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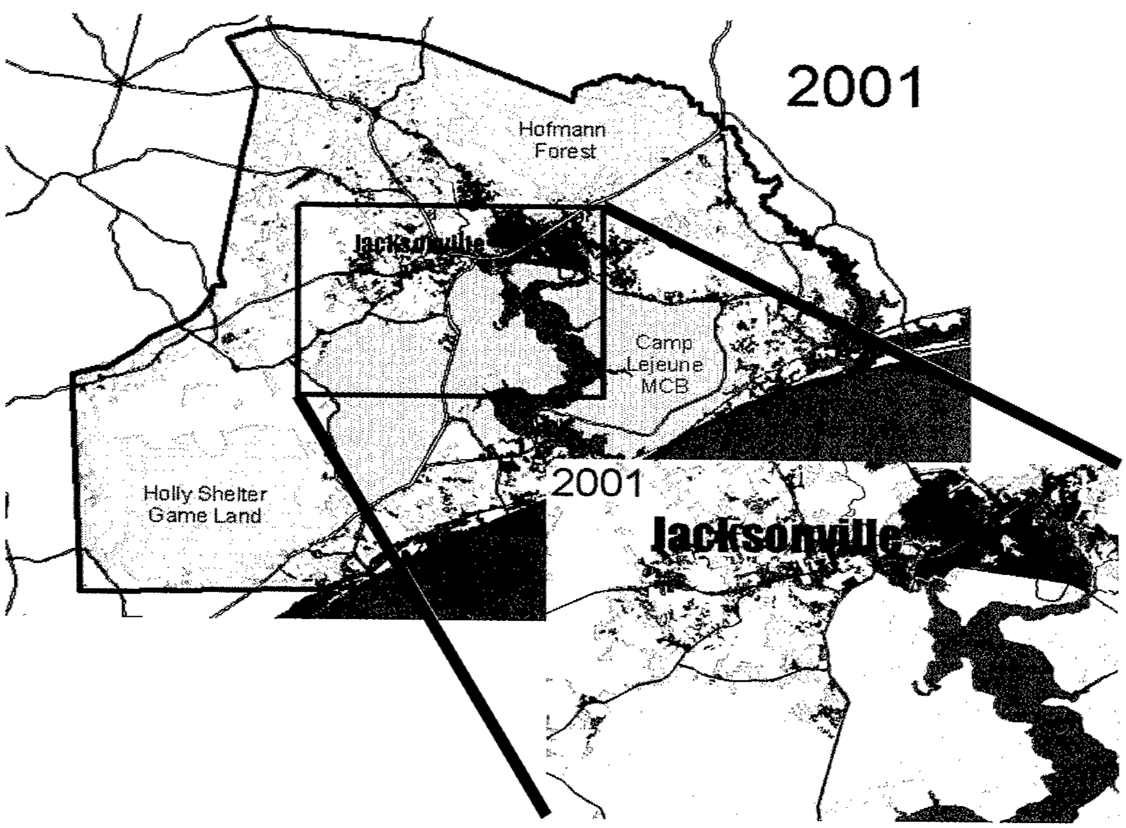
Historical Urban Growth Trends Around Marine Corps Base Camp Lejeune, North Carolina

Robert C. Lozar

June 2003



Construction Engineering Research Laboratory

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Historical Urban Growth Trends Around Camp Lejeune, North Carolina

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Final Report

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ABSTRACT: Abstract text goes here (also in the SF 298).

Marine Corps Base (MCB) Camp Lejeune, North Carolina, is experiencing increased pressure on its military mission activities due to the development or placement of land uses near the installation boundaries. The new land uses, often described as "urban encroachment," may in some way conflict with the ongoing activities at an installation. To begin to deal with this issue, it is useful to clearly establish the historical urban growth in areas surrounding a military installation. In this study, development in each decade since the establishment in 1941 of MCB Camp Lejeune has been traced using growth information and recent advances in computer analysis techniques based on remotely sensed satellite data to establish a scientifically derived baseline of growth near the installation.

