UNIVERSIDAD SAN FRANCISCO DE QUITO

Colegio de Postgrados

Development of a spatial load forecasting module as support to decision-making in the distribution planning phase.

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Tesis de grado presentada como requisito para la obtención del título de Maestría en Sistemas de Información Geográfica

Quito, 2012

Universidad San Francisco de Quito

Colegio de Postgrados

HOJA DE APROBACIÓN DE TESIS

Development of a spatial load forecasting module as support to decision-making in the distribution planning phase.

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DEDICATION

All this thesis I want to dedicate to my beloved wife Angela and my dear son Sebastian.

ABSTRACT

This thesis presents the development of a module that has the ability to calculate the spatial load forecasting in any area of study. First the electrical distribution system are defined with its components, additionally mentioned the importance of accurate of the location and growth of demand energy.

After that describes the requirements necessary for a good spatial load forecasting, defined the methodology used in the calculation step by step. Land use is the key factor in the work done as it is considered outstanding, excluding areas of growth and are analyzed factors like close to the center and growth restriction. With these factors is possible calculate the reception index that is nothing more than the ability of each area to receive new population.

Basically divides the study area into smaller areas, which are realized all calculus needed to estimate the growth of load, and then grouped each small area.

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INTRODUCTION

Nowadays the use of Geographic Information Systems (GIS) in power systems is relatively moderate as GIS are being used generally to obtain maps, which contain all the elements of the electricity distribution. With proper use of GIS technology can determine future expansions optimally considering key factors such as hydrology, roads and current location of customers, transformers and substations, thus plan the SED in a technical way and while allowing a better economic valuation.

Spatial load forecasting in the long term [1], predicts the magnitude of demand (how much), and its location in space (where) and time (when). Since the 50s there have been several methods for estimating electricity demand, starting from the experience of the planners, the same as on a map painted the population density and growth potential, then this appeared mathematical techniques based methods monovariable models and multivariate regression, which need historical data as input parameters. Technological developments in the area to work with a computer allowed more data and more complex models.

GIS allows managing the complexity of the methods for forecasting demand for their ability to relate different geographical entities with alphanumeric attributes. This capability allows a simple representation of the data base and future data allowing the user a better understanding and analysis.

It is extremely important to get a good spatial load forecasting as the problems of generating capacity, or otherwise unmet demand can have very high costs, not only in the investments of the distributors, but also in the quality of service perceived by customers. Added to this we must not forget the long period of time needed for planning and commissioning of a power plant.

OBJECTIVES

- Develop a spatial load forecasting module through geo-processing to support in the decision-making when the electrical companies need distribution and transmission planning.

SPECIFIC OBJECTIVES

-Implement the most appropriate method to estimate spatially demand.

-Comparing different methods of calculation.

-Optimizing performance estimation module.

1. ELECTRICAL DISTRIBUTION SYSTEMS.

An important issue in electrical engineering and the development of it is the power distribution as it represents a fundamental contribution to the economic development of any country. A power distribution was considered a small branch within this field of knowledge is now considered a specialty with problems, approaches and solutions. This change has been gradual in line with changes in technology, which has forced the specialists in this field to adjust to new techniques, processes, materials, and equipment to help them fulfill their missions: distributing electrical energy optimally.

A system of power distribution is the set of elements responsible for conducting energy from one power substation to the user. Basically energy distribution comprises the primary lines of distribution, distribution transformers, distribution feeder lines, the connections and energy meters[1]

[1] Electrical distribution systems, Juan Antonio Yebra Moron

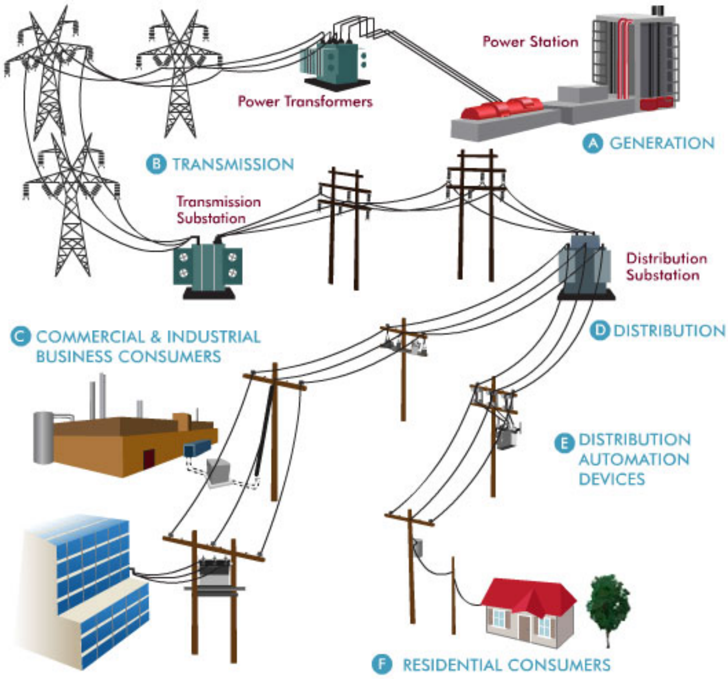

Figure 1 Distribution System

Generally the energy power systems divides in electric power systems (EPS) and electrical distribution systems (EDS), and each of them is specialized to the point that from the utilities to universities have chosen to have managements and different materials respectively.

OBJECTIVE OF AN EDS

The energy distribution must be done as efficiently as possible, ensuring that the customer receives continuous service without interruption, with a pure sine wave voltage and without harmonics. Distribution companies must also ensure well designed networks capable of supporting the load itself and future expansion load (load forecast).

CLASSIFICATION OF DISTRIBUTION SYSTEMS

Depending on the characteristics of the loads, energy volumes involved, and the conditions of reliability and safety that must operate distribution systems are classified as:

- Industrial composed of large consumers
- Commercial within large complex systems that require backups.
- Urban systems that feed urban centers with a large number of consumers.
- Rural. Feeding systems to remote areas

DISTRIBUTION TOPOLOGIES

The concessionaires have mainly two schemes feed:

- Radial Systems: are the most used, are economical but do not ensure good continuity.
- Ringed systems: they have two feed points on each bar improving service and therefore the complexity of the operation.

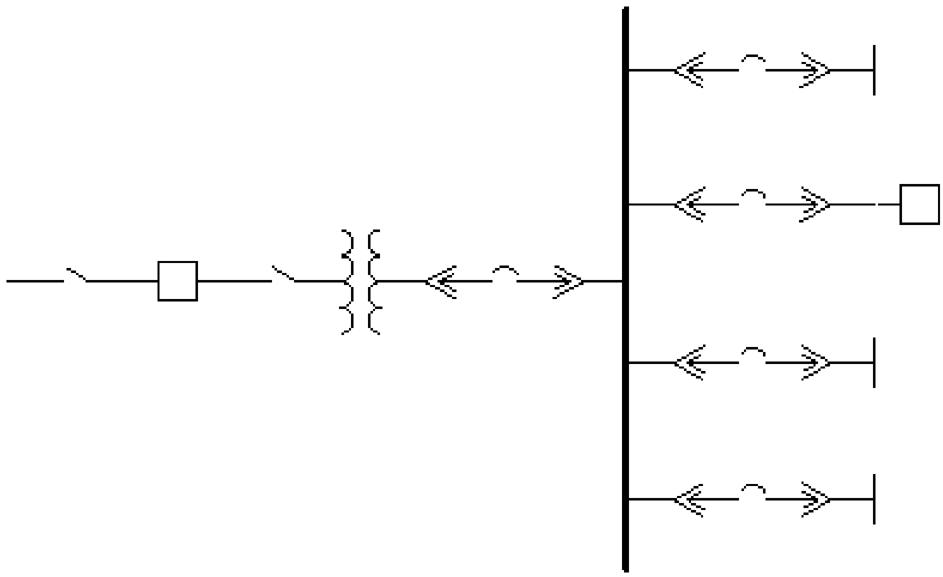

Figure 2 Radial System

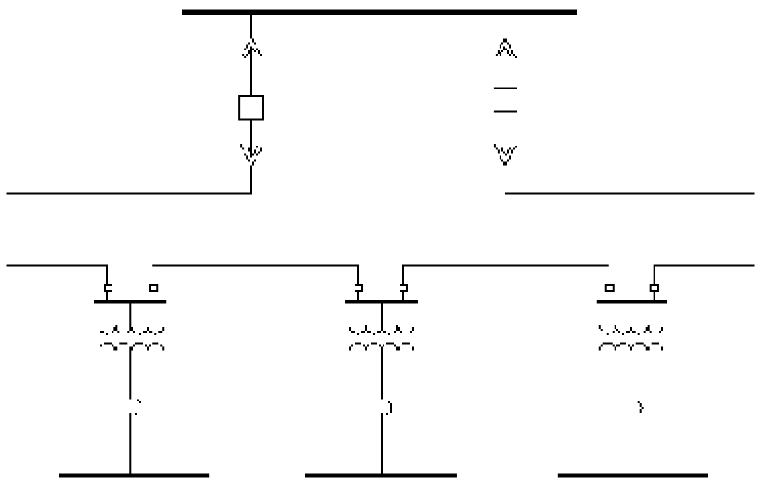

Figure 3 Ring System

TRANSFORMERS

Is called transformer or trafo (abbreviation), to an electrical device that increases or decreases the voltage in an electrical circuit of alternating current, maintaining the frequency[2]

For distribution transformers used submerged, dry and pad mounted. There are four types of transformers immersed: breathable, gas cushion, with conservative and completely filled, currently only installed last.

[2] http://es.wikipedia.org/wiki/Transformador

ESTABLISHMENT AND OPERATION

They consist essentially of closed magnetic circuits on which are wound two coils, so that both windings are traversed by the same magnetic flux. The magnetic circuit is of steel plates stacked thin to avoid eddy currents. The winding which connects the input current is called primary winding and wherein the load is connected, is called secondary.

The alternating current flowing through the primary winding magnetizing the core alternately. The secondary winding is thus traversed by a variable magnetic flux and an approximately sinusoidal variation of flow is engendered by Lenz's law, an alternating voltage in said windings.

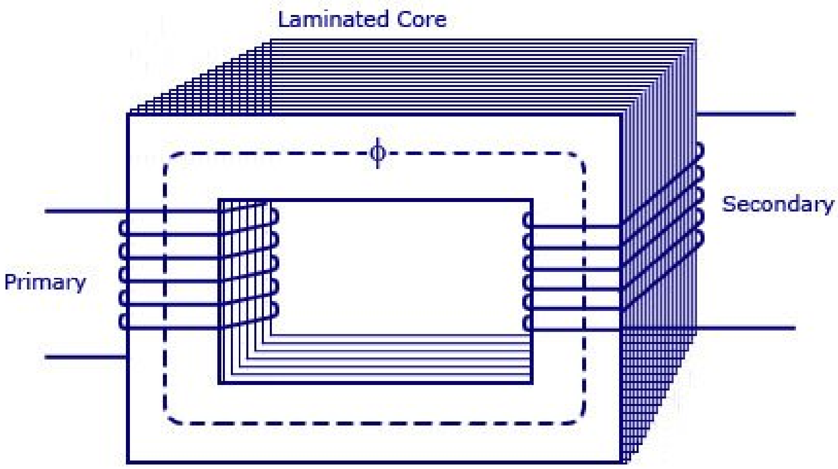

Figure 4 Primary and Seconary circuits of a trafo

BALANCE BETWEEN PRODUCTION AND CONSUMPTION.

Electricity is one of the few energy is not possible to store a large scale (except battery systems or hydraulic dams that can be considered electromechanical energy reserves of low inertia). Thus the network must ensure a balance between supply and demand in permanence. If there is an imbalance between supply and demand, it can cause two negative phenomena:

In the case in which production exceeds consumption, there is a risk of "blackout" in the rapid loss of synchronism of the alternator, whereas in the case of production exceeds consumption can also produce a "blackout" by the acceleration of the generators that produce electricity.

The mass appearance of distributed generation networks also leads to consider the overall balance of the networks, especially in tension issues. The appearance of smart grids Smart Grid should contribute to the overall balance of the transportation network (frequency, voltage), with the balance local distribution networks. They mentioned the fact becomes important to perform a spatial demand forecasting in an optimal way to ensure that consumption never exceeds production.

Within EDS there are some important analyzes listed below:

- Calculation of feeders
- Calculation of short currents
- Reactive power compensation lines
- Distribution Transformers
- Surge Protection
- Protection against over currents
- Spatial Electric Load Forecasting

Chapter 2 Spatial Load Forecasting revise, technique used to estimate demand based on land use and historical data.

2. SPATIAL LOAD FORECASTING

In order to plan the efficient use and expansion of the EDS, the distributors must be able to anticipate the need for much power should be given, where and when needed. This information is provided by Spatial Load Forecasting, a prediction of future electricity demand which includes features such as location (where) as one of its key elements, besides the magnitude (how much) and time (when)[3].

The following diagram shows of basic way that is Spatial Load Forecasting. The method can be used for different time scales as short, medium and long term, from now on all matters subject to long-term concerns.

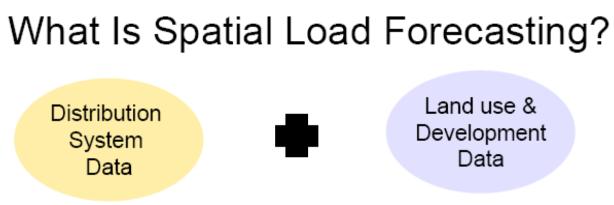

Figure 5 What is Spatial Load Forecasting

SMALL AREA FORECAST

This is the most used technique for spatial analysis and load provision is to determine the load growth by dividing the whole area into small geographic areas, in order to

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[3] Spatial Electric Load Forecasting , H. Lee Willis

achieve unification irregular areas and then by calculating the provision for extrapolations adjacent areas.

Figure 2.2 illustrates the procedure must not forget that not every small area is an area of growth forecast as these have associated geographic location.

