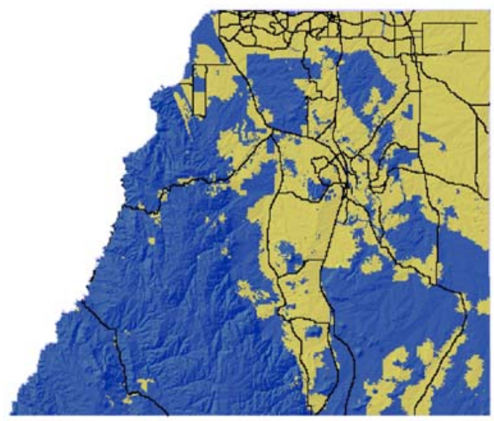
2010 Urban Extent



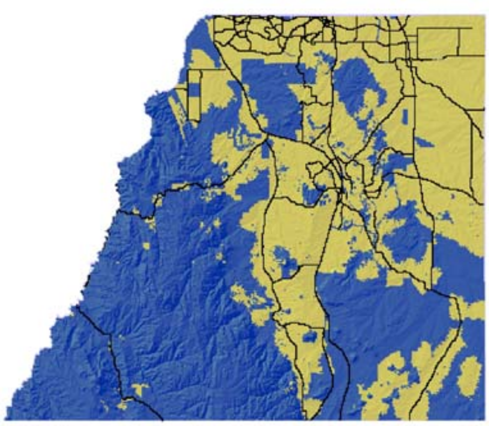
2015 Urban Extent



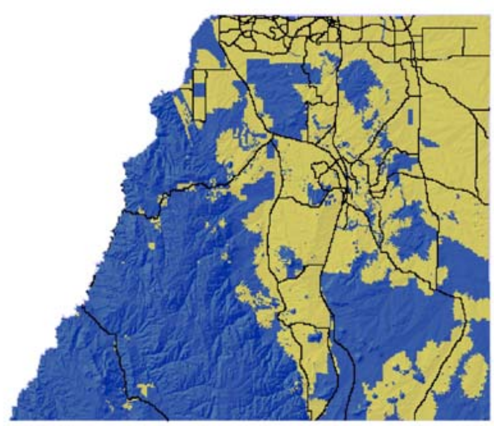
2020 Urban Extent



2025 Urban Extent



2030 Urban Extent



2035 Urban Extent

Figure 30 –30 years of Urban Growth Prediction – Douglas County, Colorado

The IREA territory is displayed over the 2030 urban extent map in Figure 31. The area of Douglas County served by IREA is the pink shaded area and the urban extent within the territory shows up as dark red. While most of the growth is not unexpected, particular attention should be paid to the south east corner of the service area. The majority of the urban growth in the southeast corner of Douglas County is served by Mountain View REA but a portion of that growth encroached into IREA territory. Currently, IREA does not have infrastructure in that area to serve the encroachment growth. Under normal invasion rules, Mountain View would be able to serve these customers due to proximity of electrical service to the customer. This would be lost revenue to IREA. Since this encroachment does not become large until the 30 year prediction, it is recommended to add facilities in this area during the 20 year work plan.

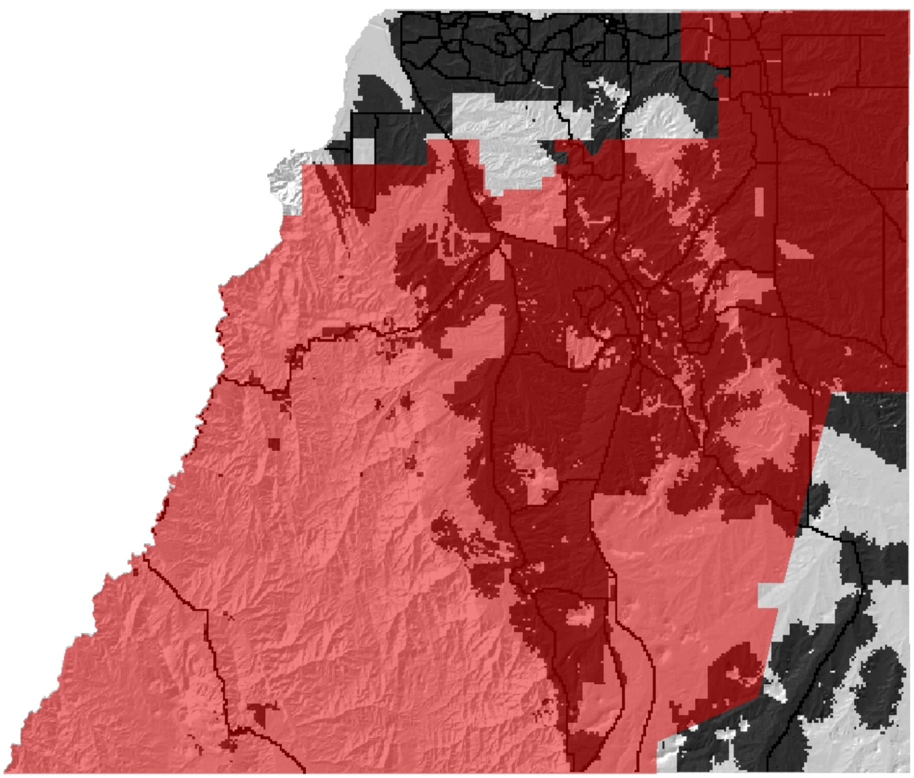


Figure 31 –Predicted 2030 Urban Extent in IREA service area

Conclusions

Although the SELF Urban Growth Simulator project was successful in creating a method for predicting growth and meeting most of the requirement goals, it did fall short in the accuracy of prediction. One of the goals was to create a method for growth prediction on the Windows operating system running on standard PC computers. In addition, the methods were required to be compatible with the most common GIS software deployed throughout the electric utility industry, that being ESRI ArcGIS. It was also required that application development occurs in common programming language that provides portability. The SELF Urban Growth Simulator meets all of these requirements by employing Visual Basic 6.0 to create Windows forms that access ESRI ArcObjects to read and write input and output raster data for urban growth simulation.

Concerns

Concerns with the Urban Growth Simulator are still present though. Although great strides were made in the efficiency of data processing in the application, calibration processes are still time consuming. This is symptomatic of many Cellular Automata models (Dietzel & Clarke, 2006b). There was a strong effort throughout the calibration process to minimize the number of coefficient sets being reviewed. There are varying thoughts about calibration methods in the literature reviewed but the methods used here were chosen for the sake of speed.

Another concern is the accuracy of the determined coefficients. The method used to determine coefficients in this project was to search coefficient ranges using only two values, high and low in the range, to determine smaller search ranges. This method quickly excluded possibilities and may have overlooked coefficient sets that would produce a better spatial correlation. Out of a possible 10 billion coefficient combinations, only 355 combinations were explored using the SELF project methods.

Another concern appeared during the calibration process. The visual checks that were performed showed that certain areas were consistently not urbanized by the growth simulator. These areas are coincident with large planned urban developments

(PUD). These large PUD do not appear to follow the rules of growth that make up the Urban Growth Simulator; yet they may have a large impact on electrical load required.

Preliminary growth prediction

The Urban Growth Simulator has a strong potential to provide a good first look at urban growth in a region. If source data is complete and careful attention is paid to the calibration process, the results of the simulator can be accurate enough to identify areas of growth that may not otherwise be realized. There should be consideration to the resolution of data and extent of study area. A restricted study area can provide localized growth patterns and not see the influence of surrounding regions. Resolution that is too small in scale may over enhance growth and influence the coefficient determination. It is recommended that different adjacent regions be studied in roughly the same scale and extent. Following that, areas that overlap these regions should also be studied in roughly the same scale and extent. The results of these multiple studies can reveal patterns that aid in a broader, complete region, coefficient determination.

County Planning and Land Development Issues

Many counties in Colorado have compiled 30 year development plans. This information about development may be more accurate that the Urban Growth Simulator in terms of type of growth. However, the simulator may in fact predict better *when* an area may develop. Exceptions to this are when policymakers limit growth due to environmental or economic reasons. The growth simulator should be used in conjunction with the long range plans of a county to be most effective in determining the electrical load needs of a region.

Other land development issues that can't be predicted are individual land owner actions. For example, approximately a third of Elbert County, CO is owned by a single land owner and the person continues to acquire more land as time passes. It is rumored that eventually that landowner will dedicate the land owned to be open space and remain undeveloped. While this has occurred in the past, often times only a portion of the land promised is actually dedicated to open space. This type of action is difficult to simulate. Should all the land intended to be open space be excluded from urban growth simulation or should this land be considered available for urban growth in the simulation. Incorrectly predicting large acreages of land can be problematic to electrical load forecasting.

Economic issues

Economic issues are not part of the Urban Growth Simulator. Douglas County was one of the top five fastest growing counties in the nation through the late 1990's and early 2000's. Due to the rapid growth of the county, property values began to soar. Prices escalated to the point that land was too expensive to develop and other counties bore the weight of Colorado's growth boom. Two of those counties taking over the role of fastest growing were Adams and Arapahoe, adjacent to the north from Douglas County. A nationwide downturn in the economy has stalled most growth in Colorado but this was prior to land price escalation in Adams and Arapahoe counties. It is expected that when growth returns, Adams and Arapahoe will see growth much sooner and in larger amounts than those that will be realized in the more expensive Douglas County.

The SELF project focused on calibrating Douglas County from 1980 to 2005. This was the period of extreme growth for Douglas County; therefore the determined coefficients are exaggerated toward rapid growth which is not likely to continue for some time. On the contrary, simulation for Adams and Arapahoe Counties over the same time frame would show a sluggish growth and set the determined coefficients too low for the growth boom they will likely see when urban growth returns to Colorado. All three of these counties are served by Intermountain REA.

Future Considerations

Self Modifying

The SLEUTH urban growth model incorporates a self modification mode. This was not employed in the SELF project. The Self Modification process would use the determined coefficients and run 100 iterations of growth cycles covering the study time frame. Each growth cycle or year, the amount of growth is determined. Based on minimum and maximum growth rates determined by the user, the coefficients will modify themselves. For example, if the maximum growth rate is exceeded, then a boom condition is present and certain coefficient will increase by 10% to promote the boom condition. In contrast, if the growth rates fall below the minimum growth rate creating a bust state, certain coefficients will decrease by 10% to reflect the declining urban growth. This self modification attempt to simulate the S-curve type of growth that has been noted in many urban expansions rather than the linear growth a fixed set of coefficients would infer. At the end of each iteration the ending coefficients are recorded. Every iteration will start with the determined coefficients from the calibration process. After all iterations are complete, the ending values are averaged and a new coefficient set is determined. Predicted growth will use these new coefficients and apply self modification throughout the prediction. Predictions should be run multiple times to insure that the randomness of the growth simulator has not overemphasized growth booms or busts.

Calibration Considerations

There are two calibration consideration when move forward from the SELF project. The first consideration is the study time frame used for the calibration process. In the SELF project, this time frame was 26 years of growth cycles from 1980 through 2005. Two problems with this time frame have been presented. The uncharacteristic growth boom that Douglas County experienced through this time frame would be neutralized by expanding the study time frame to include 50 years or more. This is possible with the source data used but would require more calibration time to determine a coefficient solution.

The second consideration is the coefficient determination process. Although the methods were systematic in the process of eliminating coefficients, the number of combinations sample were comparatively small compared to other SLEUTH model calibration processes. User of the Urban Growth Simulator should be prepared to accept the fact that the calibration process requires months, not weeks to complete. While the searching of coefficient ranges can still be systematic, the number of coefficient steps in a calibration run should be 3 to 5 steps as compared to the 2 or 3 steps used in the SELF project.

SELF Project Phase 2 – Projecting Electrical Load

There are different methods to projecting electrical load demands spatially including those written about by Lee Willis (Willis et al., 1995) and Jessica (Noonan) Valenti (Noonan) as well as current work by David Hollema of United Power in Brighton Colorado. Each of these methods should be reviewed and tested for accuracy and correlation to IREA's needs. In addition, portable recording meters need to be placed on specific load types during different seasons. For example, they should be placed on typical residential equipment for a couple weeks in the winter and a couple weeks in the summer. The same should be done for commercial property, and large power installations. It may be desirable to record different type of residential such as large or small square footage, multi-family, or air conditioned versus non-air conditioned homes. The data from these recorder meters will then be analyzed for determination of load factors and diversity factors that can be applied to different zoning and county planning data. This data coupled with historical meter read data and substation feeder load data can then be extrapolated to the urban growth predicted by the Urban Growth Simulator for the determination of required system improvements to insure adequate power delivery to the utility customers.

