

Predicting Future Urban Growth Limits Using ArcView Desktop GIS Software

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ABSTRACT: Urban economics dictate that cities must grow to maintain their vitality. Small cities increase their population and economic base, thereby expanding their city limits. Large cities manage growth so that expansion is controlled, avoiding real estate and economic depressions. Former Albuquerque Mayor David Rusk argues in Cities Without Suburbs that cities with aggressive growth strategies prosper while land locked cities lose vitality, economic base and eventually, population. The City of Madison, Wisconsin is on the threshold of being prohibited from growing by its' neighbors. Using ArcView software, an "Annexation Potential" formula was developed to identify and analyze growth limits, generating an Ultimate Growth Area map.

INTRODUCTION

My colleagues and I have often remarked while discussing topical planning issues facing our municipality that it is now possible to envision the ultimate growth limits of our city. Urban economics dictate that cities must grow to maintain their vitality. Small cities concentrate upon increasing their economic (commercial and industrial) base and population (housing stock) thereby necessitating expansion of the city limits. Large cities focus upon managing their growth so that they do not expand too fast or too far which could create real estate and economic depressions (Eldredge, 1967, pg. 157-166). In his book Cities Without Suburbs, David Rusk (1993) puts forth an argument that cities which have an open, aggressive annexation policy grow and prosper whereas those cities which are "hemmed in" by incorporated suburbs or lack the political and legal tools to expand their boundaries in response to internal needs presented by their citizens become stagnant and lose vitality, economic base and eventually, population

City of Madison Development Plans

The City of Madison, Wisconsin adopted their Peripheral Area Development Plan in 1990 to address these issues. This plan states in part:

- X *Madison's need to plan for future urban development and long-term city growth begins with the expectation of continued employment, population and housing increases in the Dane County region;*
- X *Most of this increase will be accommodated through growth of the regions cities and villages; and*
- X *The City of Madison expects to continue to have a significant share of regional and Urban Area economic and residential growth.*

Indeed, City of Madison policy makers have publicly stated concerns on numerous occasions when considering annexation petitions or potential growth limiting exurban developments that the City of Madison may, some day, become surrounded by incorporated municipalities similar to Milwaukee and other cities. This presents a public policy and planning dilemma: cities need to grow and expand to preserve their vitality and economic well being while environmental concerns and urban sprawl control seem to call for strict growth

limits. Local political policy makers need to more actively explore the possibility that their city may be on the verge of becoming, in Rusk's words, "inelastic."

Urban Growth Patterns

The disciplines of geography, sociology, urban planning, architecture and landscape architecture have long evaluated urban form and function. The pattern, function and expansion of urban environments has been studied and articulated for many centuries. In its historic context, these views typically centered on socioeconomic ills, strategies to promote new urban growth and design of an aesthetic, functional urban form. Writings discussing the ramifications of urban growth and suggesting methodology to control this process are a relatively recent phenomena. It wasn't until the mid 1960's that environmentalists, planners, architects, landscape architects and sociologists began to understand the ongoing pattern of urban growth. The emergence of computer technology and sophisticated geographic analysis software has fostered a new methodology toward studying urban form. Approaches to the study and analysis of growth management issues using Geographic Information Systems are very limited. The techniques proposed by McHarg are the foundation for suitability analysis, analytic overlay and theme-on-theme selection processes. Numerous texts describe the technical process of GIS analysis, however the literature is singularly lacking in the application of Geographic Information System techniques for the study and prediction of future urban growth boundaries.

Predicting Growth

It is now possible, within the context of the existing geographic, environmental, legal, and political framework extant in Dane County, Wisconsin to predict, with some certainty, the potential future growth boundaries of the City of Madison and to forecast when growth thresholds will likely be reached. Drawing upon this author's background knowledge as a city planner, prediction of this ultimate growth boundary can be accomplished utilizing ArcView 3.2 Desktop Geographic Information System software and spatial analysis techniques. The variables necessary to perform this analysis were available in digital format.

The implications of this issue also emerge from the literature. Failure to manage our resources in a climate of population expansion and continued conversion of farm land, woodlands, wetlands and open spaces to urbanized land uses will likely lead to severe environmental impacts. Ian McHarg (*Design With Nature*, 1969), Rachel Carson (*Silent Spring*, 1962) and a legion of environmentalists following have expounded on the fallacy of uncontrolled urban sprawl upon the carrying capacity of the land. In contrast, David Rusk, Douglas Porter (*Managing Growth in America's Communities*, 1997), Jonathan Barnett (*The Fractured Metropolis*, 1995), and others continue to analyze the urban environment and warn that strict controls on urban growth may have other severe repercussions. Rusk goes so far as to assert, through his studies, that a City which is constricted to the point of no outward growth will actually start to decay (Rusk, 1993, pp. 17, 34, 44, and 74).

It is hoped that by identifying and analyzing annexation factors and city growth,

policy makers can be made aware of the possibility that an existing, growing and flexible urban environment (the City of Madison, Wisconsin) could eventually become entirely surrounded by other incorporated municipalities and ultimately become an “inelastic city.” The ultimate question is, perhaps: *When will this growth boundary be reached?*

Purpose of the Study

An application was devised wherein ArcView 3.2 Desktop Geographic Information System software and spatial analysis techniques were employed to test the assumption that the future urban boundaries of the City of Madison could be predicted. The objective of this study was to:

Identify the factors that affect physical growth boundaries of a city given existing municipal growth, urban development patterns, environmental or geographical constraints, and political processes and apply these factors to the City of Madison, Wisconsin.

BACKGROUND

Annexation Process

The City of Madison is located in the geographic center of Dane County. Municipal expansion radiates from the existing urbanized center, given the constraints of geography (lakes) and other political subdivisions (existing, surrounding incorporated municipalities) Other incorporated cities and villages are located between Madison and the county boundary (see Figure 1). The location of these other incorporated municipalities also limit potential city growth.