Contents

List of Figures and Tables

Figures

Tables

Conversion Factors

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

Preface

This study was conducted for the Director, Training Resources Management Division (TRMD), Marine Corps Base, Camp Lejeune, North Carolina, under Reimbursable project CNN-Q782, M6700102MP44029, entitled "Land Use Study." The technical monitor was Mr. Joseph Ramirez, Director, TRMD.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Robert C. Lozar. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Stephen Hodapp is Chief, CEERD-CN-N, and John T. Bandy is Chief, CEERD-CN. The associated Technical Directors were Dr. William D. Severinghaus and Mr. William D. Goran, CEERD-CV-T. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Military installations are experiencing increased pressure on their training and readiness mission activities due to the development or placement of land uses near the installation boundaries. These new land uses may in some way conflict with the ongoing activities at an installation. Such concerns are often described as "urban encroachment." Military installations are increasingly asked to alter activities within their boundaries to alleviate conflicts. Examples include restricting flight routes or eliminating firing ranges. Such operational restrictions can limit an installations' ability to meet vital mission requirements.

To deal effectively with issues of potential mission restrictions, an installation planner needs to establish two "trajectories of change":

1. Clearly define the historical urban growth trends in areas surrounding a military installation.
2. Provide scientifically based projections of future growth and change.

With knowledge of historical growth and projections of future growth, military and civilian planners can cooperate in anticipating and devising appropriate strategies to avoid or otherwise deal with potential conflicts before they occur. Problem avoidance is usually much less expensive and more effective than mitigation after the fact.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL), Champaign, IL, has engaged in several research projects investigating tools for encroachment risk assessment. One approach is to create an installation-specific historic urban growth series. A historic urban growth series is a set of cartographic illustrations that depict the changes in land use around an installation. This visual presentation quickly conveys the potential for conflicts as the separation between military lands and the neighboring community disappears. Presented one after another, this time series is a powerful tool for showing the changing conditions around an installation.

Marine Corps Base (MCB) Camp Lejeune, NC, is one of the installations experiencing the effects of land use encroachment on its military actions. Camp Lejeune was established in 1941. It is located in Onslow County along the Atlantic Ocean. The installation is divided by the New River with the town of Jacksonville to its North. Jacksonville has been steadily growing (Table 1); much of the county has kept pace. As a result, undeveloped land available for training mission expansion was quickly disappearing. In 1992 the installation acquired a large section of land known as the Great Sandy Run Area (GSRA). The footprint of the entire installation now forms a figure eight. The towns of Verona and Dixon are positioned at the north and south sides, respectively, of the narrow section of the figure eight. Further to the southwest is the Holly Shelter Game Land in Pender County and to the North is the Hofmann Forest. The installation is located along the shoreline of the Atlantic Ocean where ocean front property has been developed for many years. For purposes of the national census, the city of Jacksonville added Camp Lejeune to the city's population figures in July 1990. Table 1 shows the official population figures for the city and county.

The population figures do not reflect several important issues to Camp Lejeune:

- The surrounding areas (and Jacksonville) have experienced rapidly increasing population
- Areas that are not urban may still present threats to the military activities on the installation.

Table 1. Jacksonville City and Onslow County Population.

Census Year	Jacksonville Population	Onslow Population
1940	873	17,939
1950	3,960	42,047
1960	13,411	82,706
1970	16,239	103,126
1980	18,259	112,784
1990	30,398	149,838
2000	33,580*	150,355

To begin to lay the foundation of a comprehensive encroachment analysis, researchers proposed to prepare a set of graphic materials to establish the historical urban growth trends (point 1 on page 1) in areas surrounding the installation. In addition to identifying historic changes from old maps and aerial photography, researchers proposed to apply a procedure developed by ERDC/CERL's academic partners at

* Does not include Camp Lejeune population of 33,135.

Hunter College (City University of New York - CUNY) to determine land use from satellite imagery. The intent is to objectively identify subcategories of urban development (e.g., low and high density development per the U.S. Geological Survey [USGS] standard Land Cover categories). These subcategories will more precisely identify changes in land uses that have potential encroachment conflicts with the military missions at Camp Lejeune. Through this technique, it will be easier to coordinate this historical change tasking with any future growth projections the installation might wish to generate. The final product was to be a set of graphics showing urban growth, with an enhanced, technologically justifiable, basis behind it.

Objective

The objective of this research is to describe the findings related to the establishment of the historical urban growth trends in areas surrounding MCB Camp Lejeune using the latest scientific procedures.

Approach

To establish a scientifically derived presentation of growth near the installation, the following general approach was used.