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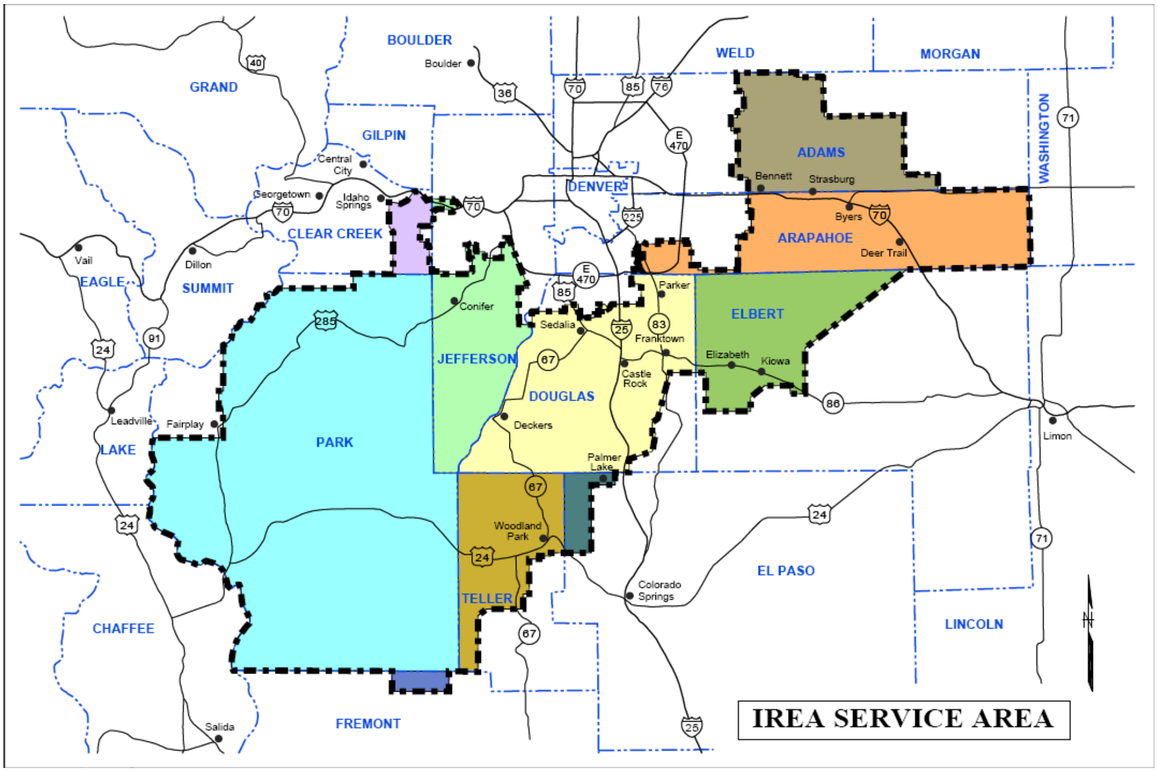
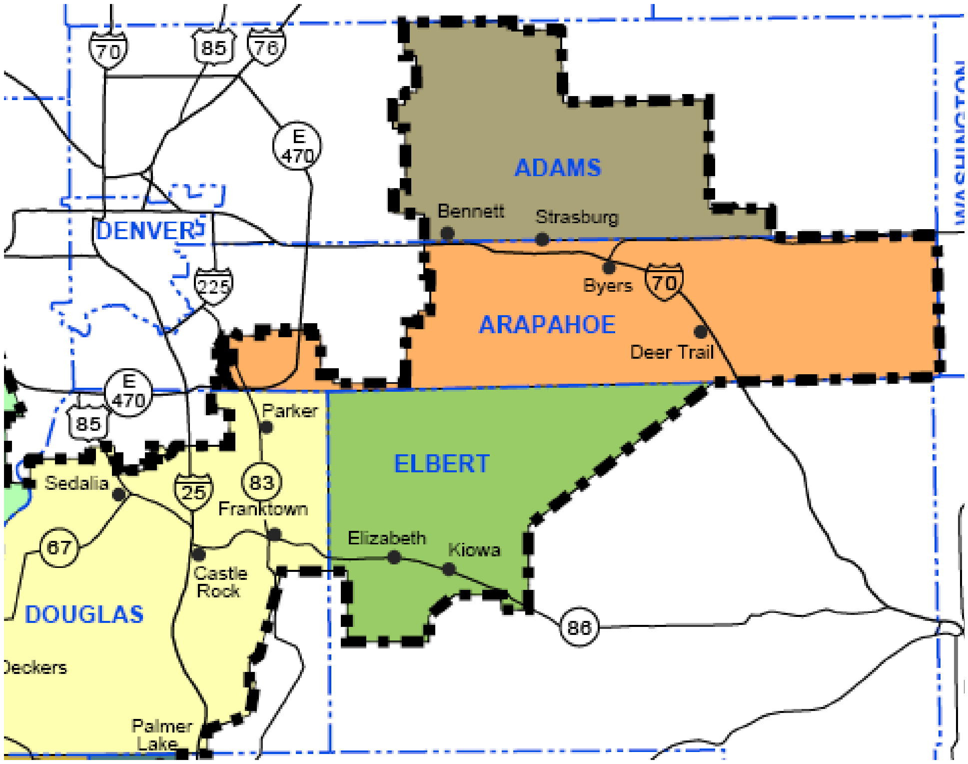
Appendix A – IREA Territory Maps