The legal process of annexation is discussed in most land use planning texts. The forces and decisions which result in any particular land owner seeking annexation of their property to a specific city or village, however is not discussed in these texts. To best understand these forces so that they may be properly reflected in the computer analysis proposed by this study, other professional planning staff from the City of Madison with expertise in the processing of annexation petitions were consulted. Various rules and guidelines emerged:

- X Annexation petitions must be presented by a private land owner who requests annexation to the municipality;
- X Only those properties that are in unincorporated townships may be annexed to an incorporated municipality;
- X Annexation areas must be contiguous to the existing limits of the annexing municipality;
- X Large rivers and lakes are “neutral” in annexations, but inhibit, rather than contribute to annexation possibility;
- X Property owned by a public agency is also “neutral” but would not encourage an annexation;
- X The form of ownership (private individual residing on the property vs. Corporate or business ownership) and the short- and long-term intent of the owner is a factor in the possibility of a parcel being petitioned for annexation (known as “Land Tenure”);
- X Most annexations involve “undeveloped” tracts of land approximately 10 acres in size or

greater;

- X Small tracts approximately 5 acres or less already occupied by an “urban” land use are resistant to annexation;
- X Property located within a statutorily authorized extraterritorial review jurisdiction surrounding incorporated cities and villages is more likely to be developed within the corporate limits of the nearby city or village than those properties which are not included within these review jurisdictions;
- X Intergovernmental agreements between adjacent or nearby communities have established growth limits or boundaries in some areas;
- X Property within Open Space Corridors, like water bodies, do not usually actively participate in annexation requests due to the severe limitations on their ability to be converted to urban land uses; and
- X Property within existing Urban Service Areas (authorizing municipal water and sewer services) are more likely to request annexation (to avail themselves of these services) than those not in these service areas.

In order to properly reflect the above stated criteria, the basic electronic data layers (themes) necessary to accomplish the analysis portion of this project were identified:

- X Existing municipal limits;
- X Water features;
- X County parcels in unincorporated townships;
- X Property ownership;
- X Land tenure;
- X Existing development patterns;
- X Extraterritorial limits;
- X Inter-governmental agreement boundaries;
- X Existing open space corridors;
- X Urban Service Areas; and, for a general reference framework,
- X Street center lines.

The above data layers, obtained from a variety of sources and geographically referenced to a common datum, would allow the analysis to be performed resulting in a clear picture of the potential ultimate municipal limits of the City of Madison under the current legal, geographic and political frameworks.

Physical and Cultural Geography

The City of Madison is located in the geographic center of Dane County, Wisconsin. Dane County consists of approximately 1240 square miles, over all. Approximately 10 square miles are contained within lakes and rivers. The remaining 786,821 acres (1229.4 sq. mi.) are undeveloped or devoted to various rural and urban land uses. The City of Madison currently contains approximately 44,015 acres (68.77 sq. mi.) within its corporate limits. Current population estimates (as of January 1, 1999) for Dane County are 413,090 and the City of Madison 205,343 (49.7% of county residents). This contrasts with previous years:

X 1970 - County: 290,272 / City: 171,769 = 59.2%;

X 1980 - County: 323,545 / City: 170,616 = 52.7%;

X 1990 - County: 367,085 / City: 190,766 = 52.0%

As one can see, the percentage of total Dane County population located within the City of Madison is declining. Due to annexation and new urban development within the city limits, the density of the City of Madison has remained relatively constant from 1960 through to the present, fluctuating from a high of 3542 persons per square mile in 1970 to a low of 3044 persons per square mile in 1999. Population projections through the year 2020 were obtained from the State of Wisconsin Department of Administration, Demographic Services Center. Table 1 and Graph 1 depict these trends and can be found in Appendix B.

There are 60 municipalities in Dane County. This includes 34 unincorporated townships, 19 villages and 7 cities, including Madison. Population growth of the other six incorporated cities located in Dane County has increased from 41,775 in 1970 to 79,447 in 1999, a 90.7% increase. Village population has increased in this same time period from 24,790 to 54,273, a 118.9% increase. The total township population has gone from 51,700 in 1970 to 74,027 in 1999, a 43.2% increase. In contrast, the City of Madison has had a population change from 171,769 in 1970 to 205,343 in 1999, for a relatively modest 19.4% increase. The area contained within the City of Madison corporate limits has increased from 48.5 square miles in 1970 to 67.46 square miles in 1999, keeping pace with the population growth as illustrated in Table 1 by the population density comparisons.

The City of Madison has contiguous corporate limits with the townships of Westport, Burke, Middleton, Madison, Blooming Grove, Cottage Grove, and Verona; villages of Shorewood Hills, Maple Bluff and McFarland; and cities of Middleton, Sun Prairie, Monona, Verona and Fitchburg. Abutting and nearby limits of other incorporated municipalities are clearly firm growth limitations, since one municipality cannot grow into another incorporated municipality.

Growth Limitations

Two categories of growth limitations may be identified. Physical growth limitations are those which may be seen in the landscape such as rivers and lakes, those which may be readily identified on a map such as municipal limits, or defined by land use such as public lands and open space corridors. Functional growth limitations are those which are imposed on municipalities by statutes, by themselves, or by others. These limitations include boundaries such as extraterritorial limits or confinements due to the use and ownership of land such as tenure and existing development patterns.

Physical growth limitations may be broadly classified as having “hard” boundaries or “soft” boundaries. Hard boundaries include adjacent limits of other incorporated municipalities and significant water features. Other than an occasional exchange of land between municipalities, one city or village may not annex another incorporated area. Major water bodies impose similar constraints. It is possible to annex lands across a small river or stream, however major rivers or lakes can pose a boundary which is difficult or impossible to bridge over in an annexation.

Soft physical growth boundaries include lands which may be difficult to include or cross over in an annexation, but which may vary considerably in breadth, function or tenure and therefore do not impose strict limitations. These boundaries include public lands (parks or natural resource areas); mapped environmental corridors (e.g.: woodlands, wetlands, flood plains, proposed parklands); mapped easements or public features (such as the proposed Ice Age Trail); and utility infrastructure (e.g.: pipelines and high tension electric lines).

Functional growth limitations also contain hard boundaries and soft boundaries. Hard boundaries consist of urban development rights and limitations which may be granted by statute or imposed by negotiated agreement. These include extra-territorial limits, inter-governmental agreement boundaries, and authorized urban service areas.

Soft functional growth boundaries include regions within which urban services may be confined or where the existing development patterns or ownership forms may inhibit annexation by an incorporated municipality. These areas are not especially difficult to include or cross over in an annexation, but due to their variation in breadth, function or tenure may impose some limitation to a municipalities ability to effectuate an annexation. These soft functional boundaries include land ownership and tenure and existing development patterns, where small parcels owned by individual owner occupants who may not wish to participate in an annexation may have an effect upon the configuration of annexed areas.