1. Baseline information was extracted from historical USGS maps of the region.
2. Parcel information was obtained from both the County of Onslow and the City of Jacksonville, NC.
3. The "CellPicker" procedure developed by Hunter College, CUNY, was applied to the National Land Cover Data (NLCD) as source data to derive land uses from the North American Landscape Characterization (NALC) images from the 1970s, 1980s, and 1990s.
4. The land uses derived from "CellPicker" were used to show how those more concentrated, more urban land uses were distributed around the study area and particularly how these critical land uses for encroachment concerns were beginning to encircle Camp Lejeune.
5. Two analysis plans were carried out to specifically define how encroachment might affect the training mission at the installation.

Scope

This report focuses on the MCB Camp Lejeune region in North Carolina. The study region includes all of Onslow County and an adjacent portion of Pender County to the west. The procedure presented here may be unique due to the resources and data available and the cooperation of the local governmental agencies. In general however, the procedure should be applicable to other areas. This study deals only with the historical residential and urbanization growth trajectory mentioned in the background. The next logical step is to provide intelligently based projections of future growth and change.

The procedure was developed through an academic partnership with Hunter College (CUNY) to determine land use from satellite imagery. The procedure was used to generate the data upon which this report is based. However that procedure is described only in passing in this report. ERDC/CERL Technical Report (TR)-03-9 (Lozar et al. 2003) deals specifically with that procedure.

Mode of Technology Transfer

This installation-specific data has been provided to MCB Camp Lejeune in support of their training resources management tasks. One task for which these results are intended is the presentation and evaluation of potential emerging restrictions on their training lands.

This report will be made accessible through the World Wide Web (WWW) at URL:
http://www.cecer.army.mil

2 Urbanization and Change Around Military Installations

The concept of following the trend of urbanization within a region and the prediction of how that might continue into the future has been developing for several decades (Steinitz 1967). ERDC/CERL has engaged in several research projects that investigated risk assessments from increased development near installations. The conceptual framework for the approach has been investigated (Rose et al. 2000). Some regions that include military installations have been studied for the alternatives that are available to policy managers (Steinitz et al. 1996). Some studies have focused on the restrictions resulting from resource depletion (Steinitz et al. 2002) more than from the development issues. These studies have helped formulate the establishment of a military-specific predictive tool (Deal 2001) for evaluating future alternatives.

Several advances have occurred that now make possible a more defensible illustration of developmental growth. First, city and regional governmental units are likely to be cooperative with installation initiatives because it is logically to everyone's benefit to cooperate. Second, data is becoming much more standardized so sharing and manipulating data is more easily accomplished.

The integration of remote sensing techniques into a single coordinated Geographic Information Systems (GIS) framework coordinates with the second of these trends. This project takes advantage of the opportunities remote sensing present. Two sources of data are the backbone:

- The National Land Cover Data is the result of a project to generate land cover data derived from images acquired in the early 1990s by the Landsat satellite's Thematic Mapper (TM) sensor.
- The North American Landscape Characterization is a project to provide complete Landsat Multispectral scanner (MSS) coverage of the conterminous United States and Mexico in the years 1973, 1986, and 1991 for the purposes of mapping land cover and land cover change (Figure 1).