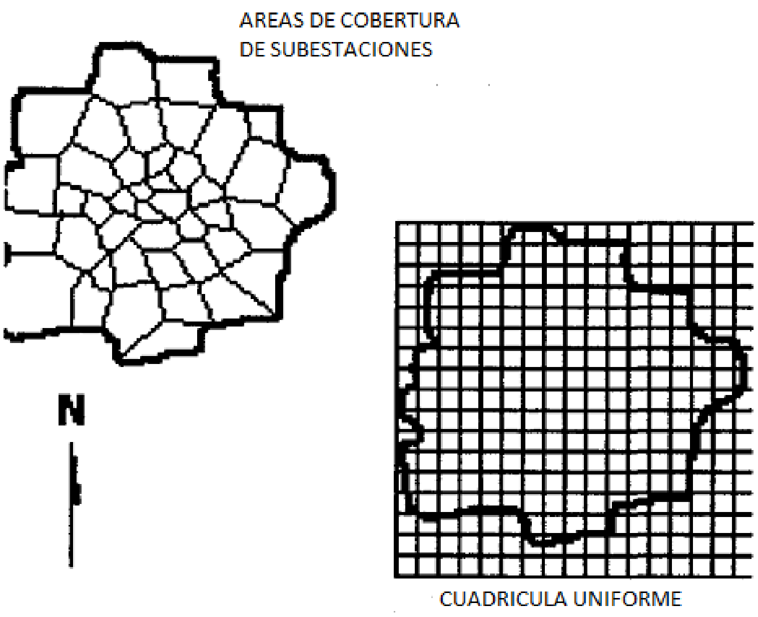


Figure 6 Small areas of forecast

RESOLUTION OF AREAS

The following table shows the recommended resolution for spatial analysis, the time horizon is also recommended for load forecasting on different elements of the SED.

Planning purpose	Planning Horizon (years ahead)	Service Area (km or km^2)	Forecasting resolution (meters)
Sub-transmission network	5 - 25	10 km	250
Substation	5 - 25	25 km^2	250
Medium voltage network	2 - 20	3 km	50
Secondary substations	1 - 15	0.5 km^2	50
Low voltage network	1 - 10	300 m	5

Table 1 Resolution for different levels of an EDS

REQUIREMENTS FOR LOAD FORECASTING

The process of transmission and distribution planning the goal is to obtain reliable results without error too large, so every feature of the process should aim to achieve this goal. The following requirements[4] are revised in order to obtain prediction scenarios very near future reality.

Requirement 1: MAGNITUDE FORECAST - THE AMOUNT OF DEMAND AND ENERGY

It refers to the peak power of each small area forecast; the planner must know this amount, not just the average consumer, at times also used the power factor.

Requirement 2: SPATIAL RESOLUTION AND ANALYSIS

The second requirement is to know the location of where growth will be charge with

[4] Spatial Electric Load Forecasting , H. Lee Willis

sufficient accuracy to validate the future of networking equipment that is used for small areas of prediction.

Requirement 3: TIME AND TEMPORARY DETAIL

The planning of the transmission and distribution usually is performed every year and in a long-term period of usually five years, all other years are interpolated, must be defined before that time will be used for prediction and it may be summer, winter or two.

Requirement 4: STANDARDIZATION OF TIME FOR THE PREDICTION

Because the climate significantly affects power peaks and energy demand, it is necessary to normalize the load forecast by this factor to assume uniform behavior and adjust these factors for an assumption of uniform climate (eg the worst summer in the last 5 years or the worst winter in the last 10 years).

Requirement 5: ACCURACY IN REPRESENTATION - ACCURACY IN PREDICTING LOAD IS NOT THE GOAL

It is more important to have the ability to spatially represent future growth rate under certain conditions before the same load growth can be calculated by analytical or statistical methods.

Requirement 6: CONSISTENCY WITH CORPORATE PREDICTIONS

Each company has its projections based on historical data trends, sales, billing and other indicators, electrical load predictions must conform to them.

Requirement 7: ANALYSIS OF UNCERTAINTY AND SENSITIVITY

It takes several different scenarios analysis in order to obtain some results; the network planner can make a better decision and thereby reduce uncertainty and make more reliable projection.

The sensitivity analysis is to pay special attention to urban culture factors that can affect the projection (transportation routes, availability, taxes).

Requirement 8: CLASSES OF CONSUMERS

It is necessary to divide the population into types of consumers; these categories are usually over 15 and can be obtained through an analysis of end-use energy. The technique is generally used to determine the load curves for consumers (residential, commercial, and industrial), which in turn can be divided to obtain a more detailed analysis (residential: low, medium and high consumption).

Requirement 9: FORMS OF CHARGE CURVES AND TEMPORARY PEAK LOADS

It defines an average annual load curve of a certain area of study; apart from this curve has a curve peak day of the year and load curves that normal left in the period. The ideal was to have a time curve for each day of the year, but this is impractical and costly.

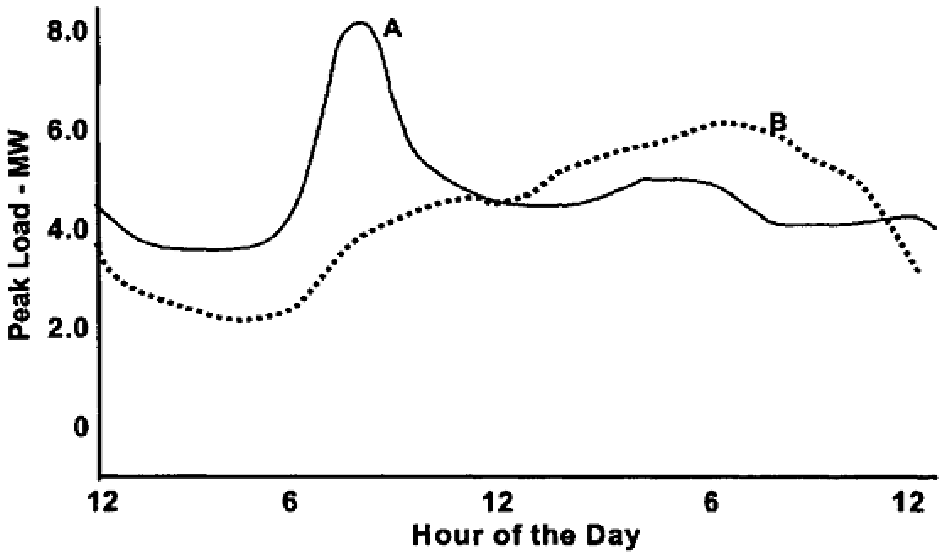


Figure 7 Load Curve a) North Florida, b) New England

Requirement 10: REQUIREMENTS ENGINEERING AND RELIABILITY

The load predictions made on the basis of how much reliability consumers want and how much they are willing to pay to maintain it. These needs vary by customer class.

Requirement 11: POWER FACTOR VOLTAGE AND SENSITIVITY

Sometimes the use is projected to maintain the load power factor current (short term) or power factor by consumer type (long term).

The following table provides an assessment of each requirement on a scale of 10 points.

Rank	Requirement	Importance
1	Forecast MW – *how much*	10
2	Locational accuracy – *where*	10
3	Temporal resolution – *when*	10
4	Weather normalization - *how*	9
5	Representational accuracy - *why*	8
6	Consistency with corporate forecast	7
7	Analysis of uncertainty - *why and how*	7
8	Consumer class forecast - *who*	6
9	Load curve shapes	5
10	Reliability value/need	5
11	Power factor/voltage sensitivity	4

Table 2 Assessment of the requirements for Spatial Load Forecasting

The next chapter will analyze the most successful method to perform a Spatial Load Forecasting

3. METHODOLOGY USED IN THE PLANNING OF THE SED

There are about 17 commonly used methods[5] for load forecast, although the methodology and the process could be carried out to label any of them in any of the following three groups: trend, simulation, and hybrid.

METHODS USED

METHODS BASED ON TRENDS

Construct a function to adjust the load growth patterns and estimate the future load. The most common method is the tendency multivariate regression fits a polynomial function, to apply this method in Spatial Load Forecasting provides a significant number of errors, the advantage is its ease and effectiveness in the short term.

SIMULATION-BASED METHODS

This method reproduces the historical load to identify temporal information, spatial and magnitude of load growth. Generally simulates urban development in terms of land use patterns and load curve, depending on the quality of the data may be an

[5] Spatial Electric Load Forecasting , H. Lee Willis, Chapter 10

acceptable method for the short term and for the long term good. Has the disadvantage of cost and effort to develop.

HYBRID METHODS

This method combines the features of the two methods mentioned, in other words this method would be easy to use, does not require many interactions or advanced knowledge of the user. In theory it would be effective in the short and long term.

METHOD RECOMMENDED TO SPATIAL LOAD FORESCASTING

The method to be studied in this research is a hybrid one that uses the Gompertz curve known as S curve widely used in transmission and distribution, this curve is used especially to predict the load growth in small areas.

There are three parameters to control the shape of the curve S

1. Horizon year load (HYL)
2. Start time ramp load growth
3. Slope of the ramp

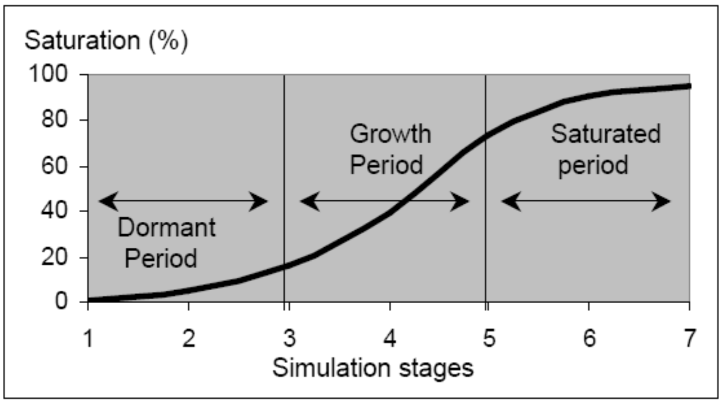


Figure 8 S curve and its 3 stages

PROCEDURE

The elements of the hybrid method associated with the method based on trends is based on two developments:

1. Aggregation bottom to up
2. Allocations up to bottom

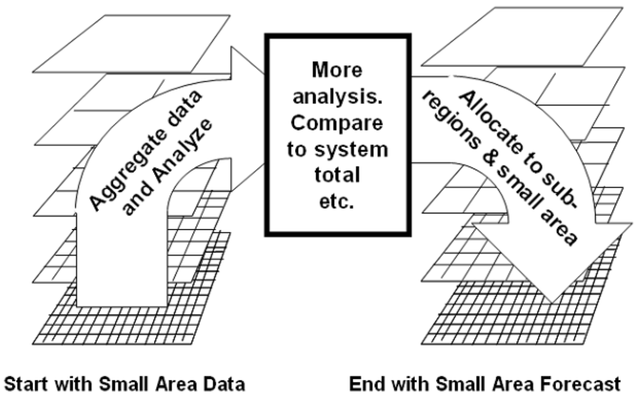


Figure 9 Aggregation and Allocation

Geographic information must be obtained from the GIS, and it's where they should divide the study area into smaller areas to make uniform grid, and each item must have associated their coordinates and their electrical characteristics. The following figure shows the described.

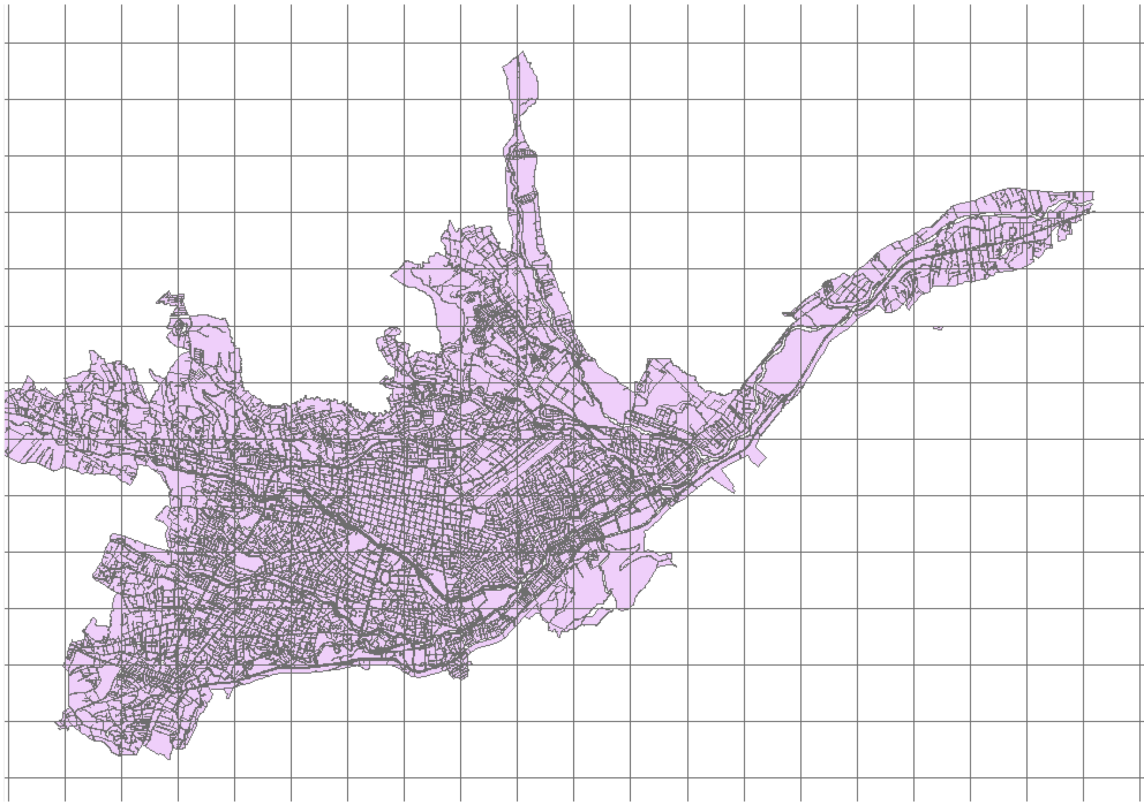


Figure 10 Cuenca city divided into areas of 1km^2

After this there is necessary to define the type of land use and make an assignment.

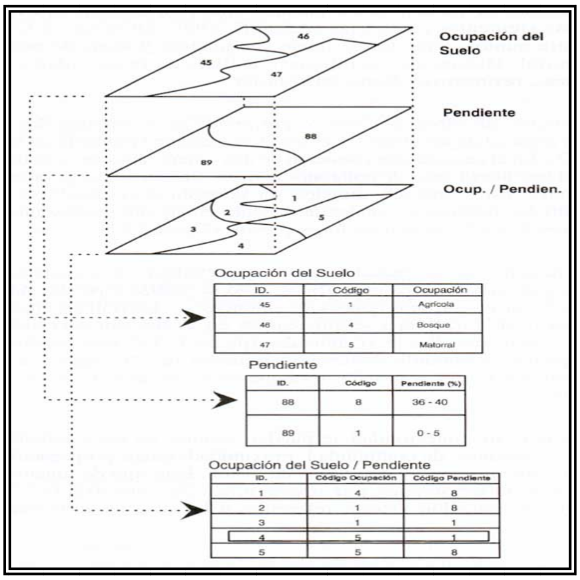


Figure 11 Allocation of use of land with the slope

After determining the types of loading and composition thereof, the following graph is very helpful to understand this concept.