METHODOLOGY

The following is a discussion of how the annexation process may be evaluated using the identified data sets. A series of factors and weighted values (criteria) were assigned to each parcel within each feature type (thematic layer). The criteria assigned to each feature type are identified in Table 2 (see pg. 10).

Project Data Sets

The basic evaluation units of this project are a set of Dane County ownership parcels which are located outside of any current incorporated municipality. A sequence of observations were made of these parcels to categorize their ability to be annexed to the City of Madison dependent upon the criteria reflected in the remaining data sets.

Parcels

This is a county-wide data set identifying all ownership/tax parcels in the unincorporated areas of Dane County. It is these lands that may possibly be annexed to a municipality. Parcels within existing incorporated municipalities are only rarely transferred from one municipality to another and are not part of this study. Other data sets will also be created as subsets of this data as described below. (See Figure 2).

Nine data layers have been identified which contribute to the process of municipal growth (see above for a discussion of selection criteria). These data sets are:

Existing municipal limits. This is a county-wide data set identifying the corporate limits of all municipalities in Dane County. This data set displays the limits of all 60 Dane County Municipalities. (See Figure 3).

Water Features. This is a county-wide data set identifying all navigable and secondary

waterways. Additional work was done to extract the Wisconsin and Yahara River corridors from the original parcel data set for this layer. (See Figure 3).

Public Lands. Property owned by public agencies, especially large tracts for hunting, parks, conservancy and open space pose impediments to annexation. While public agencies do not actively oppose annexation, they are not willing participants. Annexation petitions must be presented by the majority of electors living in the annexation area or by the majority of land owners in area. Non-participation by a large land holding may likely influence the configuration of annexation areas. (See Figure 4).

Significant Existing Corridors. This feature class may take a variety of forms, but all major corridors have a growth limiting effect, much like lakes and rivers. It is difficult to bridge or “jump” a significant corridor unless the property owner(s) wish to participate in an annexation petition. In Dane County, these corridors include the Interstate Highway System, the Ice Age Trail, the Nine Springs E-Way and the upper Yahara River and Cherokee Marsh. Streets, roads and highways are considered “neutral” for area calculations in annexation review so those corridors have not been included in this research project. Transportation corridors do impose psychological barriers to municipal growth, but the City of Madison has already bridged the “Beltline” Highway along the city’s south and west sides and the Interstate Highway corridor on the east side. (See Figure 5).

Extraterritorial Limits. State Statutes have granted municipalities review powers over zoning and subdivision activity occurring within close proximity of their borders. Villages (including 4th class cities) may exercise these review powers within one and one-half mile of their borders and cities (of the 1st, 2nd and 3rd class) within three miles of their borders. As cities grow, these limits are reviewed and adjusted from time to time. In the case of Dane County, the Regional Planning Commission reviews and establishes the specific location of these extraterritorial limits. Extraterritorial limits are exclusive and may not overlap). This boundary has the effect of limiting development within the jurisdictional limits, thereby encouraging annexation prior to development. In contrast this boundary also allows rural subdivisions to occur outside these limits without nearby city review. The result of this exurban development has often resulted in resistance of the small tract owners to future annexations. This jurisdictional limit is considered a “hard” boundary to future urban growth. (See Figure 6).

Intergovernmental Agreement Boundaries. The city of Madison has entered into a number of agreements with adjacent municipalities regarding development review, future growth boundaries, annexation activity and subdivision review. These agreements have the effect of inhibiting future growth in certain areas and may also outright assign some designated future growth areas to other municipalities. These documents are enforceable and legally binding and will, therefore, impose growth limits upon all ratifying parties. These agreements will have a limiting effect on municipal growth and have been designated a “hard” growth boundary. (See Figure 7).

Urban Service Areas. One of the basic urban services that an incorporated municipality has to offer is that of municipal sewer service. Public health and safety are closely tied to modern and efficient waste disposal systems. A popular urban growth

management tool has been the extension (or withholding) of municipal sewer and water services. Enticements for annexation to property owners or developers often centers around availability of these basic urban services. The availability of these services is regulated by the Regional Planning Commission via Urban Service Areas. The City of Madison and its urban area are included in the Central Urban Service Area and other municipalities in various other urban service areas. These approved development areas will also tend to channel urban development to their service areas and limit urban growth within their boundaries. These districts are considered somewhat firm growth limitation factors, similar to extraterritorial review limits. (See Figure 8).

Land Tenure. This term refers to how land is owned and used, including long term land use intentions. It was assumed (based upon long standing experience) that woodlands, wetlands, public and private open space, farm lands and any privately owned lands in excess of 10 acres would be able to be annexed for urban development purposes. This data is a part of the tabular data attached to the parcels data layer. For the purpose of this study, a land tenure data layer was prepared by extracting all the above items from the parcel layer. (See Figure 9).

Existing Development Pattern. Lands previously subdivided into small tracts, typically ranging from 1 to 5 acres in size, are usually very difficult for a municipality to annex due to the resistance of the owners or occupants. These parcels were extracted from the parcel data layer. A new data set was created from these parcels, reflecting areas resistant to annexation as a “soft” boundary. (See Figure 10).

These nine data layers interfaced with the parcels data layer in an analytic overlay process using theme-on-theme selection. This enabled the operator to observe coincident and naturally occurring municipal growth limits. One additional data set was also obtained for this project:

Street Center lines. In order to provide a logical and complete reference framework for these various data sets and a contextual reference for each map prepared, a county-wide street centerline layer was utilized. This data set was derived from a combination of a county-wide street centerline map and a comprehensive street centerline file for the central city area from the City of Madison. (See Figures 2 through 10).

Structure of the Analysis

The analysis portion of this project was performed utilizing ArcView 3.2 software, without extensions. The primary ArcView capability to be employed for this analysis was theme-on-theme selection. This process allows the operator to extract elements which are common to both data sets, or it may also be utilized to identify data which may be unique to only one data set, thereby eliminating potentially extraneous data in the other data set. Queries associated with the theme-on-theme selection procedure utilize Boolean logic operators such as “and”, “or”, “not”, “equal to”, “greater than”, and so forth. Queries may be ordered and data subsets created to facilitate the selection process. A discussion of the selection process used to create each data set employed in this project follows.