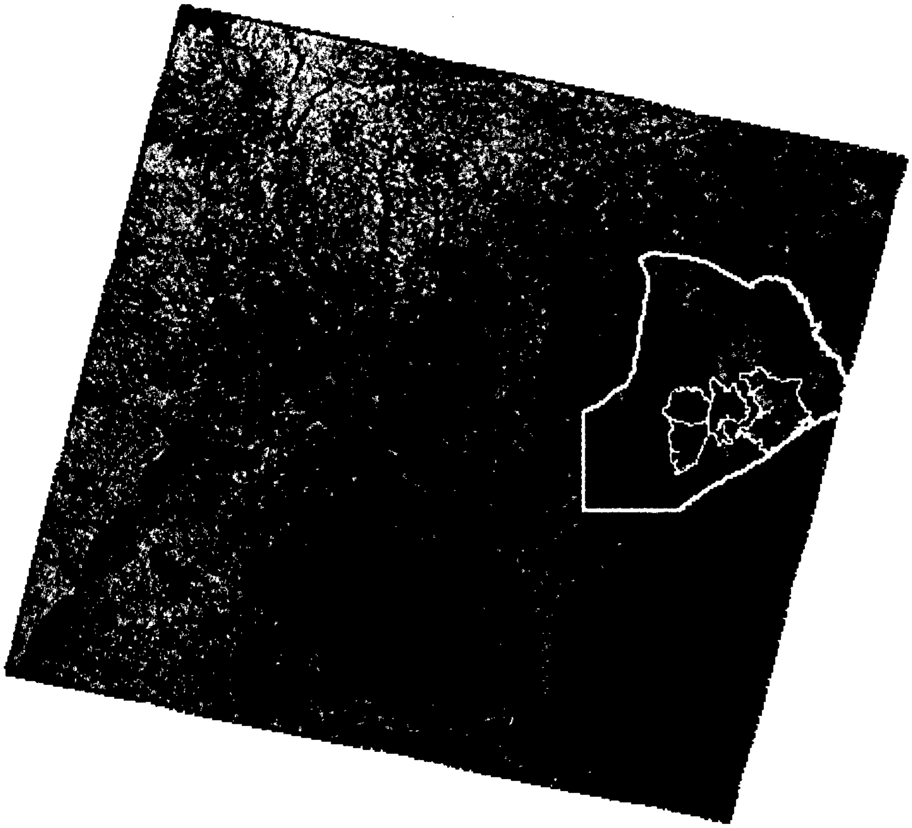

Figure 1. NALC 1980s image for path/row 1536 showing Camp Lejeune (yellow) and the study area (pale yellow).

In a series of CERL development contracts, Dr. Charles R. Ehlschlaeger at the Department of Geography, Hunter College (CUNY), New York, NY, has developed a unique procedure called "CellPicker" that uses the NLCD as base data to derive historical land cover maps from the images in the NALC data. It was our purpose to combine these sources and techniques to generate a scientifically justifiable set of graphics showing how land use changes have occurred over time.

3 Procedure for Developing the Camp Lejeune Time Series

Four primary sources of data were gathered and combined in this study. The first set is the general data that is available via the Internet. The vector files were acquired from ESRI Corporation, USGS, and the Online National Atlas. Land ownership (parcel) data was acquired from both the County of Onslow and the City of Jacksonville (Appendix A). Third, a set of historic USGS maps was reviewed; some were acquired, scanned, georeferenced, and digitzed to fill in missing information, particularly for the portion of the study area in Pender County. The quadrangles that were scanned are listed in Appendix A. Fourth, the CellPicker process was applied to the NALC images to identify "intensity" of land use changes.

The parcel information provided the initial basis for the growth presentation. The data acquired needed to be reformatted into samples by decade. Parcel information was extracted from the county data if the data indicated a taxable structure had been built within that parcel during the decade. This would imply that that parcel of land was likely to be used for a more active purpose (i.e., residential or commercial). Within the city of Jacksonville, the assumption was made that a parcel was bought for the purpose of building a structure that was to be actively usee. (This assumption was necessary because the data available from the city did not contain year-built information. In fact, the higher cost of land in the immediate Jacksonville area would encourage more immediate building i.e., "highest and best use" for real estate.) Once formatted in a compatible manner, the data from the city and county were combined.

Parcel data was not available from Pender County. For Pender County a series of USGS historical maps were reviewed and, particularly for the earlier decades, scanned and georeferenced to the other GIS data. Once in place, the scanned images were examined for areas that indicated development or land changes, particularly clearing of land areas. Occasionally, forest clearing practices could be confused with development. However, the correct interpretation became obvious where forestery-cleared areas were distant from other development and roads. Another clue to distinguish forestry vs development was that over decades the forested-cleared areas grew back while development areas always expanded. By this technique, it was possible to reliably identify the expansion of development. Data derived from this technique was reformated to make it compatible with the parcel data from Onslow

County and the City of Jacksonville. This resulted in a series of files illustrating land ownership in each decade (Figure 2).