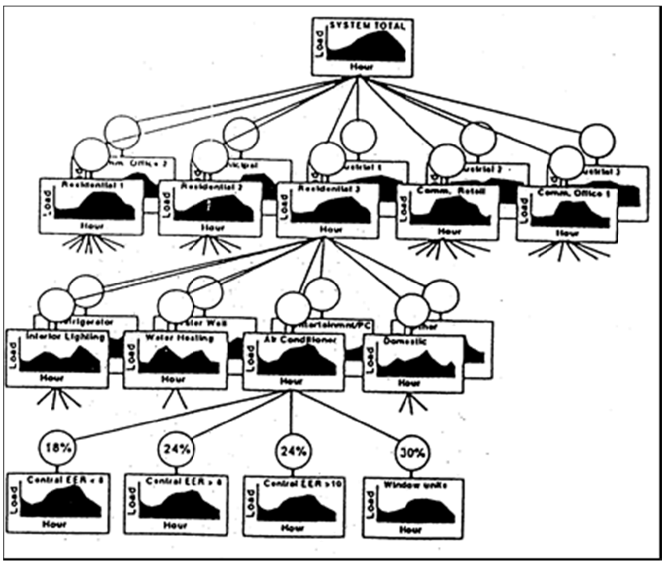
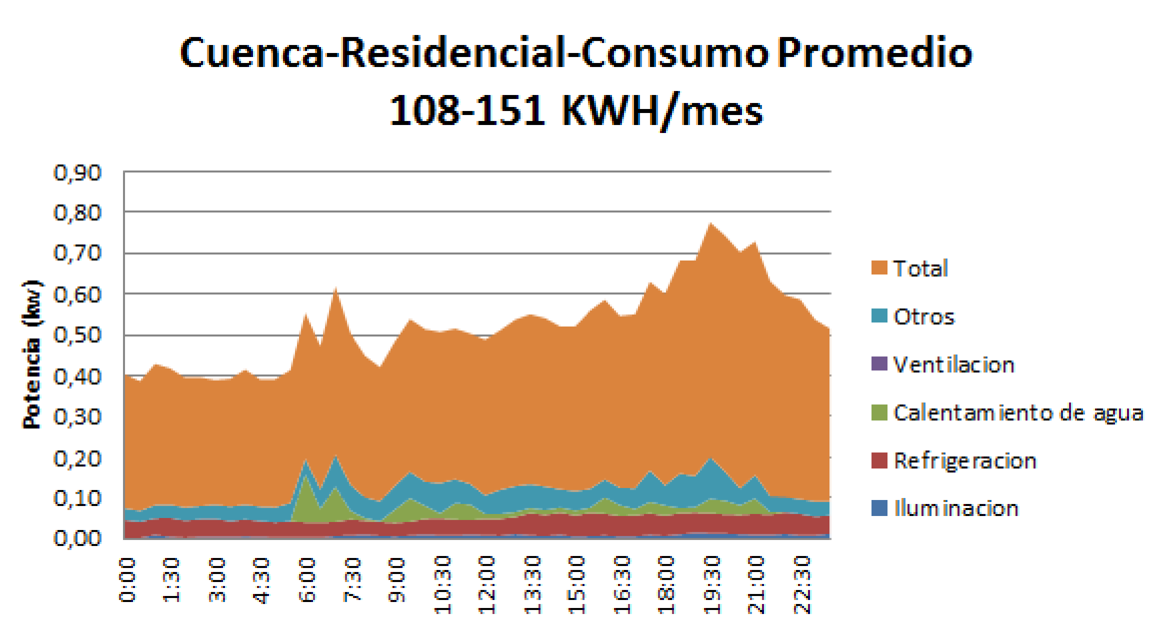


Figure 12 Determination of the total system load

The following chart illustrates a type of residential load curve with their respective components.



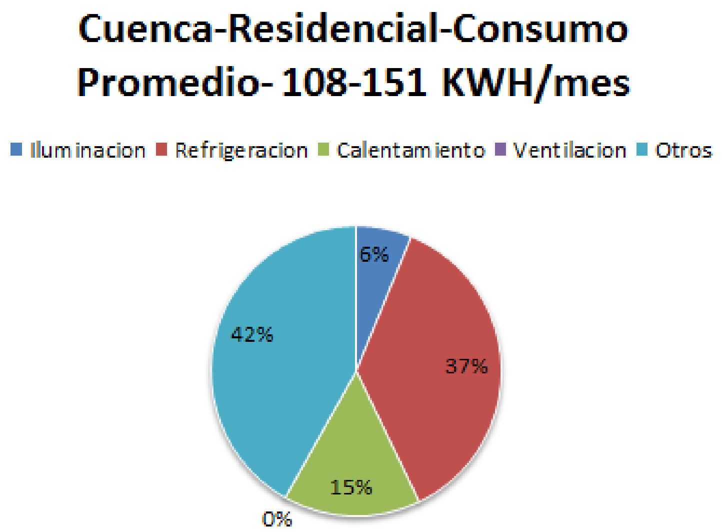


Figure 13 Average Load Profile residential customer

Category 3 of the city of Cuenca[6]

[6] Proyecto Usos Finales de Energía por Subsectores , MEER 2009

After this you must:

- Determine the types of load and load composition in each area.
- Identify areas of growth for each type of load.
- Calculate the growth of each type of load in each zone.

The following two schemes globally represent the entire process should be conducted for load prediction. Figure 14 shows a total area that is divided into multiple small areas (step 1), then for each area is calculated S curve that is a function of land use, ramp time and growth estimates, for this thesis will use cartography of Cuenca with blocks that has information of excluded areas additionally ground slope of the city, the ramp time is equal to the estimate time when the population is saturated and the growth rate is determined of historical data. In step 2 are joined to form small areas of sectors in which the load S curve would be defined by the curves S small areas preliminary step 1. In step 3 gives the S curve of the system based on the curves S in step 2. In a practical case of a distributor this process is carried out at least 3000 times until to determine the curve S total system.

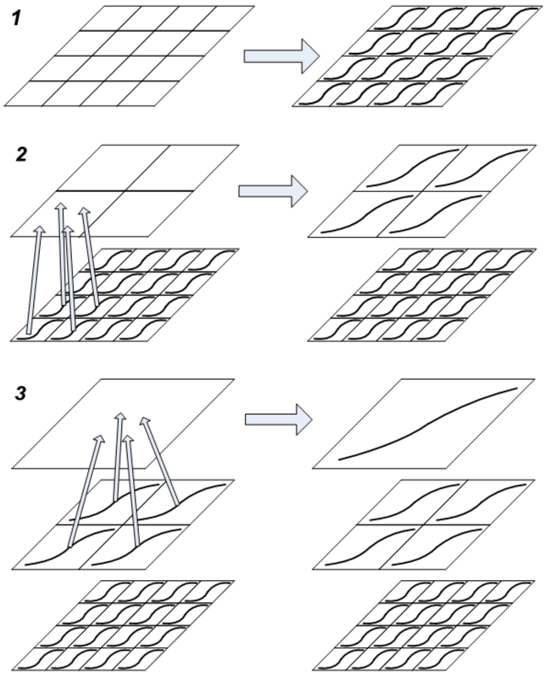


Figure 14 Aggregation bottom to up

Figure 15 shows the mapping process from top to bottom where it begins to curve S of the system, we must not forget that this curve S is modified by the network planner based on the requirements seen in the previous chapter and is changed by varying the parameters of HYL. In the end it will load forecast for each small area in each step is disaggregating the S curve from above in terms of an adjacency table that assigns each curve S effectively to each small area prediction. The prediction is assigned in empty areas that permit expansion or areas that enforcement of minimum conditions (do not cross roads, rivers, roads, not in protected areas, etc.)

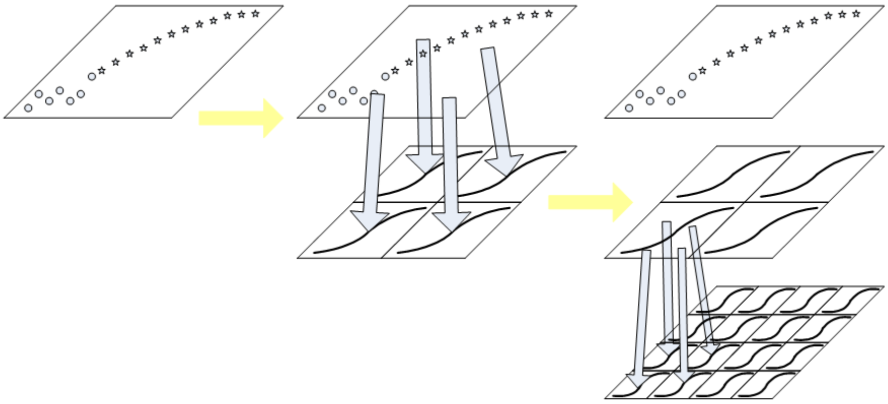


Figure 15 Allocation up to bottom

The next figures illustrate a grouped load forecast map where the more red cells represent a higher projected growth.

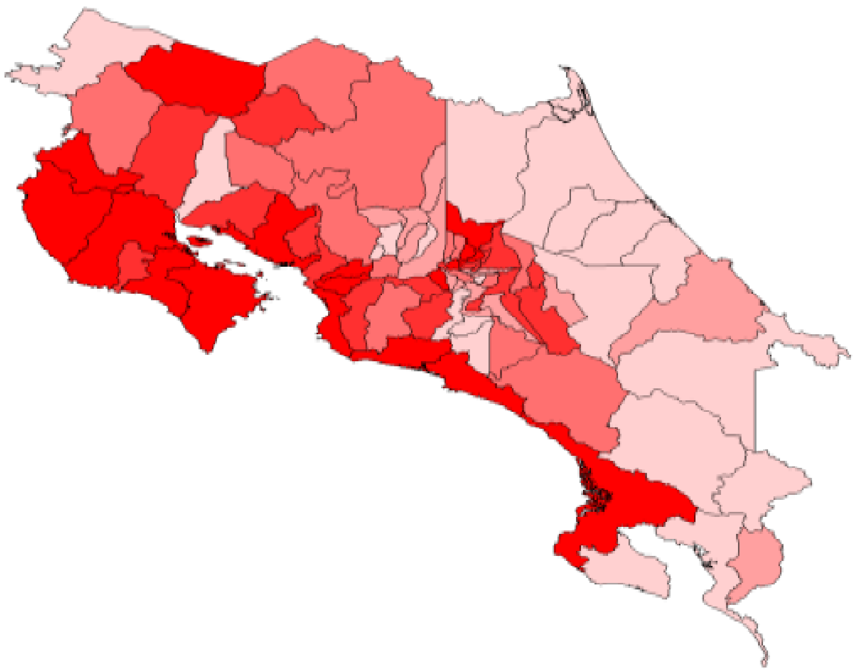


Figure 16 Map example load prediction for 15 years

As mentioned above, in this thesis the long term is used as study time understood as long-term to the period from one to ten years in the future as this period is the average time needed for planning , construction, testing and commissioning of new generating plants. The long-term prediction is required for generating system planning and transport system, an accurate prediction and modeling long-term demand can predict the optimum generation capacity and can also give us information on the matrix generating more ideally to the national electricity system.

The factors influencing the projected long-term demand are usually the price of electricity, demographic and substitute products, and also the most important economic indicators.

4. DESIGN, DEVELOPMENT AND IMPLEMENTATION

The present chapter describes the methodology used to build the spatial load forecasting module, as mentioned in previous chapters there are several methods of estimating each one with advantages and disadvantages of each method. The methodology includes development peculiarities of some of them.

In this project we develop a tool for predicting demand in the long term through geoprocessing. Three methods [3] are considered for the forecast and are widely used:

- The linear regression
- Urban centers and
- Land use.

We chose the method of land use despite being the one with higher cost of implementation because their results are best. The demand forecast will focus on the urban core of the city of Cuenca, Ecuador. In the long term, spatial load forecasting answer questions such as how much, location and time of growth.

DESIGN

Methodology applied is basically based on the method of land use, which manages data of population, electricity demand, and business census and use classification of the study area.

1. First estimates the overall population growth in the study area by the Gompertz curve, this increase is distributed in each of the micro areas in which they must divide the study area.

2. The ability of each area to receive population is determined by a reception index, which can be calculated by considering such factors as:

- Proximity to public transport routes
- Proximity to downtown
- Land Use
- Degree of restriction to the construction
- Ground Slope

It should be noted that this index should be calculated in each micro area.

3. It is essential to consider the present stores in each micro area, therefore become necessary to perform a linear prediction commercial growth.

4. Since base demand disaggregated by inhabitant and commerce, and growth projections of population and businesses is possible to calculate the future electricity demand in each micro area.

The following flowchart illustrates the modules developed by geo processing.