Observation Process

The effect of these nine attributes upon each parcel were observed and the cumulative values from these observations recorded in the parcels data table to enable the operator to observe coincident and naturally occurring municipal growth limits. The “hard” boundaries were evaluated first since they pose a significant barrier to annexation. The second set of observations involved the physical growth limitation “soft” boundaries. These reflected publicly owned lands and Ice Age Trail and other open space corridors. The third set of observations involved the functional growth limitation “hard” boundaries. These included extraterritorial review limits, existing inter-governmental agreement boundaries, and Urban Service Areas. The final set of observations involved the functional growth limitation “soft” boundaries. These constitute privately owned parcels in excess of 10 acres, small lot individual ownership parcels (those less than 5 acres in size) and rural subdivisions.

Evaluation Criteria

In order to quantify the effect of these somewhat varied growth limitation factors, an evaluation system was established to reflect the appropriate influence each layer imposed upon the aggregate growth limitation boundaries. As previously discussed, the hard physical growth limitations (other municipalities and lakes and rivers) were removed from the parcels file prior to the evaluation process. All parcels with these growth limitations were assigned a factor of 0 (zero). This effectively removed them from influencing the remaining parcels (resulting in a zero total value). All other parcels received a factor of 1 (one).

The physical soft boundary limitations (Public Lands and Open Space Corridors) were assigned a factor of 1 (one) if the parcel was within the identified data set and a factor of 2 (two) if not. It was decided to apply a multiplicative factor to the above physical criteria to represent the inclusion/exclusion nature of these criteria. These multiplicative factors either eliminate the items from consideration (zero), include them in the data set without influence (one), or enhance their weight as probable contributors (two).

Functional growth limitations were defined as having an additive influence to reflect their incremental contribution to the overall possibility of annexation. A value range of 0 to 7 was chosen to represent the relative range of annexation possibility for each feature class. This range was chosen by initially identifying the five general categories of annexation possibility (see list below). Incremental values were then assigned to these categories. A value of 0 (zero) represents parcels which are not likely to be annexed under any circumstances and values of 1, 3, 5, and 7 represent the next four categories in ascending order of annexation possibility. These initial additive increments are listed below:

Very Low Possibility to be Annexed =	0
Low Possibility to be Annexed =	1
Minimum Possibility to be Annexed =	3
High Possibility to be Annexed =	5
Very High Possibility to be Annexed =	7

After a review of these values, consideration of the relative weights assigned to the categories and sample testing (by hand calculation) of various potential observation results, it was decided to amend these values to more accurately reflect their proportional contribution to the annexation process. For example, a parcel within, say, the extraterritorial limits of the City of Madison (a very high possibility, value = 7) was considered to be slightly more than twice as likely to be annexed than a parcel lying outside all municipal extraterritorial limits (a minimum possibility, value = 3), so the final value ranges were determined to be 0 (for a parcel within another municipalities extraterritorial limits), 3, or 7.

For the soft boundary functional limitation categories (private lands of various sizes), a similar exercise was applied. Public lands received a value of 0 (zero) indicating a very low possibility of annexation, private lands less than 5 acres received a value of 1 indicating a low possibility of annexation and private lands in excess of 10 acres received a value of 3 indicating a minimum possibility of annexation. Those privately owned parcels between 5 and 10 acres in size received a relative value of 2.

To help illustrate the possible variables resulting from observations utilizing this evaluation system, a matrix of criteria and values is shown below in Table 2. Physical growth limitations establish factors of annexation potential. Functional growth limitations establish a gradation of annexation possibility.

Table 2					
Evaluation Criteria Matrix					
<u>Boundary Type</u>	<u>Growth Limitation</u>				
	Physical	Value	Functional	Value	
Incorporated Municipality	Yes	0	Extraterritorial Limits	Within Madison	7
	No	1		Outside All	3
Hard	Lakes and Rivers	Yes	Intergov't Agreements	Within Madison	7
				No	2
Soft	Public Lands	Yes	Private Land > 10 Acres	Within Other	0
		No		2	Within Madison
Soft	Open Space Corridor	Yes	Private Land < 5 Acres	Within Other	0
				No	1
Soft	Open Space Corridor	Yes	Private Land > 5 < 10 Acres	No	0
		No		2	Yes
				No	0

The evaluation totals (which are translated to “Annexation Potential” in the final analysis) are calculated thus:

$$\text{Evaluation Total} = [(\text{Incorporated Municipality}) * (\text{Lake or River}) * (\text{Public Lands}) * (\text{Open Space Corridor})] * [(\text{Extraterritorial Limits}) + (\text{Intergov't Agreements}) + (\text{Urban Service Areas}) + (\text{Private Land Acre Value})]$$

The maximum Evaluation Total would be calculated thus:

Incorporated Municipality?	No = 1
Lake or River?	No = 1
Public Lands?	No = 2
Open Space Corridor?	No = 2
Extraterritorial Limits?	Within Madison = 7
Intergov't Agreements?	Within Madison = 7
Urban Service Areas	Within Madison = 7
Private Land > 10 Acres	Yes = 3

Therefore: $[1 \times 1 \times 2 \times 2 \times (7 + 7 + 7 + 3)] = 96$

The minimum Evaluation Total (not being zero) would be calculated thus:

Incorporated Municipality?	No = 1
Lake or River?	No = 1
Public Lands?	Yes = 1
Open Space Corridor?	Yes = 1
Extraterritorial Limits?	Within Other = 0
Intergov't Agreements?	Within Other = 0
Urban Service Areas	Within Other = 0
Private Land < 5 Acres	Yes = 1

Therefore: $[1 \times 1 \times 1 \times 1 \times (0 + 0 + 0 + 1)] = 1$

Evaluation Summary

After all nine observations have been completed, a computation of the values (see above) indicates the possibility of each parcel to be annexed to the City of Madison. The functional growth limitation values are summed and then this subtotal is multiplied by the physical growth limitation factors (see above examples). The resultant evaluation total is the Annexation Potential quotient for each parcel.