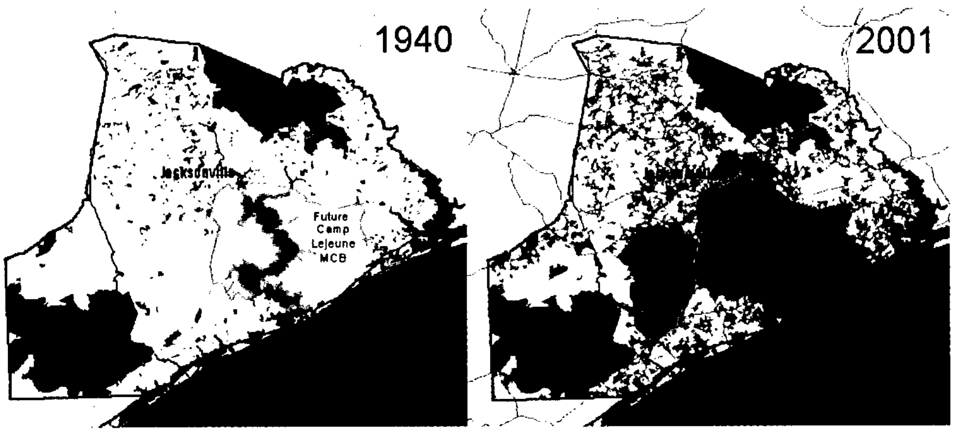

Figure 2. Example of the growth through identification of parcels with built structures. This is an input to Figure 5. If you have MS PowerPoint, double click on the 2001 frame to see it animated.

The work so far shows only the expansion of land upon which a structure was build, it does not show the intensity of the use of that land. For this purpose, the results of the CellPicker process on the NALC images were used. The process to generate the land uses for each decade is described in detail in a separate report (Lozar et al., 2003). The CellPicker process is robust but has some limitations. Limitations of the process and how they affect the results for this study area are described in Appendix B. Figure 3 shows the results for each decade (at 60 meters resolution). Figure 4 shows the NLCD set (at 30 meters resolution) to which the resolution at 60 m is compared and which was used as a "ground truth" to derive land uses in each decade.*

* Appendix C shows the statistical evaluation of the "goodness" of fit for each decade of land uses generated from the images for each of the land use types. In this project, the categories of interest are Categories 21, 22, and 23.