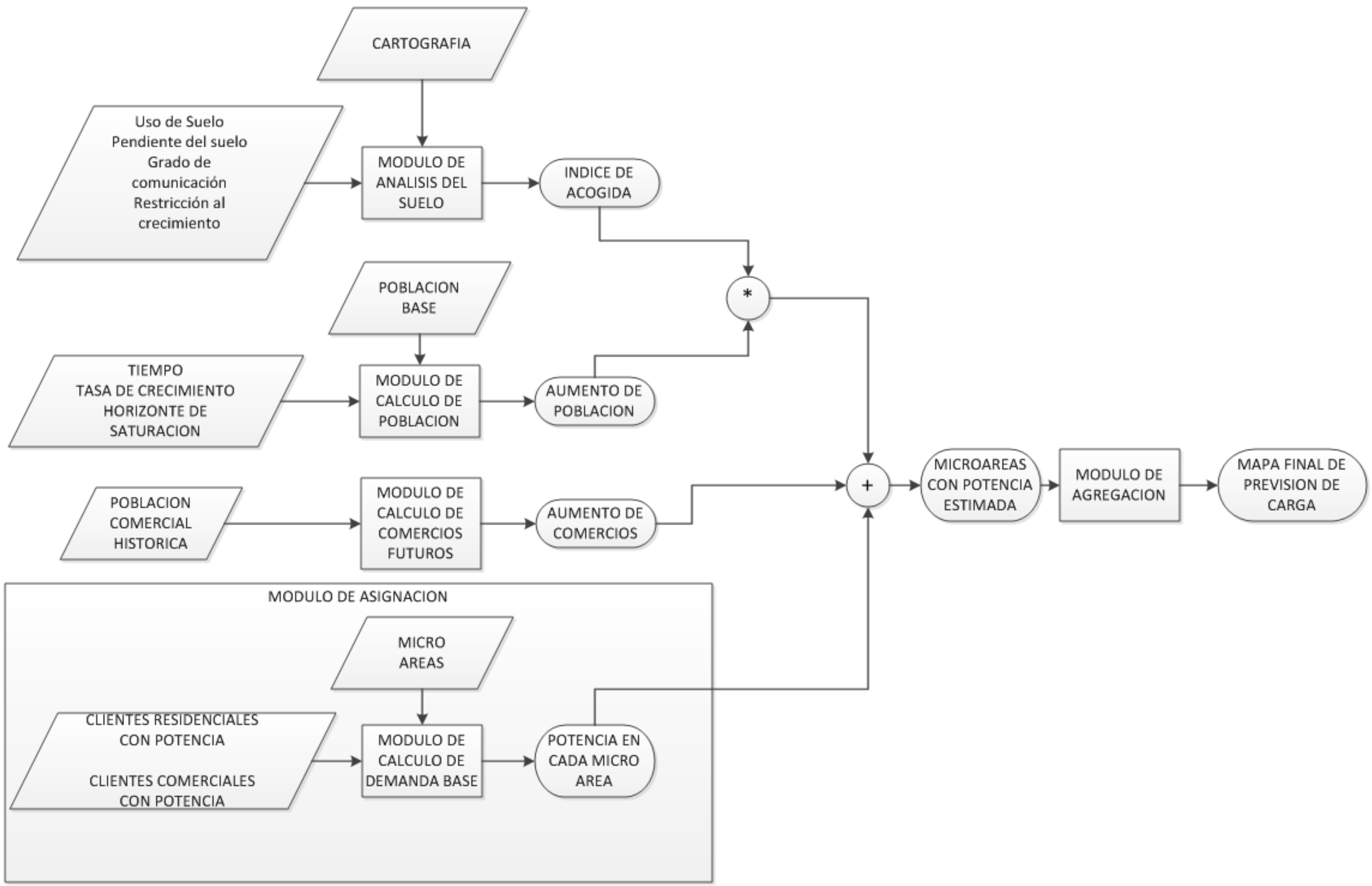


Figure 17 Layout of spatial load forecasting module

DEVELOPMENT

Method chosen is that represents greater difficulty of implementation due to the many operations of Overlay, Extract to be performed throughout the entire process before obtaining the projected demand. Additionally within the GIS is needed all the calculations involved.

Prior to the implementation of the module was necessary to obtain mapping information and census data, the following describes the data collected and its quality.

- Database of energy: This information is available from a study of energy end-uses; the database has Centrosur's monthly consumption of all customers from November 2007 until February 2009. Using SQL queries are divided based on two views, the one is a query with only urban customers, with average consumption of 2008, and does not consider residential customers with average 0Kwh, the other view query has only urban commerce with the average consumption 2008, and does not consider commercial customers with 0Kwh average. The two views were exported to dbf extension tables.

- Cuenca's cartography: the same study were available classes of features streets, lots, blocks, rivers, urban parishes, additionally provided a polygon layer representing each client of the Empresa Electrica Regional Centrosur (Centrosur) located geographically. From a course taught by a Consultant of the city which saw could be obtained files type shape of the Cantons of Azuay, ground slope, land use, the above information was transformed to WGS_1984_UTM_Zone_17S of PSAD56 by ArcMap Project tool.
- Census data: The population in 2008 was obtained from the INEC-Cuenca, were obtained from INEC historical data.

With all this information began the editing process to make it according to the needs of the study, described below all work performed preliminary implementation of the module.

- With dbf tables exported from the average consumption and the layer of points of customers was constructed a join based on the code energy meter. Obtaining a point layer with the average consumption of a year.

- All other layers were filtered through query definition or select by location to leave the end only information about the study area, in this case the urban parishes of Cuenca.

- A layer of blocks were added two fields: one to place a land use code that should be excluded from the analysis and one for observations, after these was exported to a new shape to areas not considered in the analysis . Zone excluded are colleges, schools, airport, terminal, universities and any large-scale construction cannot receive more population.
- Two additional layers were constructed: one is a mesh composed of 1km2 areas and the other concentric circles of 1km in diameter centered on the city center.
- The layer 1km2 areas by select by location tool is trimmed to leave only the polygons that intersect layer urban parish.

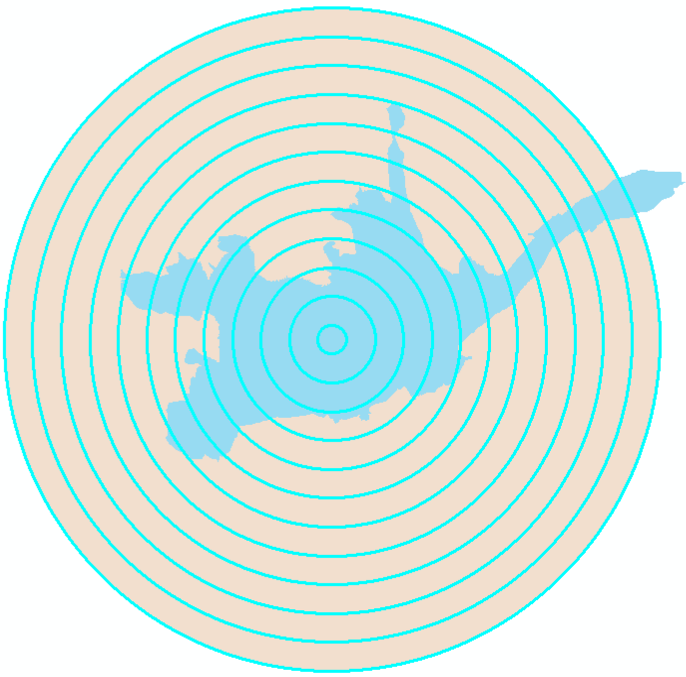


Figure 18 Concentric Circles

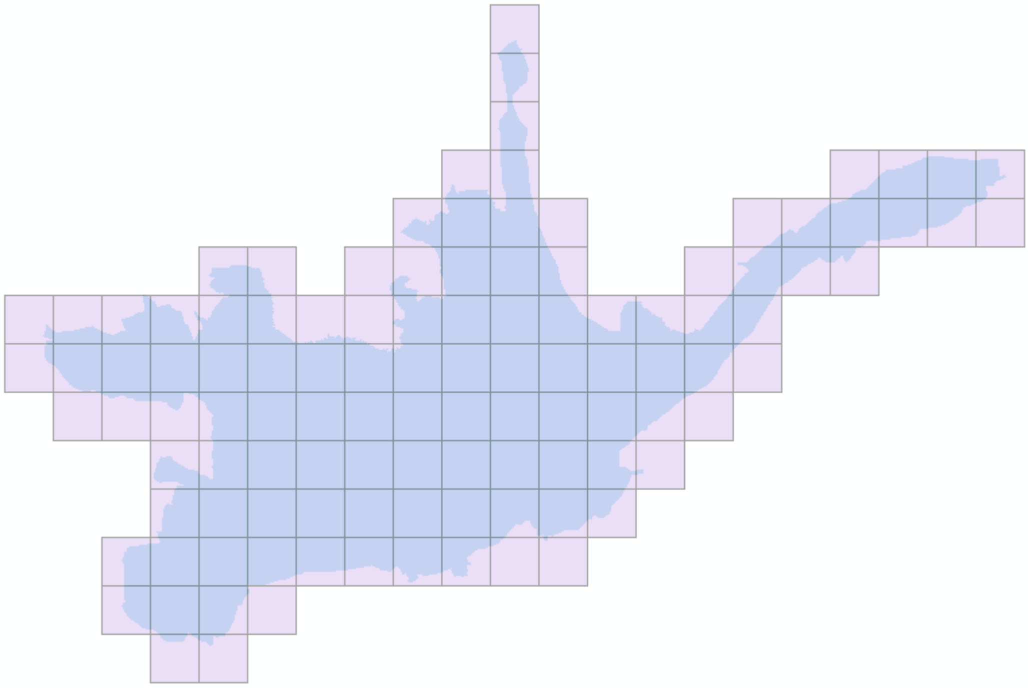


Figure 19 Areas of $1km^2$

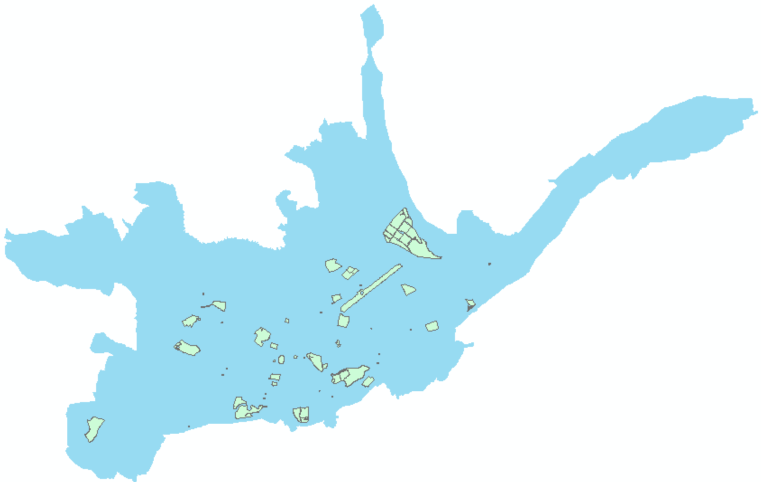


Figure 20 Zones excluded to analysis

IMPLEMENTATION

Edited previous layers and created the necessary proceeds to implement the module to estimate electricity demand forecasting. The module will be implemented to run in ArcMap 10.0 using geo-processing that can be built using Python 2.5 or Model Builder.

The first script was developed in Python and can calculate the future population, by the Gompertz curve.

$$y(t) = a * e^{-e^{-c(t-\Delta t)}} \qquad (1)$$

Equation 1 Curve Gompertz

Where *a* is HYL, c is the growth rate and Δt is the ramp time.

HYL or *a* is the saturation number of inhabitants in the time chosen like ramp time, in this case should be a number greater than 277374 (population in 2008).

c should be obtained of historical data census of population , in this case the value is 0,2

Δt is the time when the curve will saturate for example 10 years.

All those values are input variables requested in the tool.

Additionally this script calls the income growth rate of commerce, income parishes layer then run a dissolve on it to make a single polygon with characteristics of future population and commercial growth.

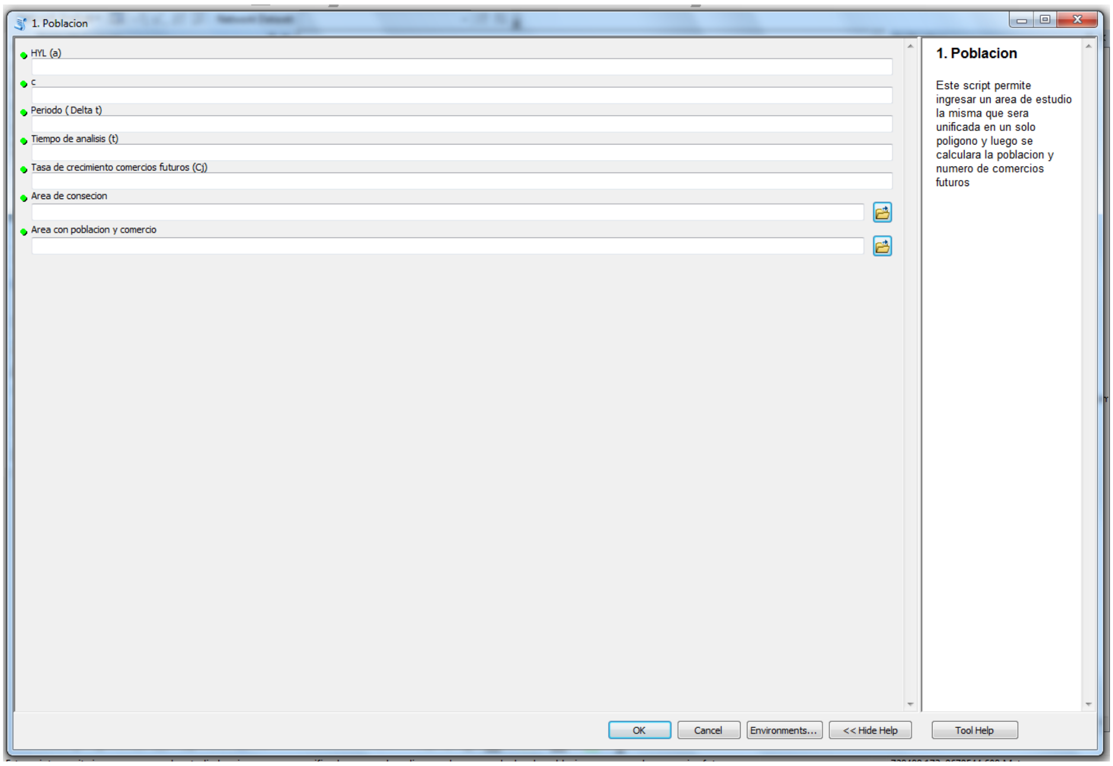


Figure 21 Module of Population

After this is another development that divides the polygon script module result in *n* micro population areas, the resulting polygons are automatically exported to a geodatabase then you can use its area attribute.