ANALYSIS OF THE DATA

The initial step in the analysis phase of this project was the preparation of the parcels data set. The Dane County parcel file, as received, contained 122,275 polygons and fifty seven data fields for each polygon. This file consisted of all county parcels plus roadways, lakes, rivers and streams. In addition, all cities and villages were included except municipalities within the “core” urban area. It was considered desirable to reduce this data set to a more manageable size and scope for this project. First, twenty four extraneous fields in the data table were eliminated to reduce processing time and file size. The table now had thirty three fields of data to assist in further analysis. Next, the polygon data set was “cleaned up” by removing sliver polygons and major lakes and rivers. Two new themes containing lakes and rivers were created from the removed polygons for display purposes in the presentation maps.

The next step was the removal from the data set of all parcels which were within the

boundaries of any incorporated municipality. It was desired to reduce the data set to a practical minimum for computer processing time and since it is not possible to annex any parcels located within another incorporated municipality, they could be removed from the potentially annexed parcels at the outset. This removal is reflected by a factor of 0 (zero) being assigned to these data layers (see Table 2). The resultant data set comprised 94,561 polygons and is illustrated in Figure 2. All ensuing parcel-based data subsets (i.e. Public lands, Private lands greater than 10 acres and Private lands less than 5 acres) were derived from this parcels file.

Observation Coding

To accommodate the recording of the observation values as described in the Evaluation Criteria section, eight fields were added to the parcels data table to enable the proper value to be entered for each observation. Values were entered into the data table using the “Calculate” utility provided within the ArcView software. This process is described below. All parcels meeting the appropriate observation criteria were selected using one of the select-by-theme processes. The observational value was then entered into the appropriate data field of the data table for the selected parcels only using the ArcView “Calculate” utility. Random visual checks of the input values were performed to maintain selection and measurement reliability at each step in the observation process. After all observational sequences had been performed, the evaluation criteria were aggregated as shown following the Evaluation Criteria Matrix (Table 2). A flow chart of this process appears on page 13.

Observation Evaluation

After all observations were performed, a ninth data field was added to the parcels data table. This field was created to accept the final “evaluation total” calculation. The “Calculate” utility was programmed to mathematically add the observation value contained in each Functional Growth Limitation category (Extraterritorial limits, Intergovernmental Agreements, Urban Service Areas, Private Land greater than 10 acres, Private Land less than 5 acres, and Private Land between 5 and 10 acres) and then multiply this subtotal by the factors contained in each Physical Growth Limitation category (Public Lands and Open Space Corridors), as described in the Evaluation Criteria section.

This evaluation total was calculated for each parcel to give an overall “Annexation Possibility” quotient. These quotients range from a low of 0 to a high of 96. The calculated arithmetic mean is 29.6, the median is 32, and the standard deviation is 15.0. A map illustrating the “Annexation Possibility” values, summarized from the evaluation totals (see Table 4), will be found in Figure 12.

RESULTS

The first step in interpreting the evaluation totals for the subjects was to define the parameters for classifying the evaluation criteria. Individual criteria for rating each observation as noted in the Evaluation Criteria section (see pg. 9) are: Very low possibility to be annexed, Low possibility to be annexed, Minimum possibility to be annexed, High possibility to be

annexed, and Very high possibility to be annexed. These criteria categories were adjusted to reflect the evaluation quotient totals for each parcel to give meaningful classifications to the final evaluation totals.