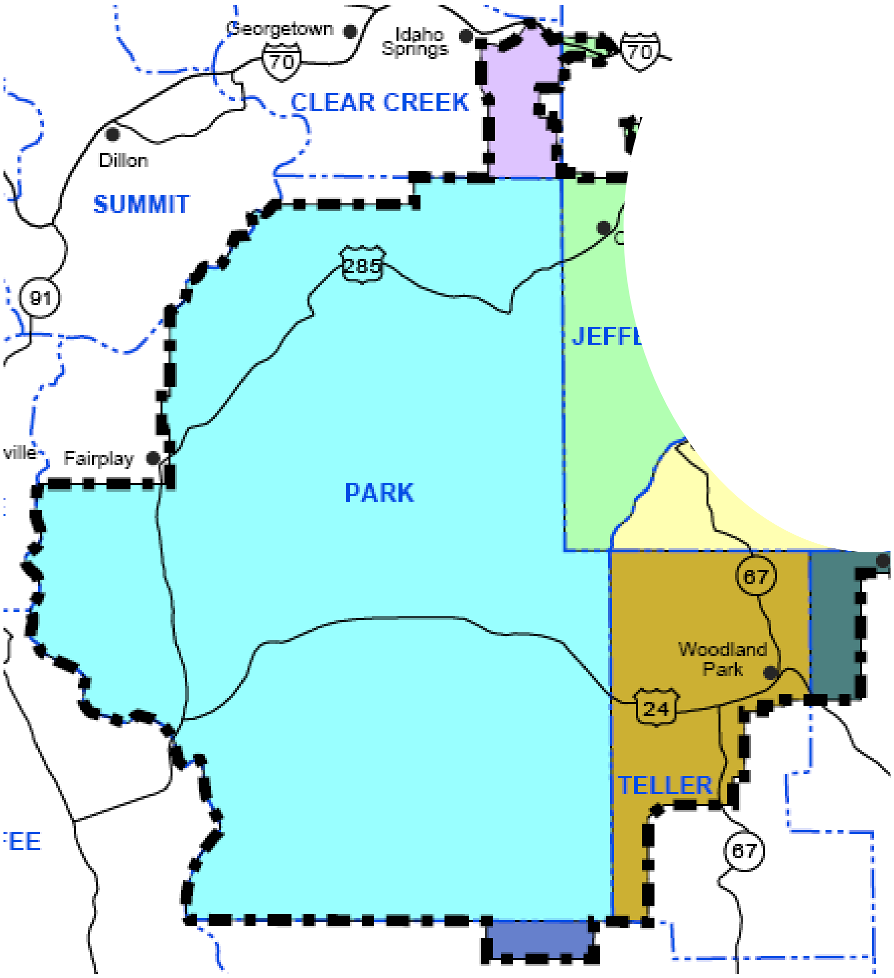
Service Territory Map



Plains Region Map

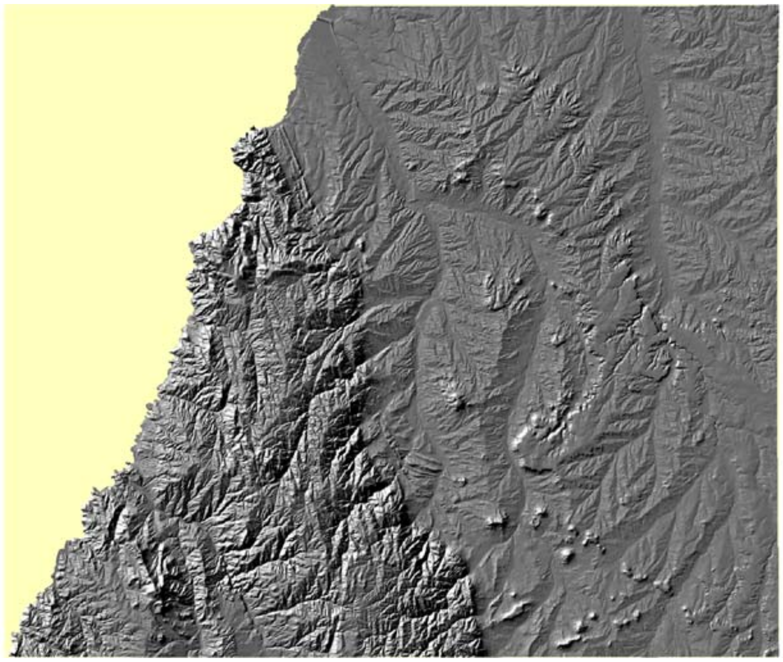


Mountains Region Map

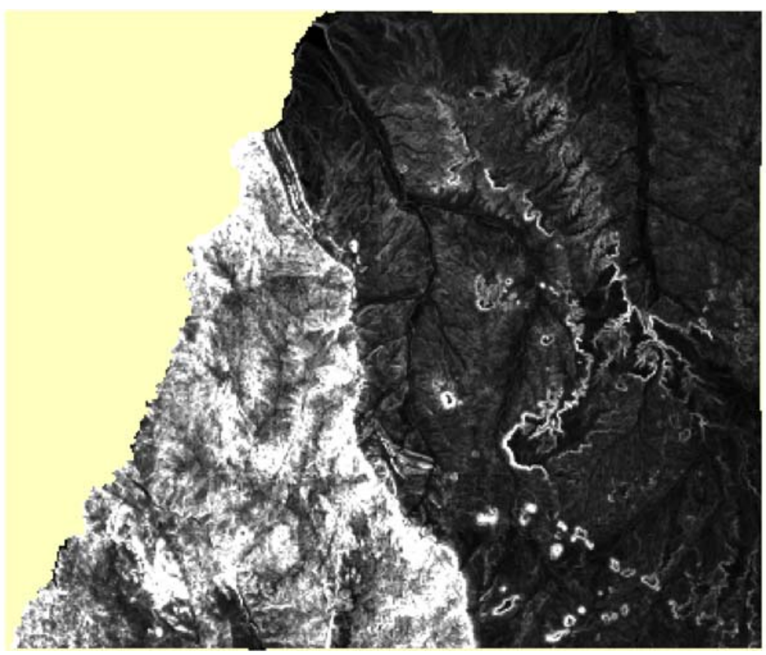


Appendix B – Self Project Input Data Examples

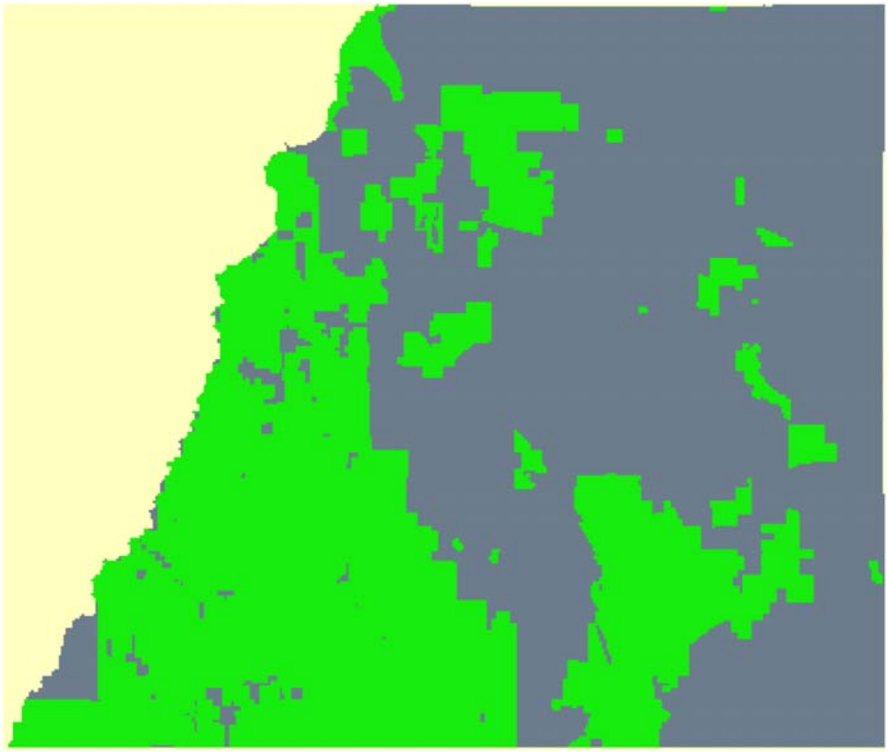
Hillshade



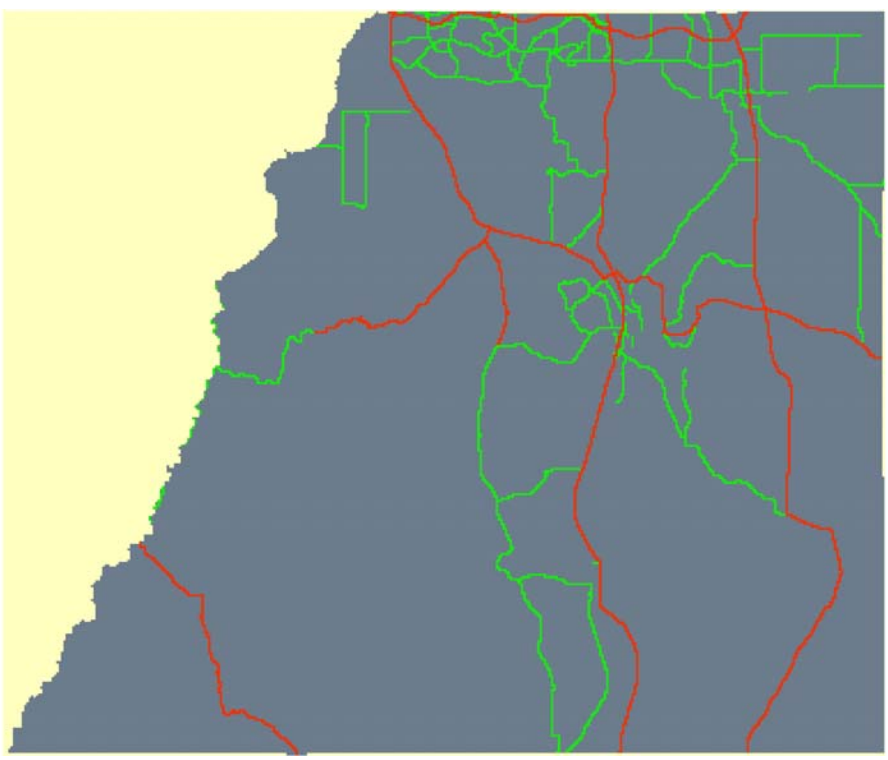
Slope



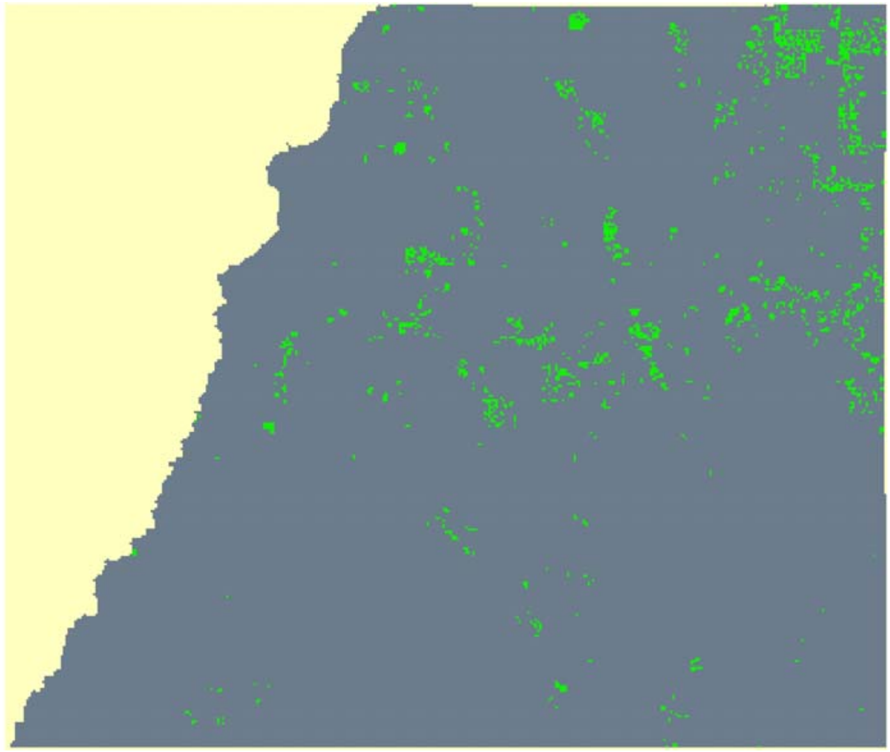
Exclusion



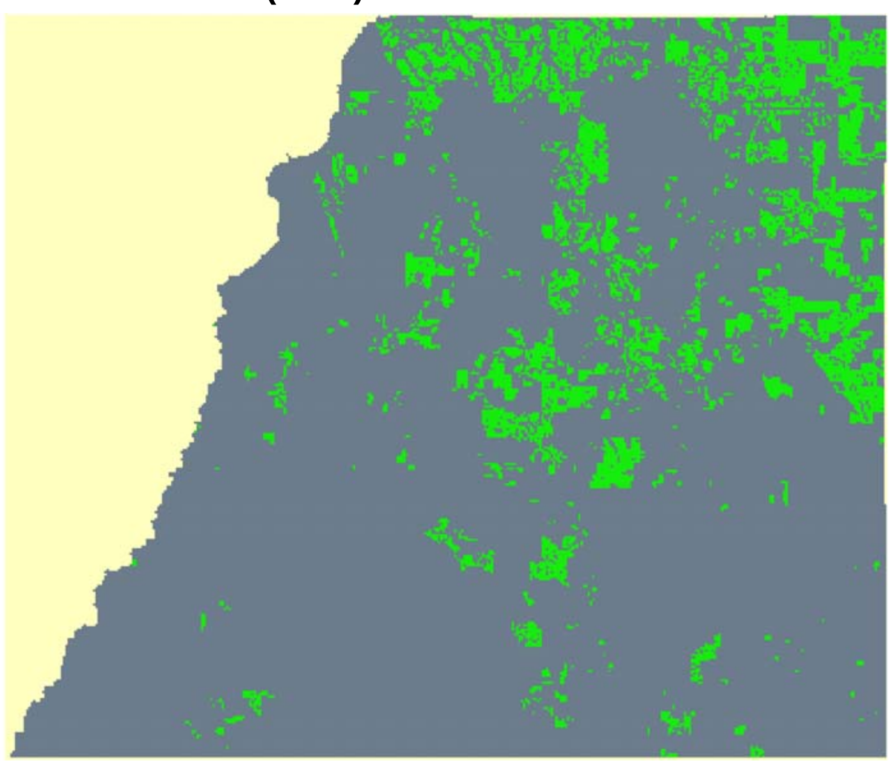
Transportation



Seed Urban Extent (1980)



Control Year Urban Extent (2005)



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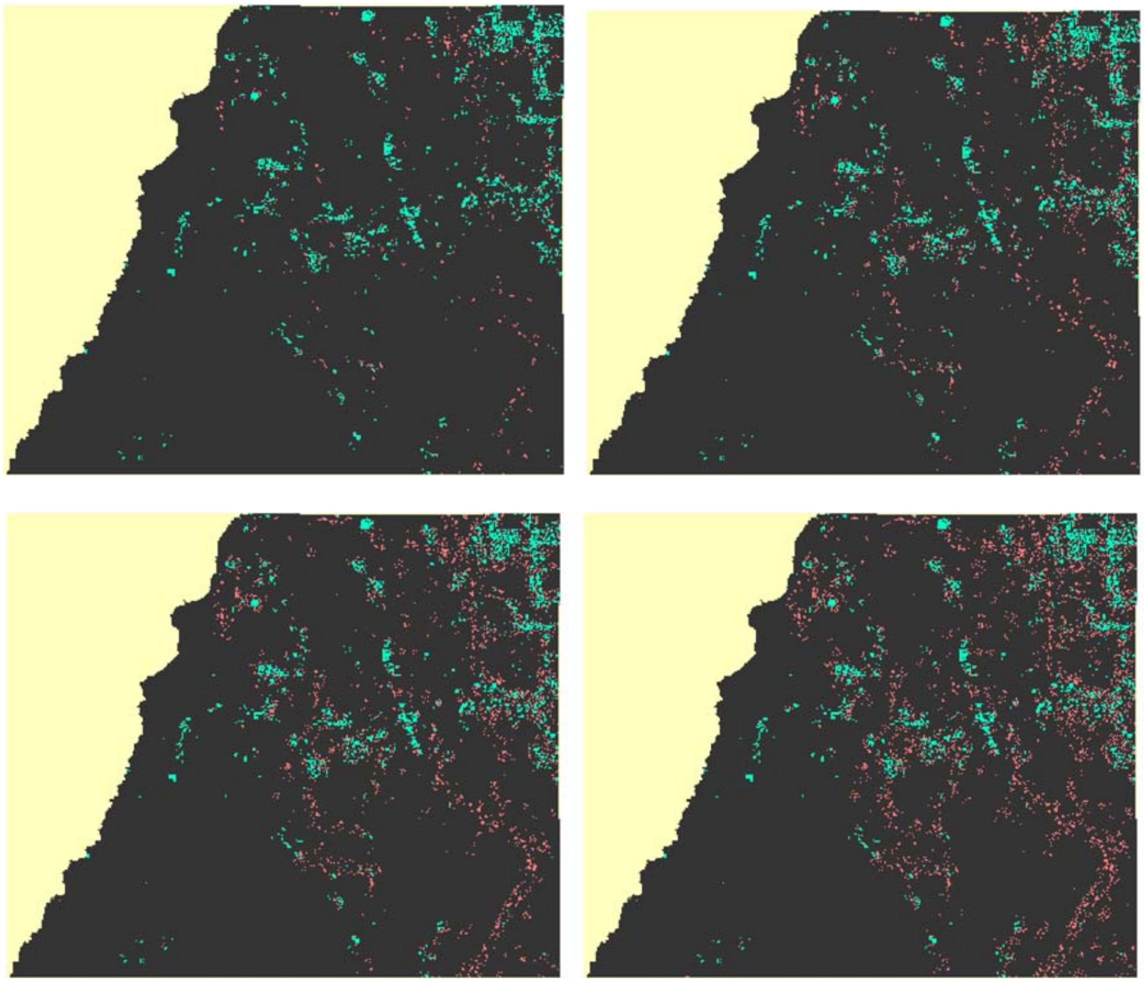
Appendix C – Growth Simulator Raster Output Examples



Simulator Output
Red represents new Growth
5yr, 10yr, 15yr, 20yr

Appendix D – Growth Simulator Statistical Output Examples

Iterations.Log

Run	Year	MC	SnG	SpG	EdG	RdG	GrwPix	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
1	1985	1	147	74	3630	1578	5429	5429	122152500		540	740250	320000	17	14	8.3706	0.1218	11745000	139725000	0.0841	25	25	25	25	25
1	1990	1	267	148	8448	2703	11566	11566	260235000		578	1066200	537314	36	30	8.2409	0.2595	29677500	283432500	0.1047	25	25	25	25	25
1	1995	1	370	187	14132	3355	18044	18044	405990000		541	1273800	843272	56	47	8.1447	0.4049	59512500	440302500	0.1352	25	25	25	25	25
1	2000	1	437	205	19668	3661	23971	23971	539347500		480	1375500	1228453	74	63	8.1647	0.5381	98640000	594562500	0.1659	25	25	25	25	25
1	2005	1	501	227	24604	3751	29083	29083	654367500		432	1416150	1631719	90	76	8.2098	0.6531	138487500	723037500	0.1915	25	25	25	25	25
1	1985	2	155	82	3543	1605	5385	5385	121162500		513	741900	334298	17	14	8.47	0.1208	11317500	121162500	0.0934	25	25	25	25	25
1	1990	2	267	129	8181	2610	11187	11187	251707500		523	1041150	577256	35	29	8.2588	0.251	29137500	251707500	0.1158	25	25	25	25	25
1	1995	2	369	174	13793	3293	17629	17629	396652500		536	1255200	833843	55	46	8.203	0.3956	59850000	396652500	0.1509	25	25	25	25	25
1	2000	2	449	204	19419	3607	23679	23679	532777500		482	1377300	1211172	73	62	8.1976	0.5316	101160000	532777500	0.1899	25	25	25	25	25
1	2005	2	515	228	24379	3718	28840	28840	648900000		440	1430250	1591312	89	75	8.2512	0.6477	143325000	648900000	0.2209	25	25	25	25	25
1	1985	3	170	94	3647	1545	5456	5456	122760000		521	736050	332793	17	14	8.3216	0.1224	11790000	122760000	0.096	25	25	25	25	25
1	1990	3	282	138	8355	2627	11402	11402	256545000		547	1049850	560978	35	30	8.1903	0.2559	28507500	256545000	0.1111	25	25	25	25	25
1	1995	3	369	185	13962	3189	17705	17705	398362500		529	1257000	849343	55	46	8.1168	0.3973	59040000	398362500	0.1482	25	25	25	25	25
1	2000	3	439	217	19561	3507	23724	23724	533790000		483	1381350	1211227	73	62	8.122	0.5326	101767500	533790000	0.1907	25	25	25	25	25
1	2005	3	497	237	24658	3628	29020	29020	652950000		443	1441650	1590389	90	76	8.1586	0.6517	142110000	652950000	0.2176	25	25	25	25	25
1	1985	4	153	90	3916	1689	5848	5848	131580000		538	755100	339006	18	15	8.2921	0.1312	12285000	131580000	0.0934	25	25	25	25	25
1	1990	4	261	146	8728	2836	11971	11971	269347500		576	1082400	555156	37	31	8.1764	0.2686	30105000	269347500	0.1118	25	25	25	25	25
1	1995	4	352	181	14341	3526	18400	18400	414000000		544	1316550	854586	57	48	8.1083	0.4129	60390000	414000000	0.1459	25	25	25	25	25
1	2000	4	422	220	20147	3789	24578	24578	553005000		500	1423650	1208385	76	64	8.1539	0.5518	102555000	553005000	0.1855	25	25	25	25	25
1	2005	4	484	258	25281	3866	29889	29889	672502500		449	1451550	1612283	93	78	8.1944	0.6712	144742500	672502500	0.2152	25	25	25	25	25
2	1985	1	211	86	3752	1439	5488	5488	123480000		463	727800	373850	17	14	8.1793	0.1231	11722500	123480000	0.0949	75	25	25	25	25
2	1990	1	413	182	8499	2260	11354	11354	255465000		434	974550	699833	35	30	7.9947	0.2548	27495000	255465000	0.1076	75	25	25	25	25
2	1995	1	548	253	13822	2590	17213	17213	387292500		427	1136250	1020878	53	45	7.9906	0.3862	55170000	387292500	0.1425	75	25	25	25	25
2	2000	1	678	307	18988	2706	22679	22679	510277500		412	1242450	1355680	70	59	8.0828	0.5091	93195000	510277500	0.1826	75	25	25	25	25
2	2005	1	756	349	23830	2836	27771	27771	624847500		412	1306200	1635455	86	73	8.1594	0.6236	132277500	624847500	0.2117	75	25	25	25	25
2	1985	2	192	82	3719	1385	5378	5378	121005000		441	724350	387602	17	14	8.1252	0.1207	11272500	121005000	0.0932	75	25	25	25	25
2	1990	2	367	187	8431	2128	11113	11113	250042500		473	967800	632569	34	29	8.0055	0.2494	27427500	250042500	0.1097	75	25	25	25	25
2	1995	2	498	251	13749	2505	17003	17003	382567500		471	1150350	916099	53	44	7.9492	0.3815	55012500	382567500	0.1438	75	25	25	25	25
2	2000	2	598	295	19257	2641	22791	22791	512797500		446	1263600	1260908	71	60	7.9965	0.5116	93307500	512797500	0.182	75	25	25	25	25
2	2005	2	653	313	24370	2768	28104	28104	632340000		433	1339500	1576871	87	73	8.0475	0.6311	133650000	632340000	0.2114	75	25	25	25	25
2	1985	3	222	116	3677	1351	5366	5366	120735000		485	722550	350582	17	14	8.3321	0.1204	11475000	120735000	0.095	75	25	25	25	25
2	1990	3	347	182	8265	2083	10877	10877	244732500		485	970800	606387	34	28	8.1589	0.2441	27855000	244732500	0.1138	75	25	25	25	25
2	1995	3	470	240	13775	2533	17018	17018	382905000		443	1159500	974763	53	44	8.0791	0.3819	57712500	382905000	0.1507	75	25	25	25	25
2	2000	3	574	296	19316	2679	22865	22865	514462500		441	1265850	1278520	71	60	8.0996	0.5132	94905000	514462500	0.1845	75	25	25	25	25
2	2005	3	647	334	24346	2808	28135	28135	633037500		426	1354050	1603838	87	73	8.1288	0.6317	132277500	633037500	0.209	75	25	25	25	25
2	1985	4	256	122	3834	1366	5578	5578	125505000		499	744300	350261	17	15	8.1136	0.1252	11925000	125505000	0.095	75	25	25	25	25
2	1990	4	435	207	8802	2139	11583	11583	260617500		492	1012950	627759	36	30	8.0508	0.2599	28552500	260617500	0.1096	75	25	25	25	25
2	1995	4	543	262	14561	2569	17935	17935	403537500		457	1194000	989705	56	47	7.9475	0.4024	58432500	403537500	0.1448	75	25	25	25	25
2	2000	4	658	316	20318	2714	24006	24006	540135000		444	1291800	1326639	74	63	7.981	0.5389	97875000	540135000	0.1812	75	25	25	25	25
2	2005	4	752	355	25360	2821	29288	29288	658980000		421	1369800	1683224	91	76	8.0389	0.6577	137002500	658980000	0.2079	75	25	25	25	25
3	1985	1	156	229	4573	3748	8706	8706	195885000		623	1130850	398102	27	23	8.0896	0.1954	13882500	195885000	0.0709	25	25	75	25	25
3	1990	1	271	405	11262	4810	16748	16748	376830000		588	1413300	730102	52	44	8.0575	0.3758	32782500	376830000	0.087	25	25	75	25	25
3	1995	1	334	494	17992	5049	23869	23869	537052500		541	1526100	1090439	74	62	8.0849	0.5356	67230000	537052500	0.1252	25	25	75	25	25
3	2000	1	399	592	24330	5108	30429	30429	684652500		485	1568400	1521464	94	79	8.1645	0.683	113962500	684652500	0.1665	25	25	75	25	25
3	2005	1	445	655	29139	5129	35368	35368	795780000		435	1552800	1952069	109	92	8.2247	0.7939	159682500	795780000	0.2007	25	25	75	25	25
3	1985	2	156	248	4774	3927	9105	9105	204862500		639	1163100	402289	28	24	8.0265	0.2043	13387500	204862500	0.0653	25	25	75	25	25
3	1990	2	260	402	11416	4900	16978	16978	382005000		576	1446300	754336	53	44	8.0491	0.381	33750000	382005000	0.0883	25	25	75	25	25
3	1995	2	333	505	18173	5074	24085	24085	541912500		546	1512150	1089066	75	63	8.0863	0.5404	67590000	541912500	0.1247	25	25	75	25	25
3	2000	2	383	570	24228	5143	30324	30324	682290000		469	1528500	1567804	94	79	8.1586	0.6806	114772500	682290000	0.1682	25	25	75	25	25
3	2005	2	423	637	28777	5154	34991	34991	787297500		427	1539750	1968566	108	91	8.2171	0.7856	158917500	787297500	0.2019	25	25	75	25	25
3	1985	3	172	247	4896	3716	9031	9031	203197500		659	1132650	387382	28	24	8.1059	0.2026	13882500	203197500	0.0683	25	25	75	25	25
3	1990	3	286	401	11518	4794	16999	16999	382477500		582	1424550	747062	53	44	8.1042	0.3814	33660000	382477500	0.088	25	25	75	25	25
3	1995	3	367	524	18211	4987	24089	24089	542002500		545	1526100	1090899	75	63	8.1335	0.5405	67072500	542002500	0.1237	25	25	75	25	25
3	2000	3	423	622	24404	5027	30476	30476	685710000		465	1566150	1588984	94	80	8.2106	0.6841	111915000	685710000	0.1632	25	25	75	25	25
3	2005	3	453	668	29289	5053	35463	35463	797917500		426	1543350	1998433	110	93	8.2679	0.7962	157027500	797917500	0.1968	25	25	75	25	25