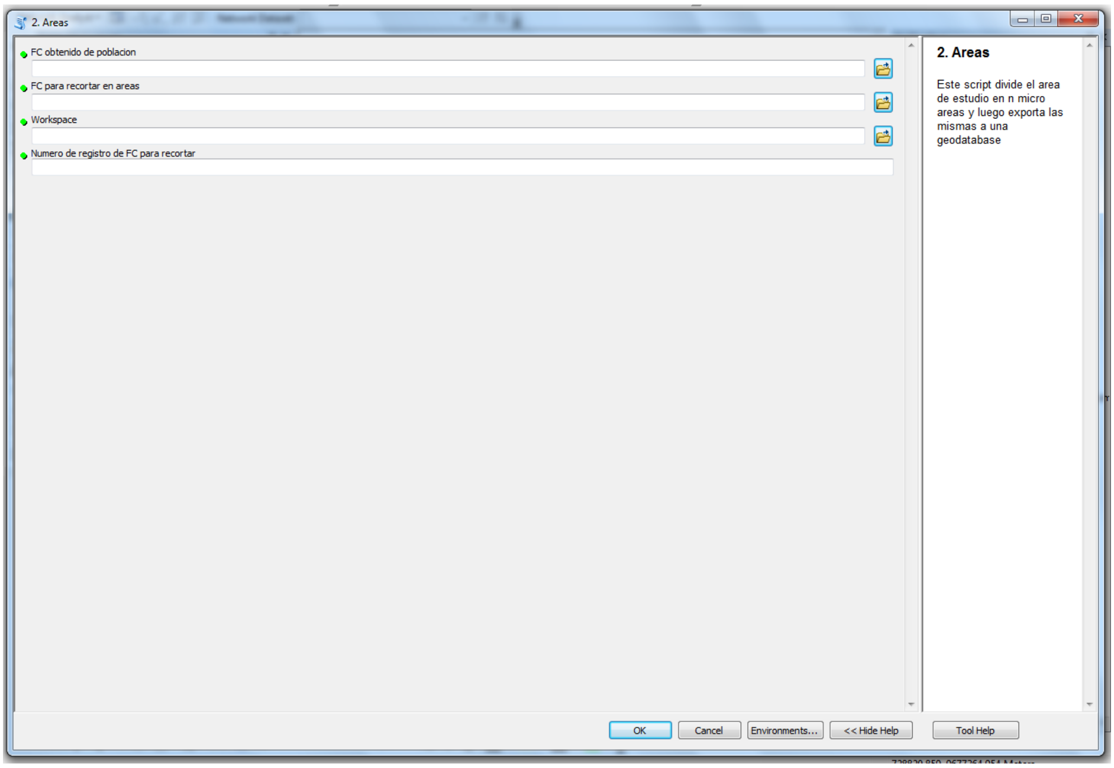


Figure 22 Module of division in small areas

With the information available it is possible to make the allocation of residential and commercial power that is contained within each micro area. For accomplishing this is to use Python with 2 scripts one called residence and one commercial.

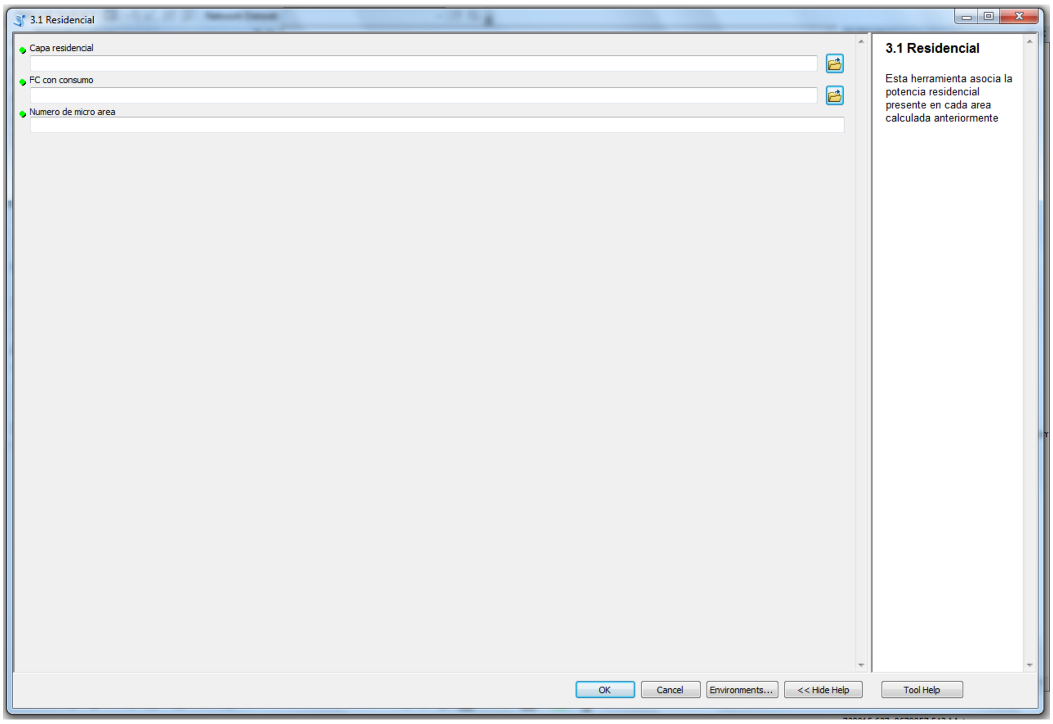


Figure 23 Residential Module

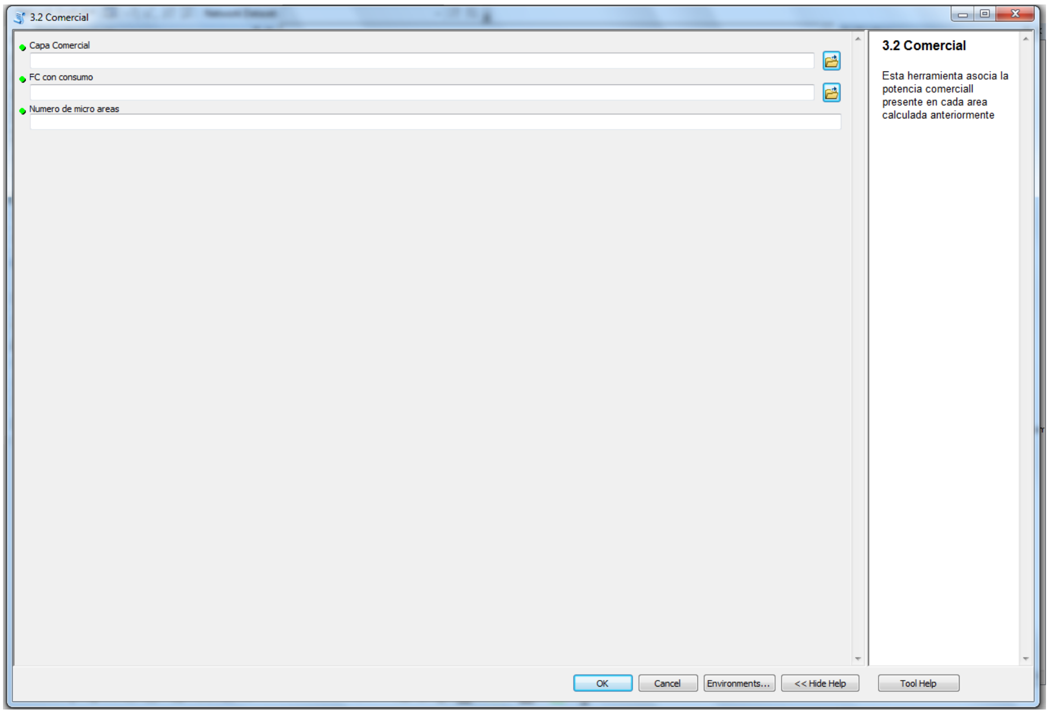


Figure 24 Commercial Module

After running each module that delayed approximately 11 minutes each one, were obtained polygons that have attributes of residential consumption of each micro area and other polygons that have commercial consumption of each micro area.

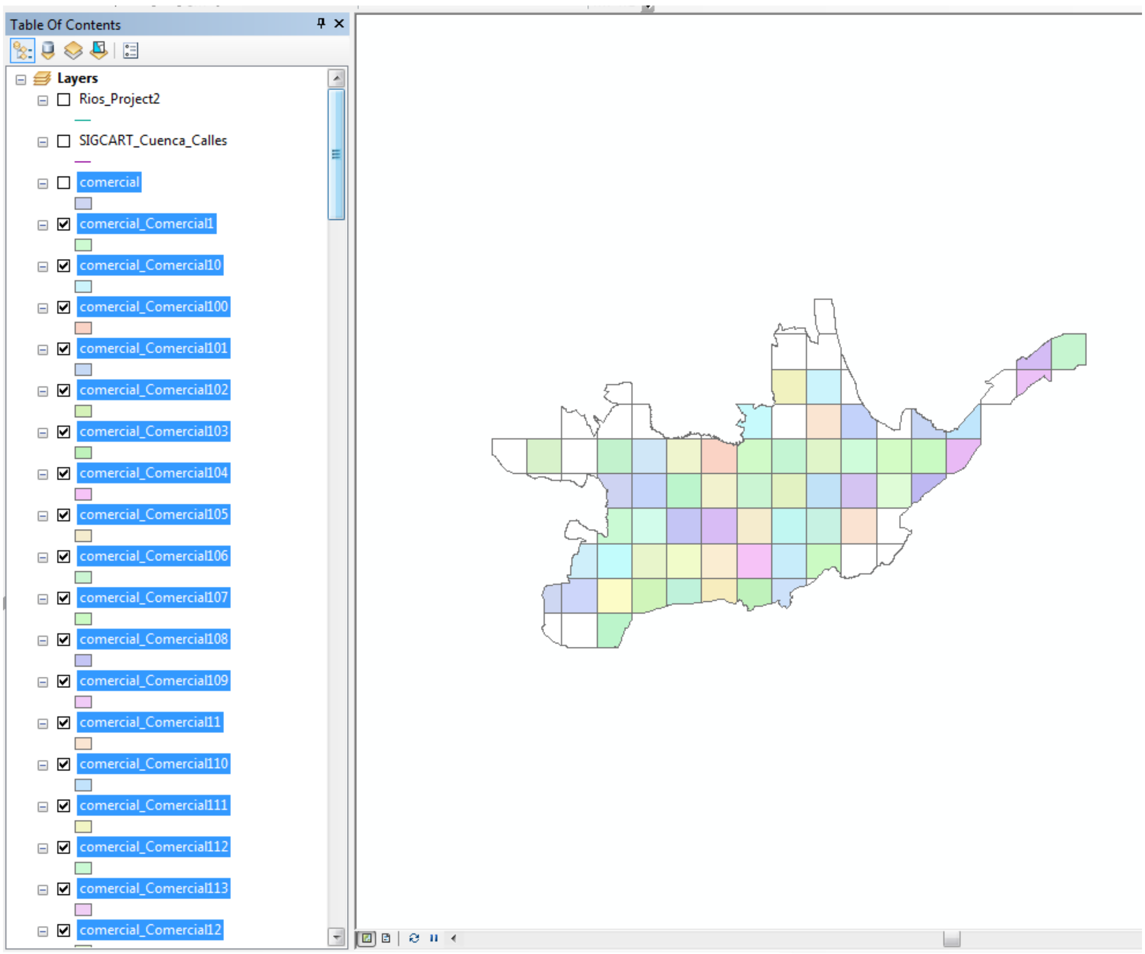


Figure 25 Polygons with consumption commercial

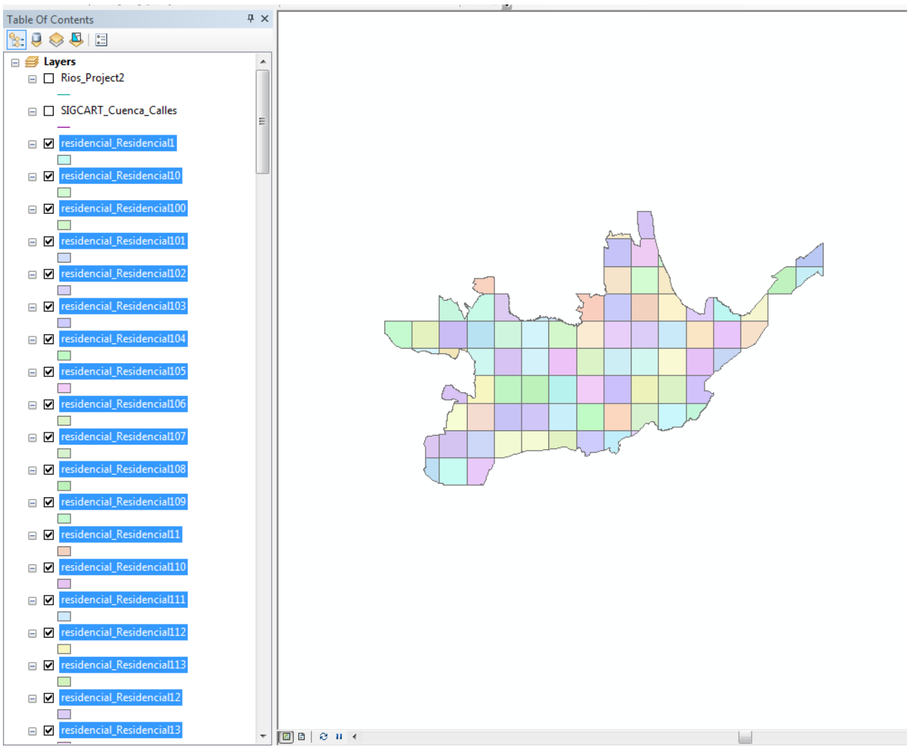


Figure 26 Polygons with consumption resiential

This step is necessary to use the Merge tool for 2 occasions one to join all commercial polygons in one layer and another to join all residential polygons with the same objective.

Once done with the tool spatial join is necessary to unite the two previous polygons and you get a single polygon that has among its attributes residential and commercial consumption of each micro area.

Finally, a model was developed to add those two consumption, because there was commercial consumption <null> that do not allow a direct sum.