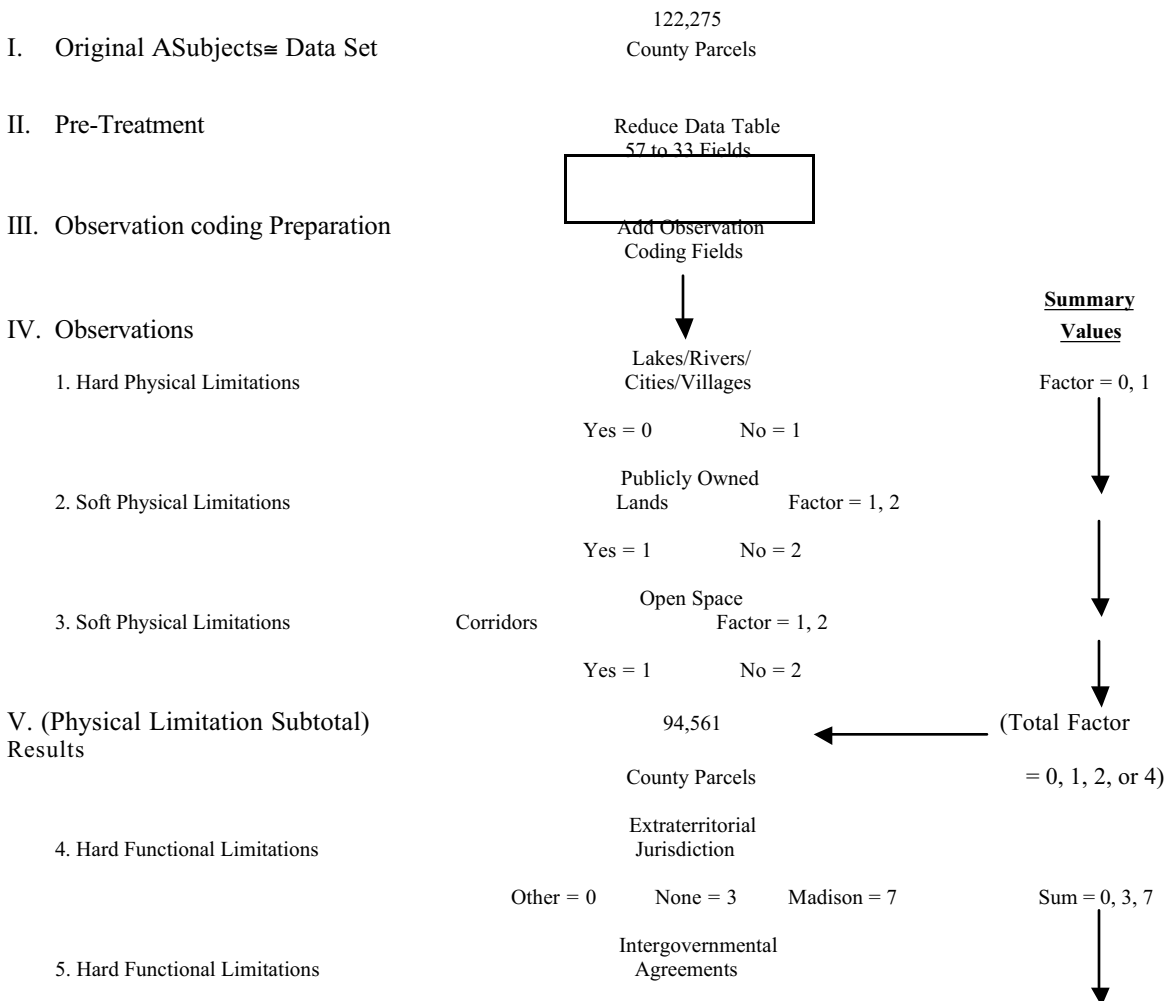
Evaluation Quotient Totals

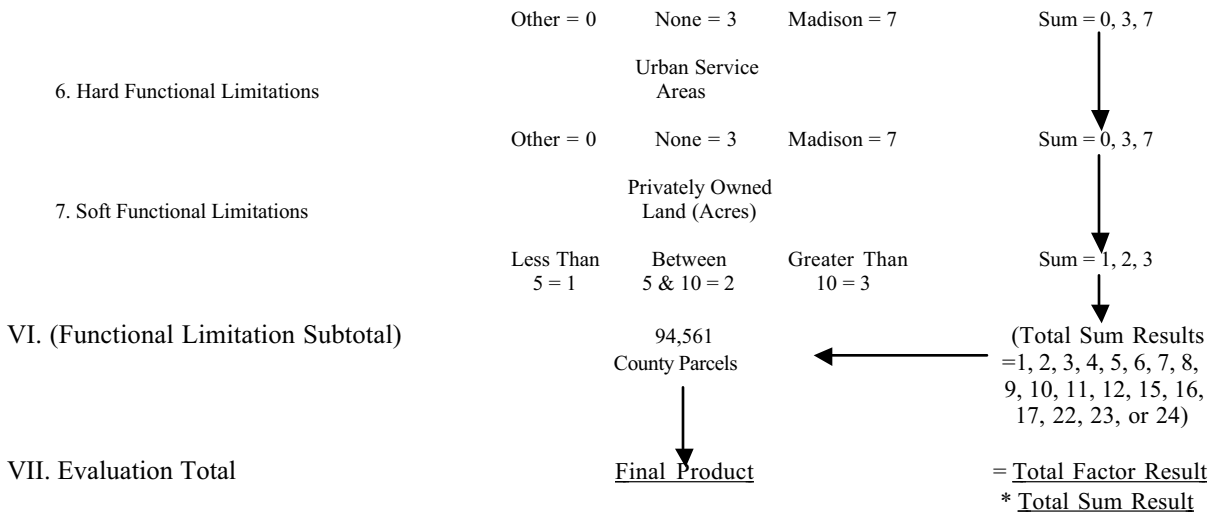
After a review of the evaluation total data, it became apparent that the simple data classification systems provided within the ArcView software (e.g. equal area, equal interval, normalized, quantiles, etc.) would not provide useful results. Two of the classification systems available in the ArcView software did provide acceptable data distributions. These were natural breaks and standard deviations.

Natural breaks are calculated using a statistical formula called Jenk’s optimization. This process attempts to minimize the statistical variance within each of the categories chosen by the researcher (in this case, seven initial categories). The results using this method tend to group the “middle” ranges where there are typically few large value changes and to separate the outliers. Category boundaries are usually placed where large groupings occur,

Chart 1

Observation Coding Flowchart





where discernable patterns emerge, or where there are significant changes in the values.

Standard deviations reflect the value changes relative to the calculated arithmetic mean. This classification system also separates the outliers, but it tends to group the middle range values without regard to valuation changes or clusters. Data grouping tends to be “smoother” utilizing this method since classes are more uniform than the natural breaks method. This system usually works well with larger data sets.

The advantage of these two systems provided within the software is that they minimize the tendency to distribute data evenly (even if it is grouped or clustered) and they recognize the strength of the data at each end of the range. Both characteristics are very important for this project. The initially posed question was to identify the characteristics that will lead to a possibility of annexation to the City of Madison and to evaluate the degree to which the parcels exhibit those characteristics. The qualifying parcels will be those with a larger evaluation total. Both classification systems display this trait well. A review of the data distribution shows that while there is a relatively broad overall distribution to the data, there are significant data peaks, valleys, clusters, and groupings. (See Table 3 and Graph 2).

The data distribution was visually analyzed prior to making a definitive choice for the classification system. Both software provided systems seemed to give a realistic presentation of the data, however the natural breaks method recognizes the peaks, valleys, and data clusters better than the standard deviation system, so this method was ultimately chosen.

For these reasons (data distribution and classification), seven categories were initially chosen to display the natural breaks for the final annexation quotient data. The computer software was first allowed to choose the seven classification thresholds. These seven classifications represented three categories of low possibility, one category of less than the minimum possibility, and three categories of high possibility. It was then decided to collapse the three low and one less than minimum category into two categories identified as low and very low possibility. The focus of this project is to identify the parcels that *may* be annexed, so the three “possible” categories are of most interest. The five chosen final categories are:

Very Low Possibility to be Annexed



Low Possibility to be Annexed
 Minimum Possibility to be Annexed
 High Possibility to be Annexed
 Very High Possibility to be Annexed

Refining the Classification Categories

Thresholds for each of the above categories were refined from the classification thresholds initially identified by the software by calculating which combinations of the individual annexation criteria values (see Table 2) would be required to achieve an aggregate evaluation total to fit within the final annexation quotient categories. For example, if a parcel was publicly owned (factor = 1), was located within an open space corridor (factor = 1), was located within another municipalities= extraterritorial limits (sum = 0), was located within another municipalities= intergovernmental boundaries (sum = 0), was located within another municipalities= Urban Service Area (sum = 0), and was not privately owned (sum = 0), then it would exhibit a very low possibility to be annexed to the City of Madison. This evaluation quotient would be calculated as: $[1 \times 1 \times (0 + 0 + 0 + 0)] = 0$, the lowest possible quotient.

Conversely, if a parcel was not public land (factor = 2), was not located within an open space corridor (factor = 2); was located within Madison=s extraterritorial limits (sum = 7), was located within Madison=s intergovernmental boundaries (sum = 7), was located within Madison=s Urban Service Area (sum = 7), and was privately owned and in excess of 10 acres (sum = 3), then it would exhibit a very high possibility to be annexed to the City of Madison. This evaluation quotient would be calculated as: $[2 \times 2 \times (7 + 7 + 7 + 3)] = 96$, the highest possible quotient.