Actuals.Log

Run	Year	MC	SnG	SpG	EdG	RdG	GrwPix	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
	1985							1303	29317500		457	489150	176012	4	3	9.3452	0.0327								
	1990							2350	52875000		467	601500	223314	7	6	9.5143	0.0679								
	1995							4170	93825000		481	755700	303399	13	11	9.3513	0.1406								
	2000							6838	153855000		555	977550	371432	21	18	9.2847	0.2648								
	2005							9207	207157500		590	1144200	439436	29	24	9.4629	0.4032								

Averages.Log

Run	Year	MC	SnG	SpG	EdG	RdG	GrwPix	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
1	1985		156.25	85	3684	1604.25	5529.5	5529.5	124413750		528	743325	331524.25	15	14.25	8.36	0.12	11784375	128806875	0.09	25	25	25	25	25
1	1990		269.25	140.25	8428	2694	11531.5	11531.5	259458750		556	1059900	557676	31.5	30	8.22	0.26	29356875	265258125	0.11	25	25	25	25	25
1	1995		365	181.75	14057	3340.75	17944.5	17944.5	403751250		537.5	1275637.5	845261	49	46.75	8.14	0.4	59698125	412329375	0.15	25	25	25	25	25
1	2000		436.75	211.5	19698.75	3641	23988	23988	539730000		486.25	1389450	1214809.25	65.75	62.75	8.16	0.54	101030625	553533750	0.18	25	25	25	25	25
1	2005		499.25	237.5	24730.5	3740.75	29208	29208	657180000		441	1434900	1606425.75	80	76.25	8.2	0.66	142166250	674347500	0.21	25	25	25	25	25
2	1985		220.25	101.5	3745.5	1385.25	5452.5	5452.5	122681250		472	729750	365573.75	14.75	14.25	8.19	0.12	11598750	122681250	0.09	75	25	25	25	25
2	1990		390.5	189.5	8499.25	2152.5	11231.75	11231.75	252714375		471	981525	641637	30.75	29.25	8.05	0.25	27832500	252714375	0.11	75	25	25	25	25
2	1995		514.75	251.5	13976.75	2549.25	17292.25	17292.25	389075625		449.5	1160025	975361.25	47.25	45	7.99	0.39	56581875	389075625	0.15	75	25	25	25	25
2	2000		627	303.5	19469.75	2685	23085.25	23085.25	519418125		435.75	1265925	1305436.75	63.25	60.5	8.04	0.52	94820625	519418125	0.18	75	25	25	25	25
2	2005		702	337.75	24476.5	2808.25	28324.5	28324.5	637301250		423	1342387.5	1624847	77.5	73.75	8.09	0.64	133801875	637301250	0.21	75	25	25	25	25
3	1985		158	235.75	4697.75	3745	8836.5	8836.5	198821250		629.25	1125637.5	399118.25	24.25	23.25	8.08	0.2	13786875	198821250	0.07	25	25	75	25	25
3	1990		265	391.75	11169.25	4806	16632	16632	374220000		579.75	1410937.5	736009.75	45.25	43.25	8.07	0.37	33300000	374220000	0.09	25	25	75	25	25
3	1995		342.5	503.75	17815.75	5022.25	23684.25	23684.25	532895625		544.75	1516575	1075075.75	64.5	61.75	8.11	0.53	67044375	532895625	0.13	25	25	75	25	25
3	2000		402	589.5	23947.75	5090.25	30029.5	30029.5	675663750		476	1553475	1531929	81.75	78.25	8.19	0.67	112966875	675663750	0.17	25	25	75	25	25
3	2005		441	645	28755.25	5113.75	34955	34955	786487500		433.5	1549162.5	1938406.25	95.25	91.25	8.25	0.78	158490000	786487500	0.2	25	25	75	25	25
4	1985		199.5	295	4705.25	2854.75	8054.5	8054.5	181226250		556.5	1023037.5	418750	21.75	20.75	7.87	0.18	12796875	181226250	0.07	75	25	75	25	25
4	1990		342.75	501.25	11057.75	3412	15313.75	15313.75	344559375		546.25	1263487.5	726711.5	41.75	40	7.94	0.34	30825000	344559375	0.09	75	25	75	25	25
4	1995		433.25	631.75	17843.75	3586.25	22495	22495	506137500		508	1399387.5	1099867.75	61.25	58.5	8.01	0.5	62955000	506137500	0.12	75	25	75	25	25
4	2000		493	718.5	24145.25	3622.75	28979.5	28979.5	652038750		444.25	1447837.5	1588225.75	79.25	75.75	8.08	0.65	107763750	652038750	0.17	75	25	75	25	25
4	2005		542.5	790.75	29127.75	3712.5	34173.5	34173.5	768903750		419.75	1450725	1960905	93.25	89.25	8.16	0.77	151908750	768903750	0.2	75	25	75	25	25
5	1985		142.5	66.75	17224	3424	20857.25	20857.25	469288125		435.25	1234800	1199473.75	57	54.5	8.23	0.47	22421250	469288125	0.05	25	75	25	25	25
5	1990		191	95	30300.75	3739	34325.75	34325.75	772329375		365	1394962.5	2261695.25	93.75	89.5	8.27	0.77	44431875	772329375	0.06	25	75	25	25	25
5	1995		211.75	106.25	36184.5	3757	40259.5	40259.5	905838750		344.25	1462050	2787127.5	110	105.25	8.27	0.9	80454375	905838750	0.09	25	75	25	25	25
5	2000		223	110	38326.5	3757.5	42417	42417	954382500		325.25	1506225	3099394.25	115.75	110.75	8.32	0.95	132260625	954382500	0.14	25	75	25	25	25
5	2005		229.75	112.75	39060.75	3758.75	43162	43162	971145000		324.5	1539112.5	3159799.25	117.75	112.75	8.35	0.97	177221250	971145000	0.18	25	75	25	25	25
6	1985		199.75	83.25	16955	2549	19787	19787	445207500		385	1109325	1291436.25	54.25	52	8.06	0.44	21712500	445207500	0.05	75	75	25	25	25
6	1990		285.75	122.75	29494	2740.75	32643.25	32643.25	734473125		331.75	1265812.5	2376886.75	89.25	85.25	8.18	0.73	42828750	734473125	0.06	75	75	25	25	25
6	1995		325.5	141.75	35197.75	2751.75	38416.75	38416.75	864376875		310.75	1355175	2953016.25	105	100.25	8.24	0.86	76359375	864376875	0.09	75	75	25	25	25
6	2000		340.25	149.25	37474.5	2753.25	40717.25	40717.25	916138125		303.25	1413600	3195704.75	111.25	106.25	8.29	0.91	121843125	916138125	0.13	75	75	25	25	25
6	2005		352.75	155.25	38531.5	2753.75	41793.25	41793.25	940348125		297	1464562.5	3344829	114	109	8.33	0.94	165105000	940348125	0.18	75	75	25	25	25
7	1985		140.5	201.5	21003	4885.25	26230.25	26230.25	590180625		439.25	1421475	1466687.25	71.75	68.5	8.14	0.59	23220000	590180625	0.04	25	75	75	25	25
7	1990		178.25	252.5	33139.75	4947.75	38518.25	38518.25	866660625		363.5	1464187.5	2534000.25	105	100.5	8.22	0.86	45061875	866660625	0.05	25	75	75	25	25
7	1995		186.25	263.75	36894.25	4948.25	42292.5	42292.5	951581250		340.5	1496812.5	2955228.75	115.75	110.5	8.29	0.95	81652500	951581250	0.09	25	75	75	25	25
7	2000		190.75	270	37826.5	4948.5	43235.75	43235.75	972804375		331.25	1539675	3099413.5	118	112.75	8.35	0.97	133183125	972804375	0.14	25	75	75	25	25
7	2005		196	275.25	38166.25	4948.5	43586	43586	980685000		333.5	1565025	3102130.75	119.25	114	8.37	0.98	177654375	980685000	0.18	25	75	75	25	25