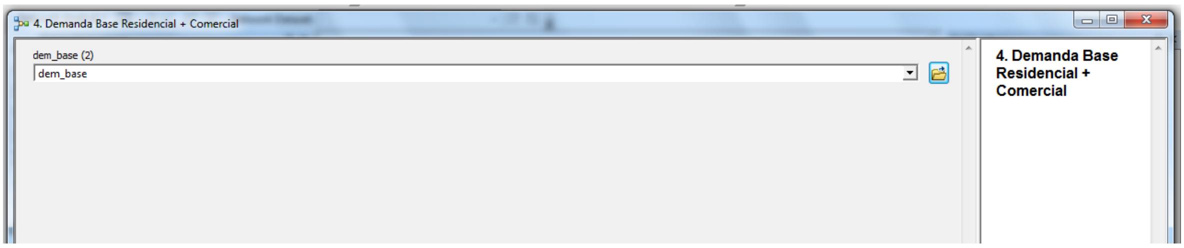


Figure 27 Sum of consumption

Below is a map of base demand of 2008

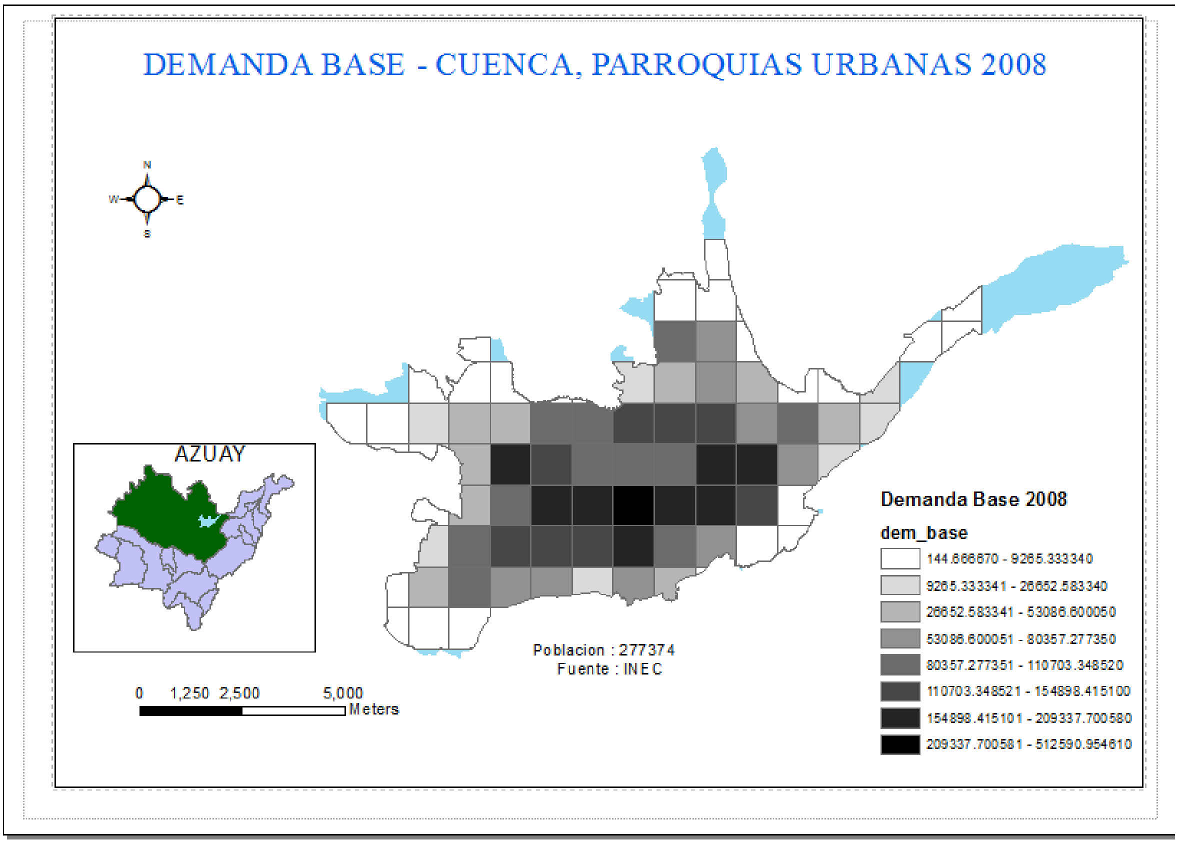


Figure 28 Base Demand - 2008

So far we have calculated the base demand that will serve for the calculation of the projected demand. At this stage, another script was realized to determine the percentage of use of land available for growth in each micro area, the script handles subtract of the area of each micro the surface of streets, rivers, exclusion zones defined above and also all sectors with slope than 50 degrees, after this we get in each micro area an actual rate of use of available land. The script was developed to be run from ARCMAP but there were errors in the execution specifically by having the application open for that reason you should run the script directly in Python. The running time is approximately 50min.

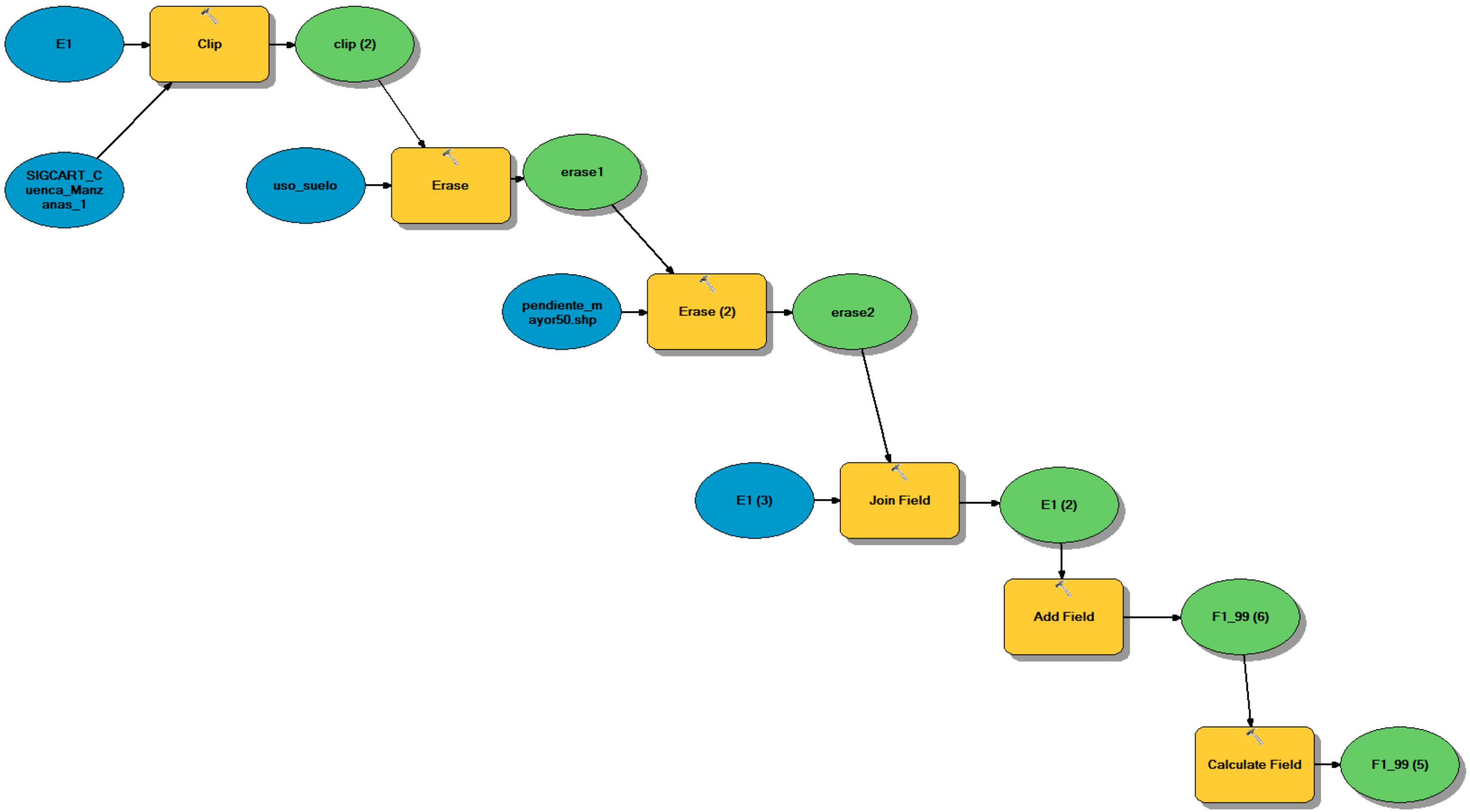


Figure 29 Diagram to calculate of land use

This script gives results in the creation of a new field in the polygons of micro areas this field contains the percentage of land use. Then we return to the Merge tool to merge all these polygons in a single layer, in this polygon we created two more fields to categorize restriction to growth and proximity to downtown, the circles layer created above will serve to make this categorization.

RECEPTION INDEX

To allocation the growth of global population projection to each micro area [7] is used the concept of reception index. The reception index of a micro area is not more than the ability there in for receiving new inhabitants. Consider that the population growth in a micro area of the city *j* is directly proportional to the overall population growth of the city.

Modeling reception index can oscillate from a very simple calculation to many factors considerations in this thesis have chosen four factors for calculating the same:

- Areas excluded: these are all areas that cannot accommodate population such as stadiums, airports, universities, and others.
- Ground Slope: it offers outstanding layer ranges from 0 to 100 degrees, for the study constructed a shape containing areas with slope greater than 50 degrees.

- Degree of communication: the closeness that each micro area from the center of town which is where all the institutions necessary for any procedure.
- Restriction to growth is reverse earlier and represents the difficulty of each micro area to accommodate more people, for example the center is saturated so the closer to the center the more restriction.

The factors described are calculated using GIS tools. It is known that these factors vary annually causing a change in the reception index, for simplicity of calculation, and because not vary greatly thereof are considered fixed. In implementing are grouped the first 2 factors then weighted with 50% considering that land use is the most important to receive new residents. For it is not known for sure the weight of each factor may weigh them all with the same weight.

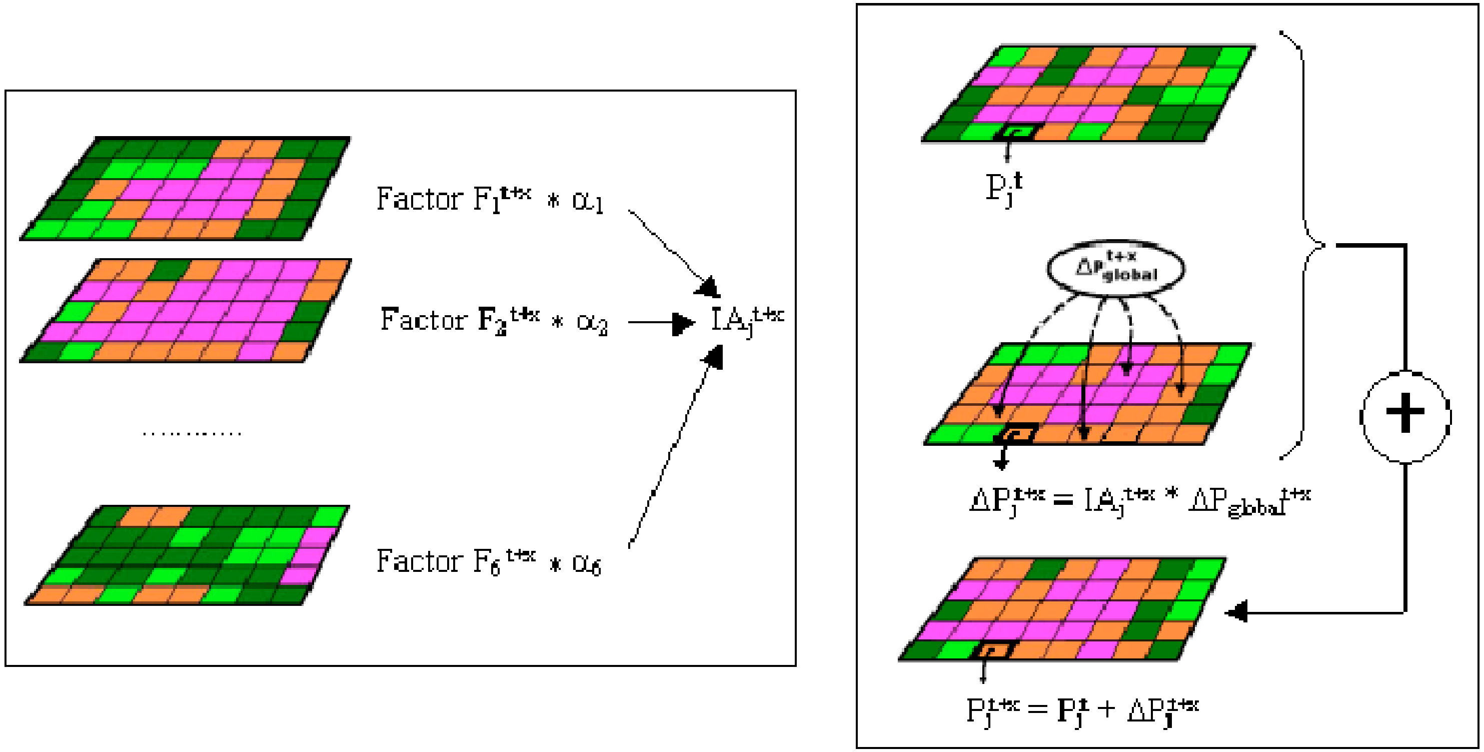


Figure 30 Calculation of the reception index and future population.

Source: ZABALZA Ignacio…., “Aplicación de los SIG a la previsión de demanda eléctrica”

The reception index in each micro area was calculated as follows

$$IA_j^{t+x} = \alpha 1 * F_{1j}^{t+x} + \alpha 2 * F_{2j}^{t+x} + \alpha 3 * F_{3j}^{t+x} \quad (2)$$

Equation 2 Reception Index

Where α is the weight of each factor, for this study was defined as follows:

F_{1j}^{t+x} = Result land use script that felt excluded areas and soil slope, this value is a percentage.

F_{2j}^{t+x} = Degree of Communications, 12 categories are closer to the center while the higher the value.

F_{3j}^{t+x} = Growth restriction, are 12 categories closer to the center while a higher value to the growth of the opposition.

For this job the weights were determined by simple observations, considering that land use as minimum should be equal to 50% because otherwise there will be no ability to receive population probably could not have great growth in each area, additionally this factor is compound for usable areas and ground slope, the degree of communications is 10% because this do not represent a great obstacle at the time of building. The growth restriction is very important for this reason its weight is 40%.

However is possible change the weight of each factor in the field calculator and build more scenarios.

α1=weighting of 50%

α2= weighting of 10%

α3= weighting of 40%

Thus the formula to apply in each micro area would

$$IA_j^{t+x} = \frac{0.5 * F_{1j}^{t+x} * 12 + 0.1 * F_{2j}^{t+x} + 0.40 * (12 - F_{3j}^{t+x})}{12}$$

We developed an additional module to calculate the RI (Reception Index) for each micro area.