Finally, if a parcel was not public land (factor = 2), was not located within an open space corridor (factor = 2); was located within either Madison=s extraterritorial limits, within one of Madison=s intergovernmental boundaries, or within Madison=s Urban Service Area (total sum = 7), and was privately owned and in excess of 10 acres (sum = 3), then it would just meet the minimum possibility to be annexed to the City of Madison. This evaluation quotient would be calculated as: $[2 \times 2 \times (7 + (0) + (0) + 3)] = 40$, the minimum quotient considered possible to be annexed. All possible evaluation quotient values and their number of occurrences (counts) are illustrated in Table 3.

Table 4

Annexation Quotient Matrix Evaluation Totals

<u>Annexation Possibility</u>	<u>Physical Factors</u>		<u>Functional Totals</u>		<u>Evaluation Total</u>		<u>Parcel Count</u>
	<u>Hard</u>	<u>Soft</u>	<u>Hard</u>	<u>Soft</u>	<u>Min</u>	<u>Max</u>	
Very Low Possibility to be Annexed	1	1	0	0	0	27	32269
Low Possibility to be Annexed	1	2	13	1	28	39	53183
Minimum Possibility to be Annexed	1	4	7	3	40	51	2483
High Possibility to be Annexed	1	4	10	3	52	79	4961

Very High Possibility to be Annexed 1 4 17 3 8

Note: Above individual Annexation Quotient values for physical and functional limits are the minimum for each category

From Table 4 the summary totals for calculating the minimum evaluation total thresholds may be observed. For example, the minimum value for subjects classified as “High Possibility to be Annexed” is: $[1 \times 4 \times (7 + 3 + 0 + 3)] = 52$. Maximum thresholds are defined by the next higher minimum value. The evaluation total ranges have an average of eight individual value calculation totals. Clearly, a range of combinations of observational values exist for each parcel.

In summary, a quotient value of 80 or greater is considered a very high possibility to be annexed to the City of Madison. A quotient value of 52 to 79 is considered a high possibility that it would be ultimately annexed to the City of Madison. A quotient value of 40 to 51 is the minimum to be considered possible for annexation to the City of Madison. A quotient value of 20 to 39 is considered a low possibility to be annexed to the City of Madison. A quotient value of less than 20 is considered a very low possibility for annexation to the City of Madison. A map illustrating these Annexation Possibility categories will be found in Figure 12.

Interpreting the Results

An examination of this Annexation Possibility map reveals the following: Parcels exhibiting very high possibility, high possibility and minimum possibility to be annexed are in close proximity to the existing city limits and that those with very high possibility to be annexed are closest, those with a high possibility next farthest, and those exceeding the minimum possibility farther yet with few exceptions, even though proximity or distance from the city limits was not a criteria in this project. This stratification of the nearby parcels in the “higher possibility” annexation categories helps to confirm the internal and ~~external validity of this project. It should also be noted that there are parcels located along the~~ westerly, northwesterly, and northerly shore of Lake Mendota which are beyond other existing municipalities, are located across the lake from the City of Madison, and are beyond parcels that are classified as low possibility or very low possibility to be annexed which resulted in a classification of at least the minimum possibility to be annexed.

The inclusion of this group of parcels along the northwesterly shore of Lake Mendota in the minimum and high possibility categories was mainly due to a former extension of the City’s extraterritorial review jurisdiction around the north side of Lake Mendota and the extension of the Central Urban Service Area entirely around this lake. It was decided to remove these parcels from the “Madison” Urban Service Area (value = 7 on Table 2) and classify these parcels as within Middleton’s and Waunakee’s Urban Service Areas (value = 0 on Table 2) due to their proximity to these two communities and their remoteness from the City of Madison.

City of Madison planning staff also met recently and made modifications to

Madison's extraterritorial review jurisdiction boundaries. It was decided to remove those parcels from the north side of Lake Mendota between Middleton and Waunakee, those lying between Waunakee and the upper Yahara River due to recent expansion of Waunakee's village limits, and also to remove those parcels south of Meadowview Road in the Town of Dunn. ~~A second adjustment was made to the evaluation criteria for those parcels lying outside of these revised boundaries.~~

The resultant Amended Annexation Possibility for all parcels is presented in the map depicted in Figure 13, with a close-up view of the Madison area depicted in Figure 14. Final parcel counts are presented for the five Annexation Possibility categories in Table 5. The above modifications resulted in 1,933 parcels moving from the minimum possibility and high possibility categories to the low and very low possibility categories.

Table 5

Amended Annexation Quotient Matrix

Annexation Possibility	Physical Factors		Functional Totals		Evaluation Total		Parcel Count
	Hard	Soft	Hard	Soft	Min	Max	
Very Low Possibility to be Annexed	1	1	0	0	0	27	34340
Low Possibility to be Annexed	1	2	13	1	28	39	53045
Minimum Possibility to be Annexed	1	4	7	3	40	51	2367
High Possibility to be Annexed	1	4	10	3	52	79	3144
Very High Possibility to be Annexed	1	4	17	3	80	96	1665

Note: Above individual Annexation Quotient values for physical and functional limits are the minimum for each category

Illustrating the Results

A review of the final Amended Annexation Potential map (see Figures 13 and 14) illustrates the predicted future growth areas of the City of Madison in shades of red (ranging from salmon to burgundy). Areas within other nearby incorporated municipalities extraterritorial review jurisdictions have already severely limited Madison's growth potential (see Figures 6 and 13). In addition, existing intergovernmental agreements have further limited future growth potential (see Figures 7 and 13). These functional limitations, in conjunction with the other limitations discussed in this paper, have resulted in a fairly clear line of demarcation between Madison's potential growth areas (shown in shades of red, Figures 13 and 14) from those denoting low possibilities to be annexed (shown in shades of blue).

Annexation to a municipality requires that the annexed territory be contiguous to the

existing municipal limits. Only those “Low Possibility to be Annexed” parcels located along the northeasterly and easterly edges of the City of Madison and a small area northwest of the City of Verona are contiguous to parcels classified as Minimum Possibility and High Possibility to be Annexed. These parcels may potentially be included in future growth due to the various factors discussed previously in this paper. Those parcels within each classification which are not contiguous to the existing municipal limits or to each other were not included in the ultimate potential annexation classifications portrayed on the maps.