Statistics.Log

Run	Year	MC	SnG	SpG	EdG	RdG	GrwPix	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
1								0.9693	0.9693	0.9693	0.8973	0.8449	0.9919	0.9659	0.9754	0.0028	0.937	142166250	674347500	0.2108	25	25	25	25	25
2								0.9714	0.9714	0.9714	0.9119	0.8921	0.9984	0.9675	0.9774	0	0.9392	133801875	637301250	0.21	75	25	25	25	25
3								0.9473	0.9473	0.9473	0.9383	0.6637	0.9949	0.9435	0.9571	0.0052	0.907	158490000	786487500	0.2015	25	25	75	25	25
4								0.9565	0.9565	0.9565	0.9697	0.7448	0.9963	0.9516	0.9639	0.0007	0.9237	151908750	768903750	0.1976	75	25	75	25	25
5								0.6786	0.6786	0.6786	0.5681	0.8226	0.8273	0.6666	0.6965	0.0155	0.6143	177221250	971145000	0.1825	25	75	25	25	25
6								0.7013	0.7013	0.7013	0.5542	0.8849	0.8345	0.6892	0.7185	0.0027	0.6366	165105000	940348125	0.1756	75	75	25	25	25
7								0.5864	0.5864	0.5864	0.4545	0.9775	0.7261	0.58	0.6068	0.0043	0.5256	177654375	980685000	0.1812	25	75	75	25	25
8								0.6245	0.6245	0.6245	0.4378	0.9661	0.7429	0.6182	0.6437	0.0001	0.5537	174161250	972298125	0.1791	75	75	75	25	25
9								0.9724	0.9724	0.9724	0.8241	0.8542	0.994	0.9682	0.9772	0.0155	0.9428	143960625	661983750	0.2175	25	25	25	75	25
10								0.9731	0.9731	0.9731	0.9183	0.8927	0.9978	0.9684	0.9768	0.0027	0.9423	133093125	632480625	0.2104	75	25	25	75	25
11								0.9459	0.9459	0.9459	0.8858	0.6294	0.9968	0.9407	0.9546	0.0422	0.907	159513750	785373750	0.2031	25	25	75	75	25
12								0.9621	0.9621	0.9621	0.9862	0.7657	0.9932	0.9573	0.9682	0.0005	0.9274	151340625	780682500	0.1939	75	25	75	75	25
13								0.6832	0.6832	0.6832	0.5471	0.809	0.8246	0.6705	0.6982	0.0155	0.6031	176765625	973434375	0.1816	25	75	25	75	25
14								0.7033	0.7033	0.7033	0.5249	0.8686	0.8213	0.6883	0.7148	0.0014	0.641	169290000	952385625	0.1778	75	75	25	75	25
15								0.5801	0.5801	0.5801	0.4213	0.9579	0.7139	0.5712	0.5977	0.0004	0.5097	177496875	979447500	0.1812	25	75	75	75	25
16								0.6237	0.6237	0.6237	0.5355	0.9118	0.7765	0.6166	0.6453	0.0001	0.5625	173626875	968574375	0.1793	75	75	75	75	25
17								0.9633	0.9633	0.9633	0.7943	0.8454	0.994	0.9596	0.9697	0.0001	0.927	146677500	679702500	0.2158	25	25	25	25	75
18								0.9652	0.9652	0.9652	0.9395	0.8139	0.9957	0.962	0.9718	0.0004	0.9283	147172500	692836875	0.2124	75	25	25	25	75
19								0.9224	0.9224	0.9224	0.8144	0.4103	0.9965	0.9181	0.9334	0.0288	0.8793	166871250	811276875	0.2057	25	25	75	25	75
20								0.9412	0.9412	0.9412	0.8997	0.5534	0.9931	0.9357	0.9486	0.0083	0.9032	162894375	830199375	0.1962	75	25	75	25	75
21								0.6544	0.6544	0.6544	0.517	0.8074	0.8087	0.6398	0.6681	0.0895	0.5914	177525000	970605000	0.1829	25	75	25	25	75
22								0.6573	0.6573	0.6573	0.5889	0.8818	0.8201	0.6493	0.6763	0.0112	0.5803	176973750	973406250	0.1818	75	75	25	25	75
23								0.6203	0.6203	0.6203	0.502	0.9683	0.7726	0.6141	0.6456	0.0272	0.5525	178053750	979830000	0.1817	25	75	75	25	75
24								0.5789	0.5789	0.5789	0.4059	0.9754	0.696	0.5603	0.5902	0.0001	0.4956	177828750	983368125	0.1808	75	75	75	25	75
25								0.9682	0.9682	0.9682	0.7535	0.8413	0.991	0.9661	0.9754	0.0045	0.9341	150277500	681817500	0.2204	25	25	25	75	75
26								0.9678	0.9678	0.9678	0.8917	0.8348	0.9937	0.9637	0.9737	0.008	0.9301	147262500	674808750	0.2182	75	25	25	75	75
27								0.9254	0.9254	0.9254	0.8778	0.403	0.997	0.9187	0.9342	0.0024	0.873	166826250	816024375	0.2044	25	25	75	75	75
28								0.9431	0.9431	0.9431	0.9145	0.5743	0.995	0.9396	0.953	0.0055	0.896	162315000	824141250	0.197	75	25	75	75	75
29								0.6399	0.6399	0.6399	0.4979	0.8018	0.7949	0.6267	0.6526	0.0133	0.5685	177586875	973254375	0.1825	25	75	25	75	75
30								0.6646	0.6646	0.6646	0.5144	0.849	0.8049	0.6525	0.678	0.0141	0.5921	176895000	973046250	0.1818	75	75	25	75	75
31								0.5817	0.5817	0.5817	0.4656	0.9382	0.73	0.5754	0.599	0.0023	0.5101	177828750	980921250	0.1813	25	75	75	75	75
32								0.5768	0.5768	0.5768	0.4766	0.9602	0.7295	0.5673	0.5905	0.0026	0.5101	177761250	982046250	0.181	75	75	75	75	75

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Appendix E – Growth Simulator Statistical Analysis

Calibration 1

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
25	0.971	0.971	0.971	0.6796	0.8468	0.9954	0.968	0.9778	0.0031	0.9335	149281875	731812500	0.204	25	25	25	75	75
1	0.9703	0.9703	0.9703	0.9229	0.8651	0.9952	0.9671	0.9757	0.0264	0.9325	143876250	711922500	0.2021	25	25	25	25	25
17	0.97	0.97	0.97	0.6728	0.8476	0.9881	0.9653	0.9756	0.0006	0.9369	148381875	736183125	0.2016	25	25	25	25	75
														25	25	25	25	75

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9729	0.9729	0.9729	0.8862	0.8966	0.9946	0.9693	0.9782	0.0002	0.9386	134842500	709481250	0.1901	75	25	25	75	25
2	0.9714	0.9714	0.9714	0.9103	0.8946	0.9983	0.9667	0.9759	0.0048	0.9407	136080000	702928125	0.1936	75	25	25	25	25
25	0.971	0.971	0.971	0.6796	0.8468	0.9954	0.968	0.9778	0.0031	0.9335	149281875	731812500	0.204	25	25	25	75	75
														75	25	25	75	25

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
4	0.9618	0.9618	0.9618	0.9628	0.7914	0.991	0.9579	0.9677	0.0016	0.9291	151441875	833445000	0.1817	75	25	75	25	25
12	0.9616	0.9616	0.9616	0.9575	0.7425	0.9867	0.9557	0.9671	0.0002	0.9264	153590625	844813125	0.1818	75	25	75	75	25
28	0.9441	0.9441	0.9441	0.9524	0.4808	0.9944	0.9395	0.953	0.0001	0.9	164306250	882196875	0.1862	75	25	75	75	75
														75	25	75	75	25

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
31	0.5715	0.5715	0.5715	0.4833	0.9836	0.7336	0.559	0.5861	0.0073	0.5095	177946875	1011543750	0.1759	25	75	75	75	75
32	0.5754	0.5754	0.5754	0.4258	0.9701	0.7002	0.5639	0.5942	0.0008	0.4897	178115625	1012050000	0.176	75	75	75	75	75
15	0.5879	0.5879	0.5879	0.3992	0.9653	0.6984	0.5826	0.6108	0	0.5091	178042500	1009850625	0.1763	25	75	75	75	25
														25	75	75	75	75

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.9714	0.9714	0.9714	0.9103	0.8946	0.9983	0.9667	0.9759	0.0048	0.9407	136080000	702928125	0.1936	75	25	25	25	25
19	0.9291	0.9291	0.9291	0.8904	0.444	0.9973	0.9219	0.9383	0.0314	0.8841	168660000	856912500	0.1968	25	25	75	25	75
20	0.9399	0.9399	0.9399	0.89	0.5566	0.9971	0.9342	0.9475	0	0.8977	163732500	864793125	0.1893	75	25	75	25	75
														75	25	75	25	75

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9729	0.9729	0.9729	0.8862	0.8966	0.9946	0.9693	0.9782	0.0002	0.9386	134842500	709481250	0.1901	75	25	25	75	25
25	0.971	0.971	0.971	0.6796	0.8468	0.9954	0.968	0.9778	0.0031	0.9335	149281875	731812500	0.204	25	25	25	75	75
1	0.9703	0.9703	0.9703	0.9229	0.8651	0.9952	0.9671	0.9757	0.0264	0.9325	143876250	711922500	0.2021	25	25	25	25	25
														25	25	25	75	25

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9729	0.9729	0.9729	0.8862	0.8966	0.9946	0.9693	0.9782	0.0002	0.9386	134842500	709481250	0.1901	75	25	25	75	25
25	0.971	0.971	0.971	0.6796	0.8468	0.9954	0.968	0.9778	0.0031	0.9335	149281875	731812500	0.204	25	25	25	75	75
2	0.9714	0.9714	0.9714	0.9103	0.8946	0.9983	0.9667	0.9759	0.0048	0.9407	136080000	702928125	0.1936	75	25	25	25	25
														75	25	25	75	25

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
5	0.6921	0.6921	0.6921	0.513	0.8612	0.8201	0.6802	0.7105	0.0803	0.6243	176866875	1000237500	0.1768	25	75	25	25	25
29	0.6574	0.6574	0.6574	0.5029	0.7683	0.8042	0.6476	0.6732	0.0624	0.5848	177631875	1000316250	0.1776	25	75	25	75	75
27	0.9235	0.9235	0.9235	0.8813	0.3907	0.9971	0.9155	0.932	0.0535	0.8723	167461875	853706250	0.1962	25	25	75	75	75
														25	75	25	75	75

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.9714	0.9714	0.9714	0.9103	0.8946	0.9983	0.9667	0.9759	0.0048	0.9407	136080000	702928125	0.1936	75	25	25	25	25
10	0.9729	0.9729	0.9729	0.8862	0.8966	0.9946	0.9693	0.9782	0.0002	0.9386	134842500	709481250	0.1901	75	25	25	75	25
17	0.97	0.97	0.97	0.6728	0.8476	0.9881	0.9653	0.9756	0.0006	0.9369	148381875	736183125	0.2016	25	25	25	25	75
														75	25	25	25	25

Run Frequency in top 3

Run	Freq.	Diff	Sprd	Brd	SlRs	RdGr
2	4	75	25	25	25	25
10	4	75	25	25	75	25
25	4	25	25	25	75	75
1	2	25	25	25	25	25
17	2	25	25	25	25	75
4	1					
5	1					
12	1					
15	1					
19	1					
20	1					
27	1					
28	1					
29	1					
31	1					
32	1					

Solution

Diff	Sprd	Brd	SlRs	RdGr		
25	25	25	25	75		
13	13	13	13	63	Start	
38	38	38	38	88	End	
25	25	25	25	25	Step	
2	2	2	2	2	32	Runs

Searching LeeSalee solution

Calibration 2

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
5	0.9487	0.9487	0.9487	0.6469	0.8919	0.9982	0.9435	0.958	0.0761	0.9392	160486875	775625625	0.2069	13	38	13	13	63
12	0.9825	0.9825	0.9825	0.0062	0.9336	0.9855	0.979	0.986	0.006	0.9795	110255625	538509375	0.2047	38	13	38	38	63
27	0.9861	0.9861	0.9861	0.1892	0.9708	0.99	0.9843	0.9902	0.0047	0.9813	101362500	495056250	0.2047	13	13	38	38	88
														13	13	38	38	63

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.99	0.99	0.99	0.8298	0.9925	0.997	0.9895	0.9929	0.005	0.9886	85691250	423078750	0.2025	38	13	13	38	63
26	0.989	0.989	0.989	0.8416	0.9912	0.9923	0.9867	0.9918	0	0.9844	83970000	412706250	0.2035	38	13	13	38	88
18	0.9888	0.9888	0.9888	0.8573	0.9889	0.9966	0.9887	0.9923	0.0027	0.9844	82158750	416160000	0.1974	38	13	13	13	88
														38	13	13	38	88

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
25	0.9848	0.9848	0.9848	0.9439	0.9876	0.9929	0.9813	0.9865	0.0034	0.9831	77293125	385183125	0.2007	13	13	13	38	88
14	0.9416	0.9416	0.9416	0.9097	0.8034	0.9969	0.9356	0.9492	0.0035	0.9306	164148750	858223125	0.1913	38	38	13	38	63
1	0.9884	0.9884	0.9884	0.8843	0.9902	0.9966	0.9824	0.9879	0.0001	0.9831	78249375	387258750	0.2021	13	13	13	13	63
														13	13	13	38	63

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.99	0.99	0.99	0.8298	0.9925	0.997	0.9895	0.9929	0.005	0.9886	85691250	423078750	0.2025	38	13	13	38	63
26	0.989	0.989	0.989	0.8416	0.9912	0.9923	0.9867	0.9918	0	0.9844	83970000	412706250	0.2035	38	13	13	38	88
1	0.9884	0.9884	0.9884	0.8843	0.9902	0.9966	0.9824	0.9879	0.0001	0.9831	78249375	387258750	0.2021	13	13	13	13	63
														38	13	13	38	63

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
30	0.9444	0.9444	0.9444	0.7977	0.8358	0.9992	0.9373	0.9526	0.0329	0.9306	164475000	846146250	0.1944	38	38	13	38	88
13	0.9513	0.9513	0.9513	0.579	0.8839	0.9984	0.9471	0.9598	0.027	0.9381	161060625	800156250	0.2013	13	38	13	38	63
5	0.9487	0.9487	0.9487	0.6469	0.8919	0.9982	0.9435	0.958	0.0761	0.9392	160486875	775625625	0.2069	13	38	13	13	63
														13	38	13	38	63

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.99	0.99	0.99	0.8298	0.9925	0.997	0.9895	0.9929	0.005	0.9886	85691250	423078750	0.2025	38	13	13	38	63
18	0.9888	0.9888	0.9888	0.8573	0.9889	0.9966	0.9887	0.9923	0.0027	0.9844	82158750	416160000	0.1974	38	13	13	13	88
26	0.989	0.989	0.989	0.8416	0.9912	0.9923	0.9867	0.9918	0	0.9844	83970000	412706250	0.2035	38	13	13	38	88
														38	13	13	38	88

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.99	0.99	0.99	0.8298	0.9925	0.997	0.9895	0.9929	0.005	0.9886	85691250	423078750	0.2025	38	13	13	38	63
18	0.9888	0.9888	0.9888	0.8573	0.9889	0.9966	0.9887	0.9923	0.0027	0.9844	82158750	416160000	0.1974	38	13	13	13	88
26	0.989	0.989	0.989	0.8416	0.9912	0.9923	0.9867	0.9918	0	0.9844	83970000	412706250	0.2035	38	13	13	38	88
														38	13	13	38	88

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
31	0.8855	0.8855	0.8855	0.8189	0.5808	0.9846	0.8788	0.8984	0.3289	0.8674	174048750	895888125	0.1943	13	38	38	38	88
15	0.8937	0.8937	0.8937	0.8178	0.5975	0.9904	0.886	0.9036	0.3222	0.8884	173283750	892006875	0.1943	13	38	38	38	63
8	0.8743	0.8743	0.8743	0.767	0.5322	0.9821	0.8691	0.8873	0.2691	0.856	172918125	928946250	0.1861	38	38	38	13	63
														13	38	38	38	63