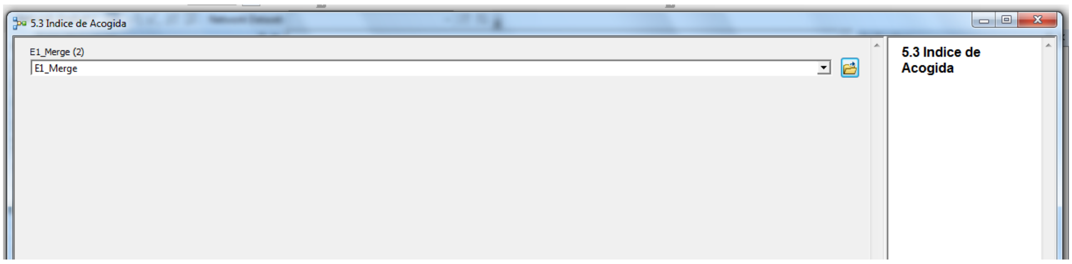


Figure 31 Module to calculate the reception index

Finally, we must perform a Spatial Join between the layer of micro areas with the RI and the layer obtained “base demand”. The resulting layer will base demand disaggregated, total demand, the reception index, population estimated growth and growth commercial rate.

With the following formulas [3] and knowing the population of 2008 in the study area, we can calculate the future demand and growth in each micro area. Within this layer was used Field Calculator tool for calculation.

$$P_j^{t+x} = P_j^t + (IA_j^{t+x} * \Delta P_{global}^{t+x}) \qquad (3)$$

Equation 3 Future population

Where:

P_j^{t+x}=future population by area

P_j^t= Base Population is the current population.

IA_j^{t+x}= Reception Index

ΔP_{global}^{t+x} = Global population growth (obtained of the Curve S)

The following equation is applied to determine the growth of commerce, in the study was chosen enter directly the rate of population in the module. This rate was obtained historical data externally “INEC”.

$$C_j^{t+x} = A_j * x + B_j \qquad (4)$$

Equation 4 Linear regression to estimate commerce

Finally future load in each area is equal to the sum of residential and commercial growth, as defined in the following equations.

$$LC_j^{t+x} = \frac{LC_j^t}{C_j^t} * C_j^{t+x} \qquad (5)$$

Equation 5 Forecast commercial

$$LP_j^{t+x} = \frac{LP_j^t}{P_j^t} * P_j^{t+x} \qquad (6)$$

Equation 6 Forecast residential

$$L_j^{t+x} = LC_j^{t+x} + LP_j^{t+x} \qquad (7)$$

Equation 7 Forecast of each micro area

Where:

LC_j^t = base demand commercial is the current load commercial in each area, in this case in 2008, to get this is necessary to group the points with average load in each area.

C_j^{t+x} = Future Commerce is obtained of the equation (4) thought of historical data of census

C_j^t = Current commerce is the number of commerce, in this case in 2008; to get this is necessary count the commerce of each area.

LC_j^{t+x} =Future demand commercial

LP_j^t = Base demand residential is the current load residential in each area, in this case in 2008; to get this is necessary to group the points with average load in each area.

P_j^{t+x} = Future population is obtained of the equation (3)

P_j^t = Current population is the population of the each area, thought of reception index the current population is distributed in each area.

LP_j^{t+x} = Future demand residential

L_j^{t+x} = Projected demand in each micro area is the sum of future demand commercial more future demand residential.

Equation 5 can be written as follows

$$LC_j^{t+x} = LC_j^t * \Delta Cj \qquad (8)$$

Equation 8 Forecast commercial

Where:

ΔCj = commercial growth rate that is obtained of historical data.

The end result after performing all calculations is presented below.

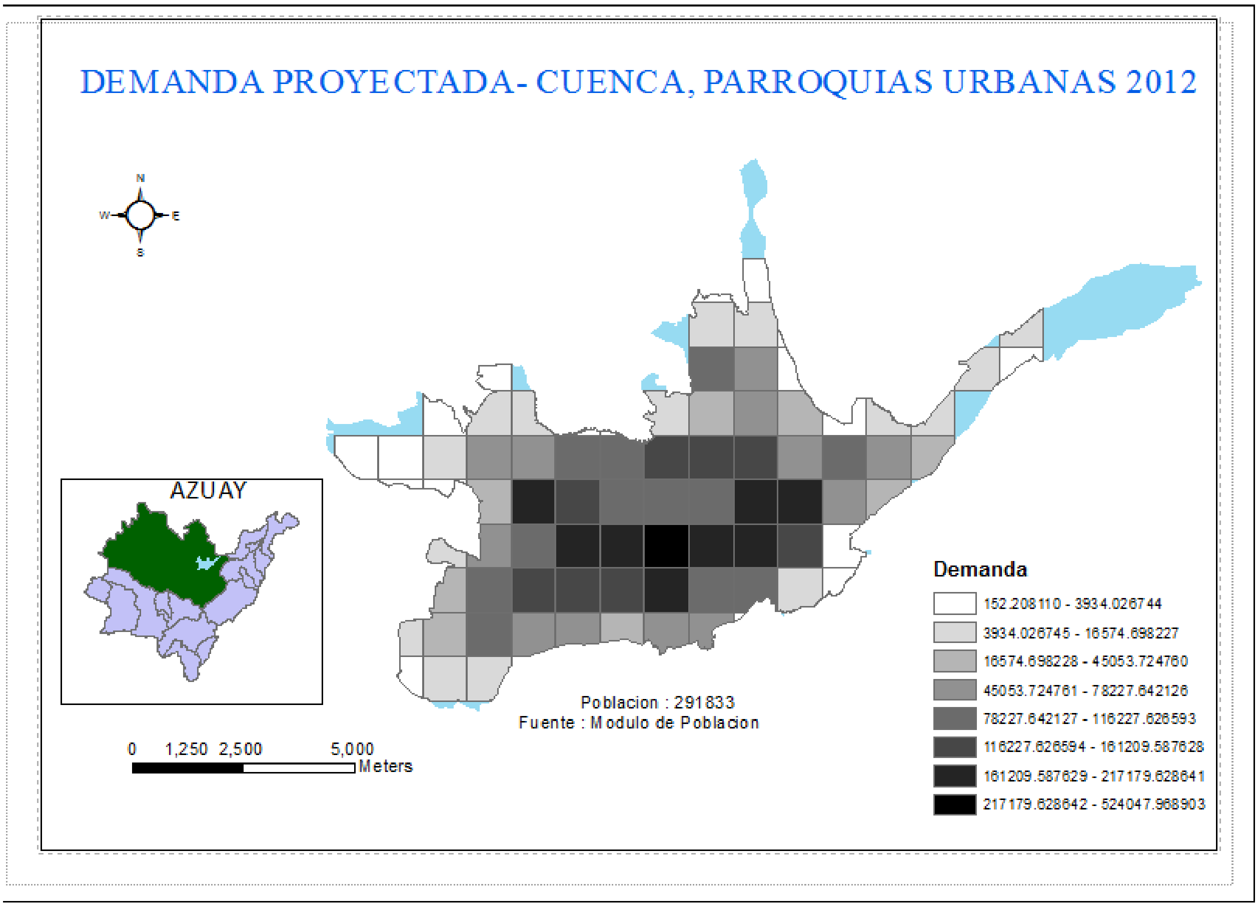


Figure 32 Projected Demand to 2012

In the final map cannot clearly see the growth which was conducted by another map just demand growth presented below.

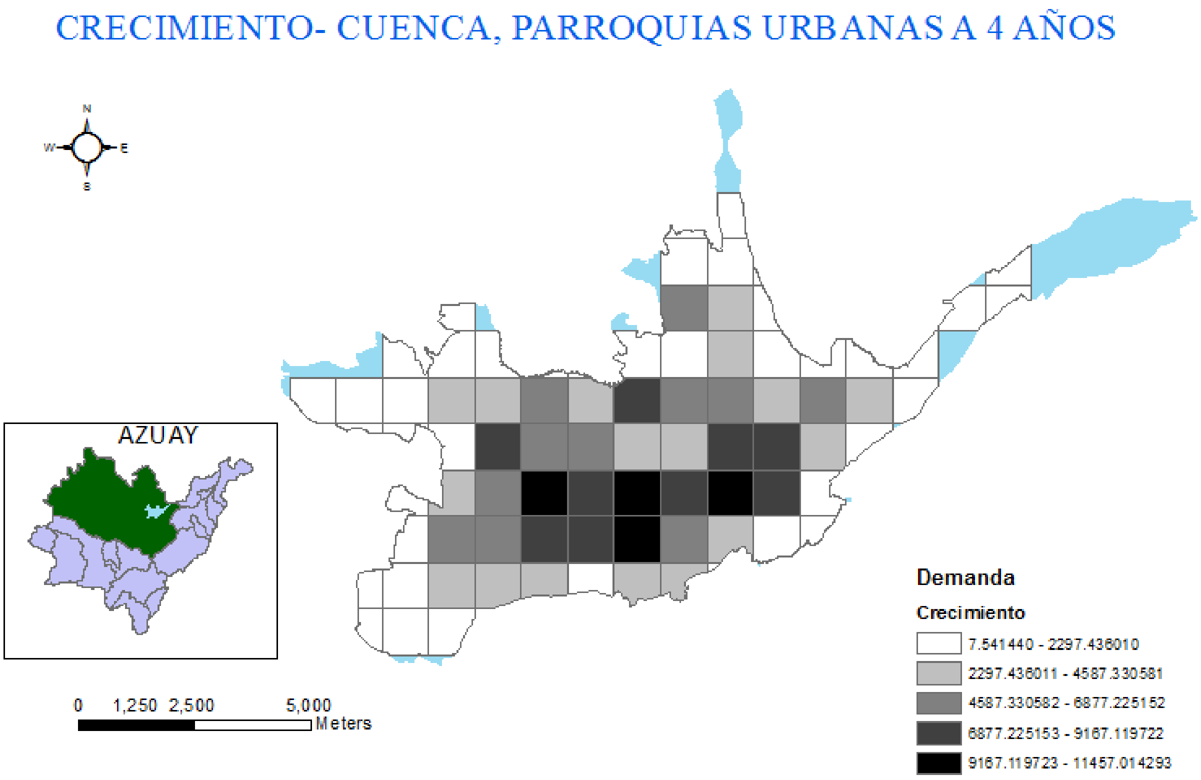


Figure 33 Growth of demand to 4 years

In the next picture you can see the integration of all scripts and models developed as a module within ArcToolbox.

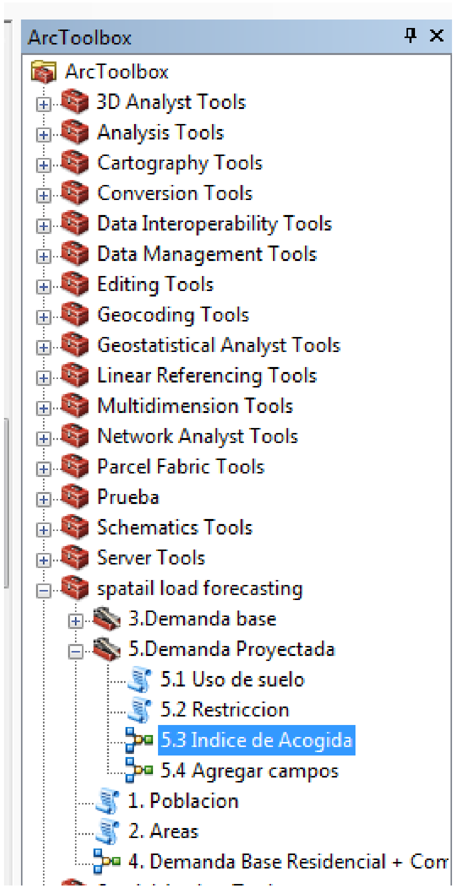


Figure 34 Spatial Load Forecasting Module as Toolbox

5. ANALYSIS OF RESULTS

In this chapter are discusses the procedures and results across all processes, further discusses various characteristics to be taken into account.

DATABASES

Database that was available was exported to dBASE format as described in the previous chapter, this was done after a join with the layer of points: Clients of Centrosur, but because the map data had several codes associated with same point matches were less than expected. This provoked that obviously the base demand obtained with residential and commercial script is less than the real. This does not mean that the scripts are bad, but they must be considered to obtain a more refined point layer is having a point for each code.

CARTOGRAPHY

The cartography available had to be placed in the same coordinate system to prevent any displacement or bad point's polygons association additionally had to create additional shape. The shape of excluded land uses should be supplemented with all city parks, all schools, colleges, streets, public green areas in the middle of streets, etc, to get better results in the module, but it did effort in areas of considerable size add to this shape.

SCRIPTS AND MODELS

The scripts and models can be automated to a higher level while providing greater flexibility for users by allowing more variables and parameters are chosen from the ArcMap interface.

The categorization process proximity to downtown and the growth restriction can also be modeled in a loop as well as automatic final calculations could be placed in one model and run simultaneously.

RESULTS

First script calculates the future population for any number of years, in this case we made a projection to 4 years and this population is assigned to a polygon that is result of a process dissolve.

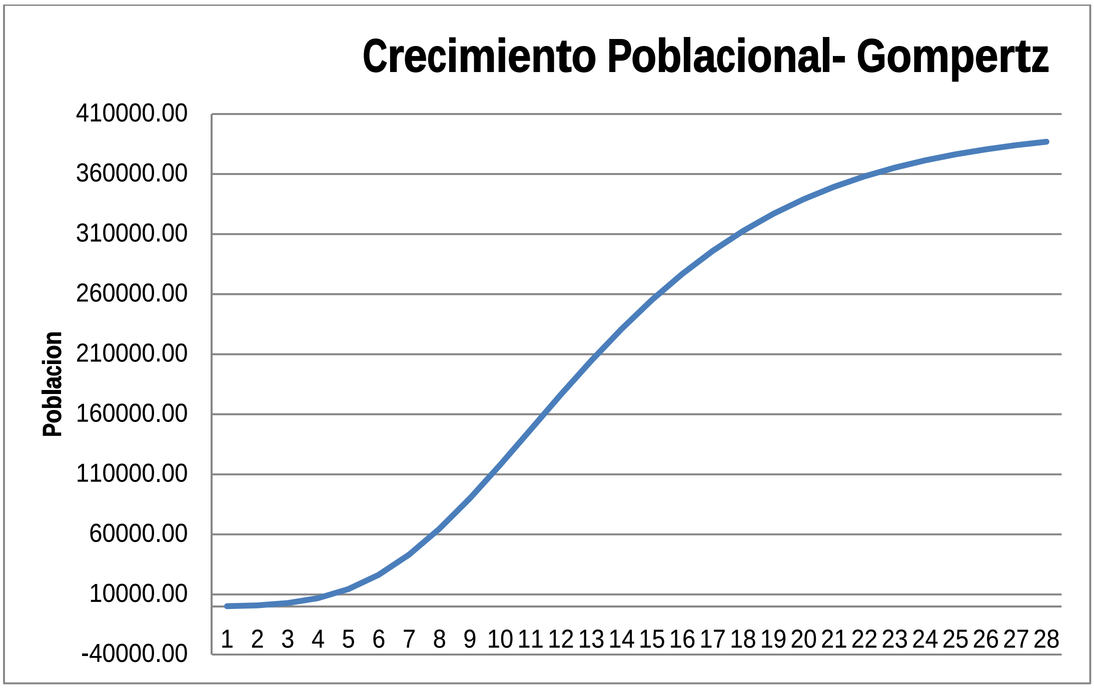


Figure 35 Population growth in Cuenca

Defined

a= 400000

c= 0.2

$\Delta t = 10$

t is variable but in this thesis the value was four years.