CONCLUSION

The “Very Low Possibility to be Annexed” parcels (rendered in dark blue) in close proximity to the existing city limits of Madison have effectively encircled the city and will likely “cut off” future growth potential as illustrated on the Amended Annexation Potential maps, Figures 13 and 14.

To best illustrate the predicted growth limitations, the available categories of “Minimum Possibility to be Annexed,” “High Possibility to be Annexed,” and “Very High Possibility to be Annexed” (including, as appropriate “Low Possibility to be Annexed” parcels) have been identified by highlighting their boundaries as illustrated in the companion maps, Figures 15 through 17. Utilizing long term population projections, (see Table 6) it is possible to predict future city size requirements and then reconcile the required area needed to support these future populations with the predicted and expected urban growth boundaries.

Coupling these trends and estimates with the annexation potential maps (Figures 15 through 17), one can make informed conclusions regarding the future physical growth boundaries of the City of Madison. Areas with a very high possibility to be annexed encompass approximately 15.7 square miles. Adding this area to the 68.8 square mile City of Madison results in a city area of 84.5 square miles which, according to the projections, may occur by the year 2032 and support approximately 249,000 people. Areas with a high possibility to be annexed (which includes the very high possibility annexation area) encompass approximately 29.9 square miles. Adding this area to the existing City of Madison results in a city area of 98.7 square miles which, according to the projections, may occur by the year 2060 and support approximately 286,000 people. Areas which exceed the minimum possibility to be annexed (which includes the high and very high possibility annexation areas) encompass approximately 50.6 square miles. Adding this area to the existing City of Madison results in a city area of 119.4 square miles which, according to the projections, may occur by the year 2098 and support approximately 346,000 people.

These projections are admittedly based upon a linear growth potential and a final population density of 2900 people per square mile. Neither of these assumptions is likely to be entirely accurate over the next 100 years. If, as predicted, the City of Madison does become an inelastic city, then growth will slow and ultimately stop, resulting in an initial increase, according to Rusk, then a decline in population density as the inelastic city accommodates its population growth within the (then) ultimate city limits.

A final map depicting the ultimate predicted growth of the City of Madison, based

upon the criteria and analysis discussed in this paper, is presented in Figure 18. If the assumptions are correct, the probable ultimate growth boundary of the City of Madison will be reached by the year 2100 and will contain approximately 350,000 people.

Appendix A

- Figure 1 Dane County Incorporated Municipalities
- Figure 2 Dane County Parcels in Unincorporated Townships
- Figure 3 Dane County Townships
- Figure 4 Dane County Publicly Owned Lands
- Figure 5 Dane County Open Space Corridors
- Figure 6 Dane County Extraterritorial Jurisdictions
- Figure 7 City of Madison Intergovernmental Agreement Boundaries
- Figure 8 Dane County Urban Service Areas
- Figure 9 Dane County Privately Owned Parcels Over 10 Acres

- Figure 10 Dane County Privately Owned Parcels Under 5 Acres
- Figure 11 Dane County Privately Owned Parcels Between 5 and 10 Acres
- Figure 12 Dane County Parcels Showing Initial Annexation Potential
- Figure 13 Dane County Parcels Showing Amended Annexation Potential
- Figure 14 Amended Annexation Potential - Detail View
- Figure 15 Future City of Madison Growth - Very Highly Possible Annexation Area
- Figure 16 Future City of Madison Growth - Highly Possible Annexation Area
- Figure 17 Future City of Madison Growth - Possible Annexation Area
- Figure 18 Future City of Madison Limits - Predicted Ultimate Growth Area

Appendix B

Table 1	City of Madison and Dane County Population
Table 2	Evaluation Criteria Matrix
Table 3	Evaluation Total Counts
Table 4	Annexation Quotient Matrix
Table 5	Amended Annexation Quotient Matrix
Table 6	City of Madison and Dane County Population - Future Projections
Graph 1	City of Madison and Dane County Population Trends Comparison Graph
Graph 2	Evaluation Total Counts

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Table 2

Evaluation Criteria Matrix
Growth Limitation

<u>Boundary Type</u>	Physical	Value	Functional	Value			
Hard	Incorporated Municipality	Yes	0	Extraterritorial Limits	Within Madison 7 Outside All 3 Within Other 0		
		No	1	Intergov't Agreements	Within Madison 7 Outside All 3 Within Other 0		
	Lakes and Rivers	Yes	0		Private Land > 10 Acres	Within Madison 7 Within Other 0 Yes 3	
		No	1	Public Lands	No	0	
	Soft	Public Lands	No		2	Private Land < 5 Acres	Yes 1 No 0
			Yes		1	Private Land > 5 < 10 Acres	Yes 2 No 0
Open Space Corridor		Yes	1		Private Land > 5 < 10 Acres	Yes 2 No 0	
		No	2	Private Land > 5 < 10 Acres	Yes 2 No 0		

Table 4

**Annexation Quotient Matrix
Evaluation Totals**

<u>Annexation Possibility</u>	<u>Physical Factors</u>		<u>Functional Totals</u>		<u>Evaluation Total</u>		<u>Parcel Count</u>
	<u>Hard</u>	<u>Soft</u>	<u>Hard</u>	<u>Soft</u>	<u>Min</u>	<u>Max</u>	
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Low Possibility to be Annexed	1	2	13	1	28	39	53183
Minimum Possibility to be Annexed	1	4	7	3	40	51	2483
High Possibility to be Annexed	1	4	10	3	52	79	4961
Very High Possibility to be Annexed	1	4	17	3	8		

Note: Above individual Annexation Quotient values for physical and functional limits are the minimum for each category

Table 5

Amended Annexation Quotient Matrix

<u>Annexation Possibility</u>	<u>Physical Factors</u>		<u>Functional Totals</u>		<u>Evaluation Total</u>		<u>Parcel Count</u>
	<u>Hard</u>	<u>Soft</u>	<u>Hard</u>	<u>Soft</u>	<u>Min</u>	<u>Max</u>	
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High Possibility to be Annexed	1	4	10	3	52	79	3144
Very High Possibility to be Annexed	1	4	17	3	80	96	1665

Note: Above individual Annexation Quotient values for physical and functional limits are the minimum for each category