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.99	0.99	0.99	0.8298	0.9925	0.997	0.9895	0.9929	0.005	0.9886	85691250	423078750	0.2025	38	13	13	38	63
2	0.9886	0.9886	0.9886	0.8316	0.9872	0.9975	0.9861	0.9917	0.0001	0.9886	85151250	421115625	0.2022	38	13	13	13	63
18	0.9888	0.9888	0.9888	0.8573	0.9889	0.9966	0.9887	0.9923	0.0027	0.9844	82158750	416160000	0.1974	38	13	13	13	88
														38	13	13	13	63

Run Frequency in top 3

Run	Freq.
10	5
18	4
26	4
1	2
5	2
2	1
8	1
12	1
13	1
14	1
15	1
25	1
27	1
30	1
31	1

Diff	Sprd	Brd	SlRs	RdGr
38	13	13	38	63
38	13	13	13	88
38	13	13	38	88
13	13	13	13	63
13	38	13	13	63

Solution

Diff	Sprd	Brd	SlRs	RdGr		
13	13	13	38	63		
7	7	7	32	57	Start	
19	19	19	44	69	End	
12	12	12	12	12	Step	
2	2	2	2	2	32	Runs

Searching LeeSalee solution

Calibration 3

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
31	0.9822	0.9822	0.9822	0.6029	0.9838	0.9935	0.9783	0.9852	0.0029	0.984	109332000	518539500	0.2108	7	19	19	44	69
15	0.9841	0.9841	0.9841	0.6674	0.9841	0.9972	0.9837	0.9899	0.0085	0.982	108445500	516118500	0.2101	7	19	19	44	57
5	0.9775	0.9775	0.9775	0.4384	0.9854	0.9912	0.975	0.9827	0.0005	0.9781	90598500	432130500	0.2097	7	19	7	32	57
														7	**19**	**19**	**44**	**57**

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
20	0.9896	0.9896	0.9896	0.9102	0.9908	0.9937	0.9916	0.9941	0.0215	0.9942	51309000	303255000	0.1692	19	7	19	32	69
12	0.9889	0.9889	0.9889	0.8718	0.9914	0.9934	0.9867	0.992	0.0191	0.9942	49626000	302634000	0.164	19	7	19	44	57
28	0.9883	0.9883	0.9883	0.9053	0.9896	0.9954	0.9858	0.9896	0.0062	0.9942	48874500	303502500	0.161	19	7	19	44	69
														19	**7**	**19**	**44**	**69**

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
14	0.9833	0.9833	0.9833	0.9767	0.9922	0.99	0.9793	0.9854	0.0001	0.976	94558500	453757500	0.2084	19	19	7	44	57
25	0.9869	0.9869	0.9869	0.9612	0.9817	0.996	0.9854	0.9927	0.0735	0.9955	40806000	261067500	0.1563	7	7	7	44	69
2	0.9875	0.9875	0.9875	0.9591	0.9825	0.9957	0.9793	0.9846	0.0092	0.9847	42601500	269950500	0.1578	19	7	7	32	57
														19	**7**	**7**	**44**	**57**

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
14	0.9833	0.9833	0.9833	0.9767	0.9922	0.99	0.9793	0.9854	0.0001	0.976	94558500	453757500	0.2084	19	19	7	44	57
22	0.9834	0.9834	0.9834	0.8747	0.992	0.9953	0.9805	0.9867	0.0011	0.976	94135500	455796000	0.2065	19	19	7	32	69
13	0.9794	0.9794	0.9794	0.8769	0.9919	0.9838	0.977	0.9848	0.0006	0.9809	88812000	427018500	0.208	7	19	7	44	57
														19	**19**	**7**	**44**	**57**

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
27	0.9868	0.9868	0.9868	0.8416	0.9749	0.998	0.9883	0.9897	0.0049	0.9913	47313000	284917500	0.1661	7	7	19	44	69
3	0.9872	0.9872	0.9872	0.8324	0.9794	0.9974	0.9922	0.9936	0.0353	0.9913	46435500	287401500	0.1616	7	7	19	32	57
15	0.9841	0.9841	0.9841	0.6674	0.9841	0.9972	0.9837	0.9899	0.0085	0.982	108445500	516118500	0.2101	7	19	19	44	57
														7	**7**	**19**	**44**	**57**

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
3	0.9872	0.9872	0.9872	0.8324	0.9794	0.9974	0.9922	0.9936	0.0353	0.9913	46435500	287401500	0.1616	7	7	19	32	57
20	0.9896	0.9896	0.9896	0.9102	0.9908	0.9937	0.9916	0.9941	0.0215	0.9942	51309000	303255000	0.1692	19	7	19	32	69
9	0.9869	0.9869	0.9869	0.2357	0.9681	0.9959	0.9886	0.9936	0.0379	0.9955	40657500	261328500	0.1556	7	7	7	44	57
														7	**7**	**19**	**32**	**57**

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
20	0.9896	0.9896	0.9896	0.9102	0.9908	0.9937	0.9916	0.9941	0.0215	0.9942	51309000	303255000	0.1692	19	7	19	32	69
3	0.9872	0.9872	0.9872	0.8324	0.9794	0.9974	0.9922	0.9936	0.0353	0.9913	46435500	287401500	0.1616	7	7	19	32	57
9	0.9869	0.9869	0.9869	0.2357	0.9681	0.9959	0.9886	0.9936	0.0379	0.9955	40657500	261328500	0.1556	7	7	7	44	57
														7	**7**	**19**	**32**	**57**

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
25	0.9869	0.9869	0.9869	0.9612	0.9817	0.996	0.9854	0.9927	0.0735	0.9955	40806000	261067500	0.1563	7	7	7	44	69
9	0.9869	0.9869	0.9869	0.2357	0.9681	0.9959	0.9886	0.9936	0.0379	0.9955	40657500	261328500	0.1556	7	7	7	44	57
3	0.9872	0.9872	0.9872	0.8324	0.9794	0.9974	0.9922	0.9936	0.0353	0.9913	46435500	287401500	0.1616	7	7	19	32	57
														7	**7**	**7**	**44**	**57**

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
25	0.9869	0.9869	0.9869	0.9612	0.9817	0.996	0.9854	0.9927	0.0735	0.9955	40806000	261067500	0.1563	7	7	7	44	69
9	0.9869	0.9869	0.9869	0.2357	0.9681	0.9959	0.9886	0.9936	0.0379	0.9955	40657500	261328500	0.1556	7	7	7	44	57
17	0.9862	0.9862	0.9862	0.0519	0.9737	0.9961	0.9818	0.9892	0.0347	0.9955	40189500	259816500	0.1547	7	7	7	32	69
														7	**7**	**7**	**44**	**69**

Run Frequency in top 3

Run	Freq.
3	4
9	4
20	3
25	3
14	2
15	2
2	1
5	1
12	1
13	1
17	1
22	1
27	1
28	1
31	1

Diff	Sprd	Brd	SlRs	RdGr
7	7	19	32	57
7	7	7	44	57
19	7	19	32	69
7	7	7	44	69
19	19	7	44	57
7	19	19	44	57

Solution

Diff	Sprd	Brd	SlRs	RdGr		
7	19	19	44	57		
3	15	15	38	51	Start	
9	21	21	50	63	End	
6	6	6	6	6	Step	
2	2	2	3	3	72	Runs

Searching LeeSalee solution

Calibration 4

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
63	0.9774	0.9774	0.9774	0.909	0.9816	0.9949	0.9743	0.9817	0.0041	0.9723	114309000	527868000	0.2165	3	21	21	44	63
39	0.9796	0.9796	0.9796	0.1408	0.9813	0.995	0.9772	0.9837	0.0206	0.9774	114223500	529668000	0.2157	3	21	21	44	57
71	0.9761	0.9761	0.9761	0.4015	0.9812	0.9935	0.9718	0.981	0.0159	0.9729	112243500	523885500	0.2143	3	21	21	50	63
														3	21	21	44	63

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
36	0.9874	0.9874	0.9874	0.7766	0.9877	0.9938	0.9864	0.9916	0.0078	0.9875	93663000	459931500	0.2036	9	15	21	44	57
44	0.9871	0.9871	0.9871	0.712	0.983	0.9943	0.9834	0.9894	0.0009	0.9836	94221000	453397500	0.2078	9	15	21	50	57
2	0.9868	0.9868	0.9868	0.8518	0.9856	0.9958	0.984	0.9896	0.0011	0.9766	87133500	424566000	0.2052	9	15	15	38	51
														9	15	21	?	57

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
3	0.9804	0.9804	0.9804	0.9718	0.978	0.9906	0.9781	0.985	0.0026	0.9853	87048000	415669500	0.2094	3	15	21	38	51
10	0.9841	0.9841	0.9841	0.9556	0.985	0.9902	0.9816	0.988	0.0012	0.9823	87115500	426055500	0.2045	9	15	15	44	51
42	0.9849	0.9849	0.9849	0.9548	0.9885	0.9929	0.981	0.9877	0.0004	0.977	86881500	418945500	0.2074	9	15	15	50	57
														9	15	15	?	51

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
13	0.977	0.977	0.977	0.8967	0.9896	0.9877	0.9754	0.9834	0.002	0.9702	105039000	497965500	0.2109	3	21	15	44	51
21	0.9783	0.9783	0.9783	0.8422	0.9894	0.9873	0.9771	0.9839	0.0057	0.9819	105502500	498271500	0.2117	3	21	15	50	51
26	0.9866	0.9866	0.9866	0.9518	0.9891	0.9934	0.9845	0.9895	0.0006	0.9809	86724000	426114000	0.2035	9	15	15	38	57
														3	21	15	?	51

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
58	0.9853	0.9853	0.9853	0.7547	0.9864	0.9972	0.9807	0.9866	0.0084	0.9766	87439500	423117000	0.2067	9	15	15	44	63
50	0.9842	0.9842	0.9842	0.8512	0.9807	0.9969	0.9804	0.9865	0.0007	0.977	86400000	421614000	0.2049	9	15	15	38	63
16	0.9809	0.9809	0.9809	0.3879	0.9674	0.9967	0.9771	0.9849	0.0222	0.974	121113000	580450500	0.2087	9	21	21	44	51
														9	15	15	44	63

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
36	0.9874	0.9874	0.9874	0.7766	0.9877	0.9938	0.9864	0.9916	0.0078	0.9875	93663000	459931500	0.2036	9	15	21	44	57
12	0.9862	0.9862	0.9862	0.762	0.9871	0.9943	0.9852	0.9912	0.0059	0.9836	92902500	454207500	0.2045	9	15	21	44	51
68	0.9866	0.9866	0.9866	0.7729	0.9838	0.9945	0.985	0.9899	0.0004	0.9832	94036500	458118000	0.2053	9	15	21	50	63
														9	15	21	44	?

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
36	0.9874	0.9874	0.9874	0.7766	0.9877	0.9938	0.9864	0.9916	0.0078	0.9875	93663000	459931500	0.2036	9	15	21	44	57
12	0.9862	0.9862	0.9862	0.762	0.9871	0.9943	0.9852	0.9912	0.0059	0.9836	92902500	454207500	0.2045	9	15	21	44	51
68	0.9866	0.9866	0.9866	0.7729	0.9838	0.9945	0.985	0.9899	0.0004	0.9832	94036500	458118000	0.2053	9	15	21	50	63
														9	15	21	44	?

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
61	0.9774	0.9774	0.9774	0.8924	0.9862	0.9938	0.9721	0.9798	0.0244	0.9708	107905500	504643500	0.2138	3	21	15	44	63
47	0.9766	0.9766	0.9766	0.8055	0.9806	0.9942	0.9729	0.9816	0.0235	0.9723	112635000	528426000	0.2132	3	21	21	50	57
16	0.9809	0.9809	0.9809	0.3879	0.9674	0.9967	0.9771	0.9849	0.0222	0.974	121113000	580450500	0.2087	9	21	21	44	51
														3	21	21	44	?

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
36	0.9874	0.9874	0.9874	0.7766	0.9877	0.9938	0.9864	0.9916	0.0078	0.9875	93663000	459931500	0.2036	9	15	21	44	57
19	0.9803	0.9803	0.9803	0.9269	0.9836	0.9923	0.98	0.9867	0.0031	0.9853	87772500	414810000	0.2116	3	15	21	50	51
3	0.9804	0.9804	0.9804	0.9718	0.978	0.9906	0.9781	0.985	0.0026	0.9853	87048000	415669500	0.2094	3	15	21	38	51
														3	15	21	?	51

Run Frequency in top 3

Run	Freq.
36	4
3	2
12	2
16	2
68	2
2	1
10	1
13	1
19	1
21	1
26	1
39	1
42	1
44	1
47	1
50	1
58	1
61	1
63	1
71	1

Diff	Sprd	Brd	SlRs	RdGr
9	15	21	44	57
3	15	21	38	51
9	15	21	44	51
9	21	21	44	51
9	15	21	50	63

Solution

Diff	Sprd	Brd	SlRs	RdGr		
9	15	21	44	51		
3	21	21	44	63		
3	15	20	44	51	Start	
9	21	23	47	63	End	
6	6	3	3	6	Step	
2	2	2	2	3	48	Runs

Diff, Sprd, and Road are split with run Freq and LeeSalee.
Searching same ranges

Calibration 5

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
5	0.9773	0.9773	0.9773	0.0911	0.9852	0.9926	0.977	0.9846	0.013	0.9661	112335000	516030000	0.2177	3	21	20	44	51
15	0.978	0.978	0.978	0.4846	0.9744	0.9965	0.9768	0.9843	0.0047	0.9691	115822500	538927500	0.2149	3	21	23	47	51
47	0.9781	0.9781	0.9781	0.1903	0.9774	0.9952	0.9729	0.9806	0.0042	0.9691	116351250	541368750	0.2149	3	21	23	47	63
														3	21	23	47	51

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
18	0.9871	0.9871	0.9871	0.8146	0.989	0.995	0.985	0.9906	0.0072	0.9852	91260000	443741250	0.2057	9	15	20	44	57
34	0.987	0.987	0.987	0.8108	0.9876	0.9951	0.9854	0.9912	0.0015	0.9825	93810000	453742500	0.2067	9	15	20	44	63
28	0.987	0.987	0.987	0.7743	0.9865	0.9957	0.9852	0.9909	0.0008	0.9864	94440000	463743750	0.2036	9	15	23	47	57
														9	15	20	44	57

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
41	0.9817	0.9817	0.9817	0.9802	0.9749	0.9931	0.9806	0.9872	0.0001	0.9833	87063750	421282500	0.2067	3	15	20	47	63
43	0.9795	0.9795	0.9795	0.968	0.9817	0.9923	0.9799	0.9861	0.0025	0.9748	88773750	427923750	0.2075	3	15	23	47	63
3	0.9823	0.9823	0.9823	0.9622	0.9868	0.9924	0.9801	0.9861	0.0012	0.9757	89673750	424331250	0.2113	3	15	23	44	51
														3	15	23	47	63

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
18	0.9871	0.9871	0.9871	0.8146	0.989	0.995	0.985	0.9906	0.0072	0.9852	91260000	443741250	0.2057	9	15	20	44	57
34	0.987	0.987	0.987	0.8108	0.9876	0.9951	0.9854	0.9912	0.0015	0.9825	93810000	453742500	0.2067	9	15	20	44	63
3	0.9823	0.9823	0.9823	0.9622	0.9868	0.9924	0.9801	0.9861	0.0012	0.9757	89673750	424331250	0.2113	3	15	23	44	51
														9	15	20	44	?