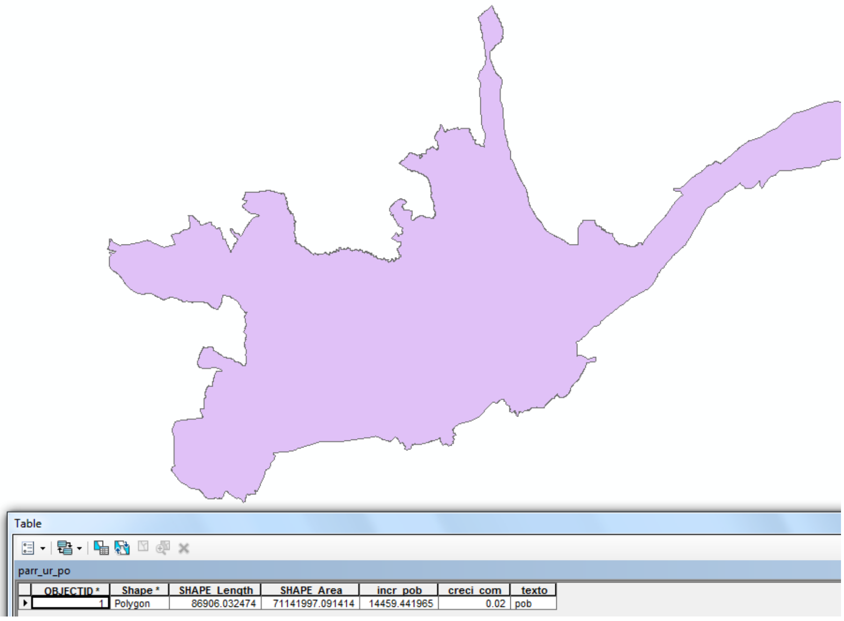


Figure 36 Polygon with growth population and rate commercial

It is seen that the results are correct; the growth rate was obtained from a commercial trend built with data from 2001 to 2008.

The second scripts which transfers the attributes of the study area to micro areas functioned properly and give as result 113 polygons of $1km^2$, this number is important because it is an input parameter and is easy to get, you just have to get the number of feature class records used to cut the study area.

The third script that associates the residential power point layer having the average consumption of 2008 to each micro area obtained in the previous module, functions properly, the unique feature of this is that generates polygons without geographic entity in the case of not having matching points within each micro areas residential. Therefore when using the Merge tool there are less polygons than the originals, in this case are 82.

The fourth script that associates the commercial power point layer having the average consumption of 2008 to each micro area obtained in the previous module, functions properly, the unique feature of this is that generates polygons without geographic entity in the case of not have matching points within each micro areas commercial. Therefore when using the Merge tool there are less polygons than the originals, in this case are 57.

Using Spatial Join tool with the two previous layers must be considered that the target layer must be “residential” is the one with more records and the field match option must be “ contains” with this guarantee then add powers to residential and commercial although there are null fields.

Model 4: Base Demand residential + commercial allows sum powers, considering the value null.

The script land use performs a clip between each micro area and the cartography blocks to obtain as result the constructible area then are erases excludable areas , then are erases areas with slope greater than 50 degrees. All this produces 113 * 3 shapes for this reason is the script with increased response time about 1 hour, finally assigns the final percentage of land use in each micro area.

The reception index model is responsible for the calculations of equation (2), the model add fields required for the final calculations.

Again it is necessary to use tools Merge and Spatial join to obtain the final layer, where are applied the equations (6), (7) and (8). The presentation of the final map is a taste of the planner.

With the help of the tool statics of each field was determined the:

Base Demand total = 5450041.405 kWh

Projected demand = 5695325.879 kWh

Whereupon the growth to 4 years = % 4.5

The rate of growth is right in a city of the characteristics of the city of Cuenca. The final map shows growth more pronounced in the areas of the down center and almost zero in the industrial park, the airport and the peripheral sectors. Note that all depends on the weighting given to each factor of the reception index.

As a final remark can be mentioned that the module meets the main requirements of Table 2.2, is flexible to any change of information, is applicable to any province, is scalable and to improve the quality of information input shapes customer specifically improve their incredibly accurate results.

6. CONCLUSIONS

Upon complete of the whole process of implementation of the module and have conducted an extensive review of the literature concerning the use of GIS in electrical distribution, we can mention the following.

Using GIS in the projection of load represents a considerable advantage over other methods because it allows include land use in the analysis to assign the projected demand and available in real places.

The total execution time editing module including input shapes to leave according to the need is approximately 2 hours, a small real time considering that manually may take weeks, in addition to the degree of accuracy is much higher.

The construction of sub modules running step by step permit decentralize process allows to optimize and verify times results at each stage.

Obtaining load curves is another method which is totally independent that consist in take power measurements each hourly intervals then using multivariate statistical the curve is disaggregate into its components, and that there will be multiple load curves.

These curves are input variables for Spatial Load Forecasting process for that matter these were replaced by the average annual consumption.

In the construction of the application for executing the entire load prediction process allows the user to vary parameters as HYL and others values to give more flexibility to the application.

The input data must be obtained by well proven processes to allow reliable analysis, without forgetting the necessary resolution for each prediction.

Using ArcMap and Python software allows complex spatial analysis in a relatively short time facilitating and implementing the scripts a way of tools.

Python enabled the calculation of the future population through its math library providing more potential for each script and avoiding out calculations.

Besides the construction of the module allows for comparisons between different scenarios by changing certain input parameters such as weights, growth rates, and each new scenario can be viewed later via the GIS.

It suggests the creation of additional modules to normalize load growth and to automatize the presentation of the map.

It is necessary to provide the module capacity to deal with problems such as demand forecasting in empty areas (without initial consumption), the transfer between substations, and the study of errors by frequency analysis.

It is recommended that the analysis of land use will be done in raster format in order to improve response time and optimize the process with adjacency tables.

It is advisable to give the module the capacity to automatically generating concentric circles used to categorize proximity to downtown and growth restriction.

The growth rate was obtained from a commercial linear regression analysis quite simple, if you want to further improve the accuracy of the results this variable should be calculated considering more parameters, something like a reception index commercial.

It is noteworthy that there is no amount of commerce in urban parishes of the city of Cuenca, the information existing is a canton level thus was necessary change the equation (5) through (8).

Results may vary to a large extent based on the weights to be given to each factor, therefore have to choose them properly and carefully before performing a sensitivity analysis.

In the development of the theory was that it was possible to export a geodatabase micro areas of two ways, with each Feature Classes tool to Geodatabase (Multiple) and the other with a loop that uses the tool to Geodatabase Feature Classes (Single), were performed in 2 ways and could see a reduction in processing time from 18 to 4 minutes respectively.

Distribution companies should implement a demand forecasting module that collects the information of GIS system, the information of commercial system and produce consistent information that is unique and comprehensive.

Additionally cadastral information should be completely categorized identifying land uses.

The method implemented land use, predicts with high accuracy the growth of electricity demand, by modeling population growth and calculation of the growth rate of commerce, which considers the influence of various factors: geographic (excluding areas , ground slope, proximity to downtown, degree of growth restriction) and demographic (population saturation or HYL)

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ANNEXES

ANNEX # 1. Script : Population

```
# ---------------------------------------------------------------------------
# poblacion.py
# Created on: 2012-09-01 23:37:48.00000
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy , math

##Pido que el usuario ingrese el valor del radio

a=arcpy.GetParameterAsText(0)
c=arcpy.GetParameterAsText(1)
dt=arcpy.GetParameterAsText(2)
t=arcpy.GetParameterAsText(3)
Cj=arcpy.GetParameterAsText(4)
##Convierto el radio a integer
a=int(a)
c=float(c)
dt=int(dt)
t=int(t)
Cj=float(Cj)
##Utilizo la funcion exp
p=a*math.exp(-math.exp(-c*(t-dt)))
##Visualizo en la ventana interactiva la estimacion de poblacion
print "El valor de la poblacion futura en " + str(t) + " años es : " + str(p) + " habitantes"


# Local variables:
ParroquiaUrbana = arcpy.GetParameterAsText(5)
Expression = p
dissolve_shp = arcpy.GetParameterAsText(6)


# Process: Dissolve
arcpy.Dissolve_management(ParroquiaUrbana, dissolve_shp, "", "", "MULTI_PART", "DISSOLVE_LINES")

# Process: Add Field
arcpy.AddField_management(dissolve_shp, "incr_pob", "DOUBLE", "", "", "", "", "", "NON_REQUIRED", "")
arcpy.AddField_management(dissolve_shp, "creci_com", "DOUBLE", "", "", "", "", "", "NON_REQUIRED", "")

# Process: Calculate Field
arcpy.CalculateField_management(dissolve_shp, "incr_pob", Expression, "PYTHON_9.3", "1")
arcpy.CalculateField_management(dissolve_shp, "creci_com", Cj, "PYTHON_9.3", "1")
```

ANNEX # 2. Script : Areas

```
# ---------------------------------------------------------------------------
# areas.py
# Created on: 2012-09-02 19:05:55.00000
# # Description:
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy


# Local variables:
parr_ur_po = arcpy.GetParameterAsText(0)
Polygon1 = arcpy.GetParameterAsText(1)
Tesis_maestria__2_ = arcpy.GetParameterAsText(2)
tesis_mdb__2_ = "C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb"
n=arcpy.GetParameterAsText(3)
n= int(n)
# Process: Split
arcpy.Split_analysis(parr_ur_po, Polygon1, "Layer", Tesis_maestria__2_, "")



# Local variables:
tesis_mdb = "C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb"

# Process: Feature Class to Feature Class
i=1
while i<=n:
    v1="C:\\Diegol\\Maestria\\Tesis maestria\\"+str(i)+".shp"
    E1="E"+str(i)
    arcpy.FeatureClassToFeatureClass_conversion(v1, tesis_mdb, E1, "",
                                                "incr_pob \"incr_pob\" true true false 19 Double 0 0 ,
                                                First,
                                                #,C:\\Diegol\\Maestria\\Tesis maestria\\1.shp,incr_pob,-1,-1;creci_com \"creci_com\"
                                                true true false 19 Double 0 0 ,First,#,C:\\Diegol\\Maestria\\Tesis maestria\\1.shp,creci_com,-1,-1", "")
    i=i+1
```

ANNEX # 3. Script : Residential

```
# ---------------------------------------------------------------------------
# spatial_join.py
# Created on: 2012-08-27 22:29:18.00000
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy


# Local variables:

residencial = arcpy.GetParameterAsText(0)
E = "C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb\\E"
spatial_joinr = arcpy.GetParameterAsText(1)
n=arcpy.GetParameterAsText(2)
n=int(n)
# Process: Spatial Join
i=1
while i<=n:

    arcpy.SpatialJoin_analysis(E+str(i), residencial, spatial_joinr+str(i), "JOIN_ONE_TO_ONE",
                               "KEEP_COMMON", "AVG_ \"AVG_\" true true false 8 Double 0 0 ,SUM,#,
                               C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb\\residencial,AVG_,-1,-1", "CONTAINS", "", "")
    i=i+1

print "lazo realizado" + str(i)
```

ANNEX #4. Script : Commercial

```
# ---------------------------------------------------------------------------
# spatial_join.py
# Created on: 2012-08-27 22:29:18.00000
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy


# Local variables:



comercial=arcpy.GetParameterAsText(0)
E = "C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb\\E"
spatial_joinrc = arcpy.GetParameterAsText(1)
n=arcpy.GetParameterAsText(2)
n=int(n)


# Process: Spatial Join
i=1
while i<=n:

    arcpy.SpatialJoin_analysis(E+str(i),comercial, spatial_joinrc+str(i),
                               "JOIN_ONE_TO_ONE", "KEEP_COMMON", "AVG_ \"AVG_\" true true false 8 Double 0 0 ,SUM,#,
                               C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb\\comercial,AVG_,-1,-1", "CONTAINS", "", "")
    i=i+1

print "lazo realizado" + str(i)
```

ANNEX # 5. Script : Land Use

```
# ---------------------------------------------------------------------------
# uso_suelo.py
# Created on: 2012-09-03 12:56:14.00000
# Description:
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# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy


# Local variables:
E1 = "C:\\Diegol\\Maestria\\Tesis maestria\\tesis.mdb\\E"
SIGCART_Cuenca_Manzanas_1 = "C:\\Diegol\\Maestria\\Tesis maestria\\usos_suelo.mdb\\SIGCART_Cuenca_Manzanas_1"
uso_suelo = "C:\\Diegol\\Maestria\\Tesis maestria\\uso_suelo.shp"
pendiente_mayor50_shp = "C:\\Diegol\\Maestria\\Tesis maestria\\pendiente_mayor50.shp"


clip_sal = "C:\\Diegol\\Maestria\\Tesis maestria\\usos_suelo.mdb\\clip_sal"
erase = "C:\\Diegol\\Maestria\\Tesis maestria\\usos_suelo.mdb\\erase"
erasef = "C:\\Diegol\\Maestria\\Tesis maestria\\usos_suelo.mdb\\erasef"


i=1
while i<=113:
# Process: Clip
    arcpy.Clip_analysis(E1+str(i), SIGCART_Cuenca_Manzanas_1, clip_sal+str(i), "")

# Process: Erase
    arcpy.Erase_analysis(clip_sal+str(i), uso_suelo, erase+str(i), "")

# Process: Erase (2)
    arcpy.Erase_analysis(erase+str(i), pendiente_mayor50_shp, erasef+str(i), "")

# Process: Join Field
    arcpy.JoinField_management(E1+str(i), "OBJECTID", erasef+str(i), "OBJECTID", "Shape_Area")

# Process: Add Field
    arcpy.AddField_management(E1+str(i), "Porcentaje", "DOUBLE", "6", "2", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field
    arcpy.CalculateField_management(E1+str(i), "Porcentaje", "12*[Shape_Area_1] /1000000", "VB", "")

    i=i+1
```