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
15	0.978	0.978	0.978	0.4846	0.9744	0.9965	0.9768	0.9843	0.0047	0.9691	115822500	538927500	0.2149	3	21	23	47	51
2	0.986	0.986	0.986	0.7147	0.9837	0.9962	0.9846	0.9896	0.0001	0.9825	93071250	449988750	0.2068	9	15	20	44	51
23	0.9765	0.9765	0.9765	0.5301	0.9738	0.9962	0.9748	0.9829	0.0017	0.9691	115455000	541031250	0.2134	3	21	23	44	57
														3	21	23	44	51

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
4	0.9866	0.9866	0.9866	0.625	0.9817	0.9943	0.9873	0.9916	0.003	0.9864	94998750	462060000	0.2056	9	15	23	44	51
34	0.987	0.987	0.987	0.8108	0.9876	0.9951	0.9854	0.9912	0.0015	0.9825	93810000	453742500	0.2067	9	15	20	44	63
28	0.987	0.987	0.987	0.7743	0.9865	0.9957	0.9852	0.9909	0.0008	0.9864	94440000	463743750	0.2036	9	15	23	47	57
														9	15	23	44	?

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
4	0.9866	0.9866	0.9866	0.625	0.9817	0.9943	0.9873	0.9916	0.003	0.9864	94998750	462060000	0.2056	9	15	23	44	51
34	0.987	0.987	0.987	0.8108	0.9876	0.9951	0.9854	0.9912	0.0015	0.9825	93810000	453742500	0.2067	9	15	20	44	63
28	0.987	0.987	0.987	0.7743	0.9865	0.9957	0.9852	0.9909	0.0008	0.9864	94440000	463743750	0.2036	9	15	23	47	57
														9	15	23	44	?

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
29	0.9771	0.9771	0.9771	0.0623	0.9776	0.9943	0.976	0.983	0.0155	0.9716	111776250	521403750	0.2144	3	21	20	47	57
7	0.9776	0.9776	0.9776	0.1509	0.9777	0.9955	0.9726	0.9808	0.0138	0.9633	114521250	538410000	0.2127	3	21	23	44	51
5	0.9773	0.9773	0.9773	0.0911	0.9852	0.9926	0.977	0.9846	0.013	0.9661	112335000	516030000	0.2177	3	21	20	44	51
														3	21	20	44	51

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
4	0.9866	0.9866	0.9866	0.625	0.9817	0.9943	0.9873	0.9916	0.003	0.9864	94998750	462060000	0.2056	9	15	23	44	51
28	0.987	0.987	0.987	0.7743	0.9865	0.9957	0.9852	0.9909	0.0008	0.9864	94440000	463743750	0.2036	9	15	23	47	57
12	0.9853	0.9853	0.9853	0.7267	0.9846	0.9943	0.9836	0.99	0.0007	0.9864	95722500	458070000	0.209	9	15	23	47	51
														9	15	23	47	51

Run Frequency in top 3

Run	Freq.
28	4
34	4
4	3
3	2
5	2
15	2
18	2
2	1
7	1
12	1
23	1
29	1
41	1
43	1
47	1

Diff	Sprd	Brd	SlRs	RdGr
9	15	23	47	57
9	15	20	44	63
9	15	23	44	51
3	15	23	44	51
3	21	20	44	51
3	21	23	47	51
9	15	20	44	57

Solution

Diff	Sprd	Brd	SlRs	RdGr		
					Start	
					End	
					Step	
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	####	Runs

LeeSalee was lower, re-evaluating calibration 4

Calibration 6

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
47	0.9729	0.9729	0.9729	0.0044	0.97	0.9949	0.9686	0.9773	0.008	0.9616	122280000	560460000	0.2182	2	23	23	47	63
7	0.9712	0.9712	0.9712	0.0828	0.971	0.9927	0.9676	0.9767	0.0082	0.9633	120573750	553192500	0.218	2	23	23	41	60
13	0.9722	0.9722	0.9722	0.0001	0.9778	0.9956	0.9699	0.9782	0.0106	0.9589	118642500	545366250	0.2175	2	23	20	44	60
														2	**23**	**23**	**?**	**60**

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
44	0.9819	0.9819	0.9819	0.3582	0.9824	0.9971	0.9802	0.9861	0.0096	0.9777	114225000	539876250	0.2116	5	20	23	47	63
34	0.9816	0.9816	0.9816	0.2267	0.9827	0.9924	0.9781	0.9858	0.0059	0.9734	111311250	527745000	0.2109	5	20	20	44	63
10	0.9811	0.9811	0.9811	0.5087	0.9848	0.9926	0.9795	0.9868	0.012	0.9734	110831250	524186250	0.2114	5	20	20	44	60
														5	**20**	**20**	**44**	**63**

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
25	0.9765	0.9765	0.9765	0.8221	0.9847	0.9942	0.9734	0.9814	0.0033	0.9693	105551250	492333750	0.2144	2	20	20	41	63
26	0.9785	0.9785	0.9785	0.7032	0.9799	0.9949	0.976	0.9829	0.0133	0.9678	109616250	520410000	0.2106	5	20	20	41	63
18	0.9802	0.9802	0.9802	0.6663	0.979	0.9946	0.9772	0.9841	0.0076	0.9678	110261250	521553750	0.2114	5	20	20	47	60
														5	**20**	**20**	**41**	**63**

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
29	0.9768	0.9768	0.9768	0.3194	0.9876	0.9919	0.9734	0.9811	0.0076	0.9633	118485000	550571250	0.2152	2	23	20	41	63
19	0.9761	0.9761	0.9761	0.53	0.9862	0.9895	0.974	0.9814	0.0076	0.9664	107355000	501528750	0.2141	2	20	23	47	60
11	0.9771	0.9771	0.9771	0.3233	0.9856	0.9952	0.9746	0.9826	0.0115	0.9711	108941250	505357500	0.2156	2	20	23	44	60
														2	**20**	**23**	**?**	**60**

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
14	0.9774	0.9774	0.9774	0.0003	0.9697	0.9974	0.9722	0.9801	0.0087	0.9636	121702500	583518750	0.2086	5	23	20	44	60
44	0.9819	0.9819	0.9819	0.3582	0.9824	0.9971	0.9802	0.9861	0.0096	0.9777	114225000	539876250	0.2116	5	20	23	47	63
16	0.9739	0.9739	0.9739	0.2699	0.9569	0.9968	0.9704	0.9781	0.0018	0.9636	125940000	593557500	0.2122	5	23	23	44	60
														5	**23**	**23**	**44**	**60**

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
44	0.9819	0.9819	0.9819	0.3582	0.9824	0.9971	0.9802	0.9861	0.0096	0.9777	114225000	539876250	0.2116	5	20	23	47	63
10	0.9811	0.9811	0.9811	0.5087	0.9848	0.9926	0.9795	0.9868	0.012	0.9734	110831250	524186250	0.2114	5	20	20	44	60
28	0.9811	0.9811	0.9811	0.006	0.9776	0.9927	0.9793	0.9858	0.0086	0.9706	114652500	544661250	0.2105	5	20	23	41	63
														5	**20**	**23**	**?**	**63**

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9811	0.9811	0.9811	0.5087	0.9848	0.9926	0.9795	0.9868	0.012	0.9734	110831250	524186250	0.2114	5	20	20	44	60
44	0.9819	0.9819	0.9819	0.3582	0.9824	0.9971	0.9802	0.9861	0.0096	0.9777	114225000	539876250	0.2116	5	20	23	47	63
28	0.9811	0.9811	0.9811	0.006	0.9776	0.9927	0.9793	0.9858	0.0086	0.9706	114652500	544661250	0.2105	5	20	23	41	63
														5	**20**	**23**	**?**	**63**

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
21	0.9744	0.9744	0.9744	0.0457	0.981	0.9946	0.9716	0.98	0.0194	0.9664	115548750	543945000	0.2124	2	23	20	47	60
15	0.9748	0.9748	0.9748	0.1429	0.9817	0.9945	0.9708	0.9789	0.0155	0.9706	120450000	553856250	0.2175	2	23	23	44	60
26	0.9785	0.9785	0.9785	0.7032	0.9799	0.9949	0.976	0.9829	0.0133	0.9678	109616250	520410000	0.2106	5	20	20	41	63
														2	**23**	**20**	**?**	**60**

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
44	0.9819	0.9819	0.9819	0.3582	0.9824	0.9971	0.9802	0.9861	0.0096	0.9777	114225000	539876250	0.2116	5	20	23	47	63
4	0.9808	0.9808	0.9808	0.3896	0.9795	0.9937	0.9777	0.9853	0.0026	0.977	115631250	541916250	0.2134	5	20	23	41	60
10	0.9811	0.9811	0.9811	0.5087	0.9848	0.9926	0.9795	0.9868	0.012	0.9734	110831250	524186250	0.2114	5	20	20	44	60
														5	**20**	**23**	**?**	**60**

Run Frequency in top 3

Run	Freq.
44	5
10	4
26	2
28	2
4	1
7	1
11	1
13	1
14	1
15	1
16	1
18	1
19	1
21	1
25	1
29	1
34	1
47	1

Diff	Sprd	Brd	SlRs	RdGr
5	20	23	47	63
5	20	20	44	60
5	20	20	41	63
5	20	23	41	63

Solution

Diff	Sprd	Brd	SlRs	RdGr		
2	23	23	47	63		
5	20	23	41	63		
4	19	22	40	62	Start	
6	21	24	42	64	End	
2	2	2	2	2	Step	
2	2	2	2	2	32	Runs

R

Calibration 7

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
7	0.9772	0.9772	0.9772	0.2629	0.9712	0.9966	0.9743	0.9814	0.0061	0.9679	119877188	553955625	0.2164	4	21	24	40	62
27	0.9795	0.9795	0.9795	0.5725	0.9793	0.9953	0.9778	0.9837	0.0058	0.9669	111192188	518675625	0.2144	4	19	24	42	64
21	0.9772	0.9772	0.9772	0.2166	0.9788	0.9947	0.9735	0.9817	0.0054	0.9657	115723125	540441562	0.2141	4	21	22	40	64
														4	21	24	40	64

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
18	0.9835	0.9835	0.9835	0.6624	0.9827	0.9963	0.9795	0.9862	0.0068	0.9727	110697188	525588750	0.2106	6	19	22	40	64
10	0.9835	0.9835	0.9835	0.6087	0.9832	0.9939	0.9799	0.9864	0.0057	0.9727	111341250	529475625	0.2103	6	19	22	42	62
														6	19	22	40	62

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
3	0.9797	0.9797	0.9797	0.8703	0.9837	0.9942	0.976	0.9832	0.0127	0.9703	109358438	512370000	0.2134	4	19	24	40	62
18	0.9835	0.9835	0.9835	0.6624	0.9827	0.9963	0.9795	0.9862	0.0068	0.9727	110697188	525588750	0.2106	6	19	22	40	64
17	0.9814	0.9814	0.9814	0.6501	0.9805	0.9933	0.9779	0.9855	0.0081	0.975	107460000	507597188	0.2117	4	19	22	40	64
														4	19	22	40	64

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
3	0.9797	0.9797	0.9797	0.8703	0.9837	0.9942	0.976	0.9832	0.0127	0.9703	109358438	512370000	0.2134	4	19	24	40	62
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
10	0.9835	0.9835	0.9835	0.6087	0.9832	0.9939	0.9799	0.9864	0.0057	0.9727	111341250	529475625	0.2103	6	19	22	42	62
														6	19	22	40	62

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
29	0.9779	0.9779	0.9779	0.0846	0.9777	0.9968	0.9746	0.9821	0.0065	0.9657	115419375	546086250	0.2114	4	21	22	42	64
25	0.9809	0.9809	0.9809	0.6116	0.9795	0.9967	0.9789	0.986	0.0051	0.975	108570938	507290625	0.214	4	19	22	42	64
7	0.9772	0.9772	0.9772	0.2629	0.9712	0.9966	0.9743	0.9814	0.0061	0.9679	119877188	553955625	0.2164	4	21	24	40	62
														4	21	22	42	64

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
20	0.9828	0.9828	0.9828	0.2981	0.9785	0.9929	0.9804	0.9867	0.009	0.9707	114080625	540078750	0.2112	6	19	24	40	64
11	0.9804	0.9804	0.9804	0.4195	0.9818	0.994	0.9802	0.9865	0.0047	0.9757	109454062	518504062	0.2111	4	19	24	42	62
														6	19	24	40	62

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
26	0.9828	0.9828	0.9828	0.2472	0.9797	0.9949	0.98	0.9871	0.0056	0.9727	110224688	526350938	0.2094	6	19	22	42	64
20	0.9828	0.9828	0.9828	0.2981	0.9785	0.9929	0.9804	0.9867	0.009	0.9707	114080625	540078750	0.2112	6	19	24	40	64
														6	19	22	40	64

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
8	0.9796	0.9796	0.9796	0.2106	0.9694	0.9961	0.976	0.9842	0.0228	0.9704	121348125	571530938	0.2123	6	21	24	40	62
1	0.9797	0.9797	0.9797	0.6338	0.9793	0.9945	0.9771	0.9851	0.0154	0.9713	108149062	505822500	0.2138	4	19	22	40	62
3	0.9797	0.9797	0.9797	0.8703	0.9837	0.9942	0.976	0.9832	0.0127	0.9703	109358438	512370000	0.2134	4	19	24	40	62
														4	19	24	40	62

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
12	0.9815	0.9815	0.9815	0.4528	0.977	0.9941	0.9786	0.9854	0.0046	0.9763	111889688	533908125	0.2096	6	19	24	42	62
2	0.9838	0.9838	0.9838	0.5087	0.9833	0.9943	0.9809	0.9876	0.0009	0.9757	109082812	520050938	0.2098	6	19	22	40	62
11	0.9804	0.9804	0.9804	0.4195	0.9818	0.994	0.9802	0.9865	0.0047	0.9757	109454062	518504062	0.2111	4	19	24	42	62
														6	19	24	42	62

Run Frequency in top 3

Run	Freq.
2	5
3	3
7	2
10	2
11	2
18	2
20	2
1	1
8	1
12	1
17	1
21	1
25	1
26	1
27	1
29	1

Diff	Sprd	Brd	SlRs	RdGr
6	19	22	40	62
4	19	24	40	62
4	21	24	40	62
6	19	22	42	62
4	19	24	42	62
6	19	22	40	64
6	19	24	40	64

Solution

Diff	Sprd	Brd	SlRs	RdGr		
1	22	19	38	59	Start	
3	24	21	41	61	End	
2	2	2	3	2	Step	
2	2	2	2	2	32	Runs

LeeSalee was lower, re-evaluating calibration 6

Calibration 8

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
29	0.9701	0.9701	0.9701	0.1397	0.9807	0.9895	0.9668	0.9765	0.0046	0.9605	118589062	537705000	0.2205	1	24	19	41	61
15	0.9696	0.9696	0.9696	0.0051	0.9786	0.9898	0.9676	0.9773	0.0072	0.9605	118710000	541892812	0.2191	1	24	21	41	59
27	0.9723	0.9723	0.9723	0.2365	0.975	0.9944	0.9686	0.9773	0.0031	0.9631	112969688	517919062	0.2181	1	22	21	41	61
														1	24	21	41	61

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9794	0.9794	0.9794	0.3036	0.9822	0.995	0.9753	0.9834	0.0076	0.9716	116614688	546778125	0.2133	3	22	19	41	59
12	0.9782	0.9782	0.9782	0.0396	0.9789	0.9952	0.9746	0.9824	0.0072	0.9708	117534375	546567188	0.215	3	22	21	41	59
18	0.978	0.978	0.978	0.3791	0.9864	0.9903	0.974	0.9812	0.0057	0.9678	114322500	537806250	0.2126	3	22	19	38	61
														3	22	19	41	59

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
26	0.9766	0.9766	0.9766	0.9354	0.9846	0.9943	0.9728	0.9809	0.0063	0.9605	113861250	536934375	0.2121	3	22	19	41	61
17	0.9734	0.9734	0.9734	0.6662	0.984	0.9857	0.9716	0.9793	0.0051	0.9667	109721250	511413750	0.2145	1	22	19	38	61
20	0.9774	0.9774	0.9774	0.6595	0.9775	0.9955	0.9738	0.9816	0.0095	0.9708	117230625	546696562	0.2144	3	22	21	38	61
														3	22	19	38	61

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
18	0.978	0.978	0.978	0.3791	0.9864	0.9903	0.974	0.9812	0.0057	0.9678	114322500	537806250	0.2126	3	22	19	38	61
26	0.9766	0.9766	0.9766	0.9354	0.9846	0.9943	0.9728	0.9809	0.0063	0.9605	113861250	536934375	0.2121	3	22	19	41	61
17	0.9734	0.9734	0.9734	0.6662	0.984	0.9857	0.9716	0.9793	0.0051	0.9667	109721250	511413750	0.2145	1	22	19	38	61
														3	22	19	38	61

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
8	0.9759	0.9759	0.9759	0.1676	0.9785	0.9961	0.9734	0.9811	0.0044	0.9667	124377188	579197812	0.2147	3	24	21	38	59
20	0.9774	0.9774	0.9774	0.6595	0.9775	0.9955	0.9738	0.9816	0.0095	0.9708	117230625	546696562	0.2144	3	22	21	38	61
28	0.9758	0.9758	0.9758	0.0001	0.9765	0.9955	0.9733	0.981	0.004	0.9667	116755312	543225938	0.2149	3	22	21	41	61
														3	22	21	38	61

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9794	0.9794	0.9794	0.3036	0.9822	0.995	0.9753	0.9834	0.0076	0.9716	116614688	546778125	0.2133	3	22	19	41	59
12	0.9782	0.9782	0.9782	0.0396	0.9789	0.9952	0.9746	0.9824	0.0072	0.9708	117534375	546567188	0.215	3	22	21	41	59
18	0.978	0.978	0.978	0.3791	0.9864	0.9903	0.974	0.9812	0.0057	0.9678	114322500	537806250	0.2126	3	22	19	38	61
														3	22	19	41	59

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9794	0.9794	0.9794	0.3036	0.9822	0.995	0.9753	0.9834	0.0076	0.9716	116614688	546778125	0.2133	3	22	19	41	59
12	0.9782	0.9782	0.9782	0.0396	0.9789	0.9952	0.9746	0.9824	0.0072	0.9708	117534375	546567188	0.215	3	22	21	41	59
4	0.9768	0.9768	0.9768	0.5026	0.9814	0.9946	0.9737	0.9817	0.0064	0.9667	117506250	543574688	0.2162	3	22	21	38	59
														3	22	21	41	59

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
25	0.9716	0.9716	0.9716	0.6398	0.9807	0.9882	0.9685	0.9771	0.016	0.9667	110137500	506888438	0.2173	1	22	19	41	61
14	0.9739	0.9739	0.9739	0.2739	0.9727	0.9951	0.9694	0.9784	0.0153	0.962	122526562	571567500	0.2144	3	24	19	41	59
2	0.976	0.976	0.976	0.4743	0.9825	0.9951	0.9728	0.9809	0.0144	0.9736	113388750	532912500	0.2128	3	22	19	38	59
														3	22	19	41	59

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
2	0.976	0.976	0.976	0.4743	0.9825	0.9951	0.9728	0.9809	0.0144	0.9736	113388750	532912500	0.2128	3	22	19	38	59
10	0.9794	0.9794	0.9794	0.3036	0.9822	0.995	0.9753	0.9834	0.0076	0.9716	116614688	546778125	0.2133	3	22	19	41	59
9	0.9731	0.9731	0.9731	0.0223	0.9809	0.9919	0.9692	0.9786	0.0062	0.9713	110565000	514541250	0.2149	1	22	19	41	59
														3	22	19	41	59

Run Frequency in top 3

Run	Freq.	Diff	Sprd	Brd	SlRs	RdGr
10	4	3	22	19	41	59
12	3	3	22	21	41	59
18	3	3	22	19	38	61
2	2	3	22	19	38	59
17	2	1	22	19	38	61
20	2	3	22	21	38	61
26	2	3	22	19	41	61
4	1					
8	1					
9	1					
14	1					
15	1					
25	1					
27	1					
28	1					
29	1					

Solution

Diff	Sprd	Brd	SlRs	RdGr		
3	22	19	38	61		
1	24	19	41	61		
1	22	19	41	61	Start	
3	24	21	41	61	End	
1	1	1	1	1	Step	
3	3	3	1	1	27	Runs

Calibration 9

TOP 3 LEESALEE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
10	0.9734	0.9734	0.9734	0.0932	0.9825	0.9905	0.9732	0.9803	0.0099	0.9638	114741562	522945000	0.2194	1	23	19	41	61
7	0.9721	0.9721	0.9721	0.2472	0.98	0.9927	0.9691	0.9771	0.0014	0.9634	112913438	517064062	0.2184	1	22	21	41	61
22	0.9684	0.9684	0.9684	0.0426	0.98	0.9887	0.9648	0.9748	0.0144	0.9609	117905625	540047812	0.2183	1	24	20	41	61
														1	?	?	41	61

TOP 3 AREA

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
9	0.9771	0.9771	0.9771	0.5444	0.9798	0.9944	0.9735	0.9825	0.0153	0.9711	116254688	549919688	0.2114	3	22	21	41	61
6	0.9761	0.9761	0.9761	0.2984	0.9798	0.9976	0.9722	0.9809	0.01	0.9645	114460312	535710938	0.2137	3	22	20	41	61
15	0.976	0.976	0.976	0.0631	0.9762	0.9952	0.973	0.9813	0.01	0.9711	119882812	559454062	0.2143	3	23	20	41	61
														3	22	20	41	61

TOP 3 CLUSTER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
17	0.9733	0.9733	0.9733	0.8992	0.9789	0.9935	0.9699	0.9787	0.0079	0.9594	118184062	550881562	0.2145	2	23	21	41	61
13	0.9716	0.9716	0.9716	0.7255	0.9804	0.9943	0.9703	0.9792	0.0065	0.9609	114671250	533643750	0.2149	1	23	20	41	61
12	0.9757	0.9757	0.9757	0.6969	0.9813	0.9953	0.9747	0.9827	0.0085	0.9638	117475312	547920000	0.2144	3	23	19	41	61
														?	23	?	41	61

TOP 3 CLUSTER PERIMETER

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
11	0.9749	0.9749	0.9749	0.4418	0.989	0.9921	0.9737	0.9819	0.0085	0.9669	116592188	537446250	0.2169	2	23	19	41	61
20	0.9742	0.9742	0.9742	0	0.9828	0.9938	0.9708	0.9791	0.0149	0.9638	120397500	558703125	0.2155	2	24	19	41	61
10	0.9734	0.9734	0.9734	0.0932	0.9825	0.9905	0.9732	0.9803	0.0099	0.9638	114741562	522945000	0.2194	1	23	19	41	61
														2	23	19	41	61

TOP 3 CLUSTER SIZE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
6	0.9761	0.9761	0.9761	0.2984	0.9798	0.9976	0.9722	0.9809	0.01	0.9645	114460312	535710938	0.2137	3	22	20	41	61
14	0.9754	0.9754	0.9754	0.0177	0.9804	0.9961	0.9724	0.9813	0.0128	0.9638	116865000	547337812	0.2135	2	23	20	41	61
18	0.9752	0.9752	0.9752	0.0343	0.9754	0.9961	0.972	0.98	0.0122	0.969	120276562	563416875	0.2135	3	23	21	41	61
														3	23	20	41	61

TOP 3 HORIZONTAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
12	0.9757	0.9757	0.9757	0.6969	0.9813	0.9953	0.9747	0.9827	0.0085	0.9638	117475312	547920000	0.2144	3	23	19	41	61
11	0.9749	0.9749	0.9749	0.4418	0.989	0.9921	0.9737	0.9819	0.0085	0.9669	116592188	537446250	0.2169	2	23	19	41	61
9	0.9771	0.9771	0.9771	0.5444	0.9798	0.9944	0.9735	0.9825	0.0153	0.9711	116254688	549919688	0.2114	3	22	21	41	61
														3	23	19	41	61

TOP 3 VERTICAL ALIGNMENT

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
12	0.9757	0.9757	0.9757	0.6969	0.9813	0.9953	0.9747	0.9827	0.0085	0.9638	117475312	547920000	0.2144	3	23	19	41	61
9	0.9771	0.9771	0.9771	0.5444	0.9798	0.9944	0.9735	0.9825	0.0153	0.9711	116254688	549919688	0.2114	3	22	21	41	61
11	0.9749	0.9749	0.9749	0.4418	0.989	0.9921	0.9737	0.9819	0.0085	0.9669	116592188	537446250	0.2169	2	23	19	41	61
														3	23	19	41	61

TOP 3 SLOPE

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
3	0.9741	0.9741	0.9741	0.5342	0.9778	0.995	0.9706	0.9797	0.0163	0.9738	114527812	531317812	0.2156	3	22	19	41	61
9	0.9771	0.9771	0.9771	0.5444	0.9798	0.9944	0.9735	0.9825	0.0153	0.9711	116254688	549919688	0.2114	3	22	21	41	61
20	0.9742	0.9742	0.9742	0	0.9828	0.9938	0.9708	0.9791	0.0149	0.9638	120397500	558703125	0.2155	2	24	19	41	61
														3	22	19	41	61

TOP 3 % URBAN

Run	Pop	Area	Compare	Clusters	Perimeter	Clst_Size	Lat	Lon	Slope	%Urban	IntSect	Union	LeeSalee	Diff	Sprd	Brd	SlRs	RdGr
3	0.9741	0.9741	0.9741	0.5342	0.9778	0.995	0.9706	0.9797	0.0163	0.9738	114527812	531317812	0.2156	3	22	19	41	61
9	0.9771	0.9771	0.9771	0.5444	0.9798	0.9944	0.9735	0.9825	0.0153	0.9711	116254688	549919688	0.2114	3	22	21	41	61
15	0.976	0.976	0.976	0.0631	0.9762	0.9952	0.973	0.9813	0.01	0.9711	119882812	559454062	0.2143	3	23	20	41	61
														3	22	?	41	61

Run Frequency in top 3

Run	Freq.
9	5
11	3
12	3
3	2
6	2
10	2
15	2
20	2
7	1
13	1
14	1
17	1
18	1
22	1

Diff	Sprd	Brd	SlRs	RdGr
3	22	21	41	61
2	23	19	41	61
3	23	19	41	61

Solution

Diff	Sprd	Brd	SlRs	RdGr		
						Start
						End
						Step
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	####	Runs

LeeSalee was lower, Solution is on Calibration 8