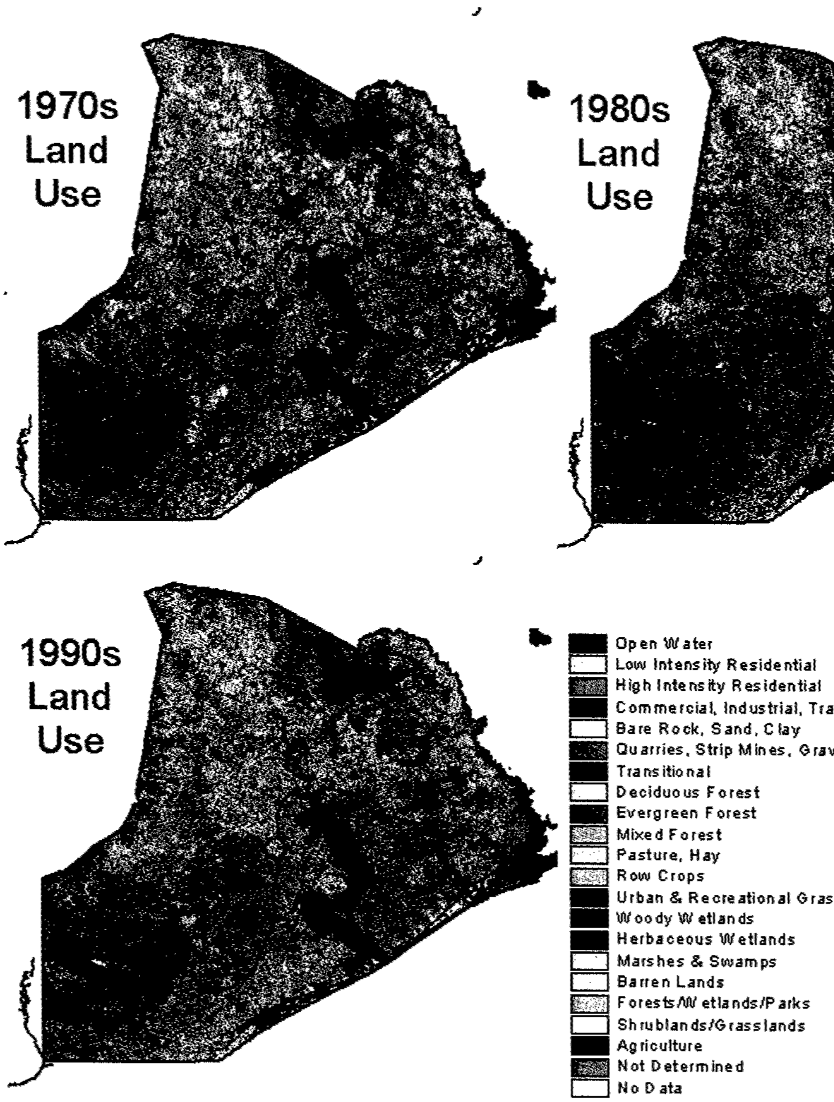

Figure 3. Land use for each decade as determined using the CellPicker method. This is an input to Figure 5.

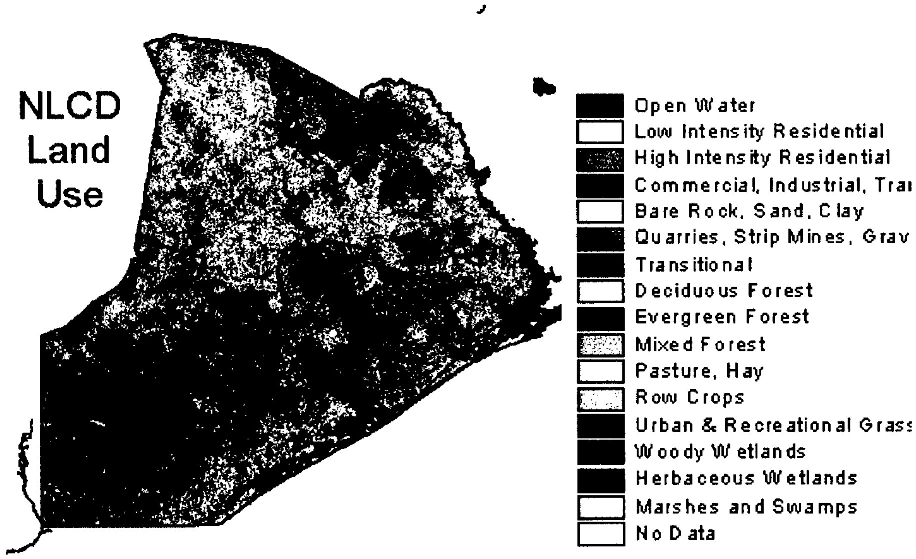

Figure 4. Land use for the early 1990s as presented in the NLCD. This is ground truth input to CellPicker.

After completing the CellPicker process, those categories that implied an active use that is likely to generate an incompatibility with the installation training mission (particularly noise) were extracted. Specifically, Categories 21 - Low Intensity Residential, 22 - High Intensity Residential, and 23 - Commercial/Industrial/ Transportation were singled out. (Although industrial and transportation uses might not be considered incompatible uses, an examination of the data indicated that most of the pixels represented commercial uses.) Since the images show only built structures, the owned/used land upon which the structures are built have to be more extensive than the area represented by the structure only. Therefore, the cells of each land use type were expanded to the size of a standard lot (roughly 90 meters) so that the land associated with the structure would be included. These three sets of land use intensities were then merged together. In locations of overlapping sets, the priority was:

1. High Intensity Residential
2. Commercial
3. Low Intensity Residential

This new data set provided an indication of intensity of usage. However, since the focus was to deal only with parcels that were built upon (that is, the intensity of use data was not to go beyond the built-upon parcel locations), the intensity of use levels were clipped off at the parcel edges. Intensity data starts with the 1972 image. Decade panels previous to 1972 used the 1972 data as the initial starting point, but are displayed using a more subdued color to show that this is the likely area of greater intensity land use. Previous to about 1960, areas of higher intensity land use were considerably limited as reflected in the population figures (Table 1). It is this greater intensity land use that is expected to more clearly represent those areas that would be in greater conflict with military activities.* An evaluation of the resulting distribution makes this reasonable. Though the USGS topographic maps do not indicate intensity directly, when checked against those maps available for this project, the distributions of building densities and their locations also suggested that this was a reasonable approach. The result of these manipulations were integrated into an animated MS PowerPoint presentation. The frames from the presentation are shown in Figure 5. Figure 6 shows a more detailed version zoomed in on the nothern edge of the installation.

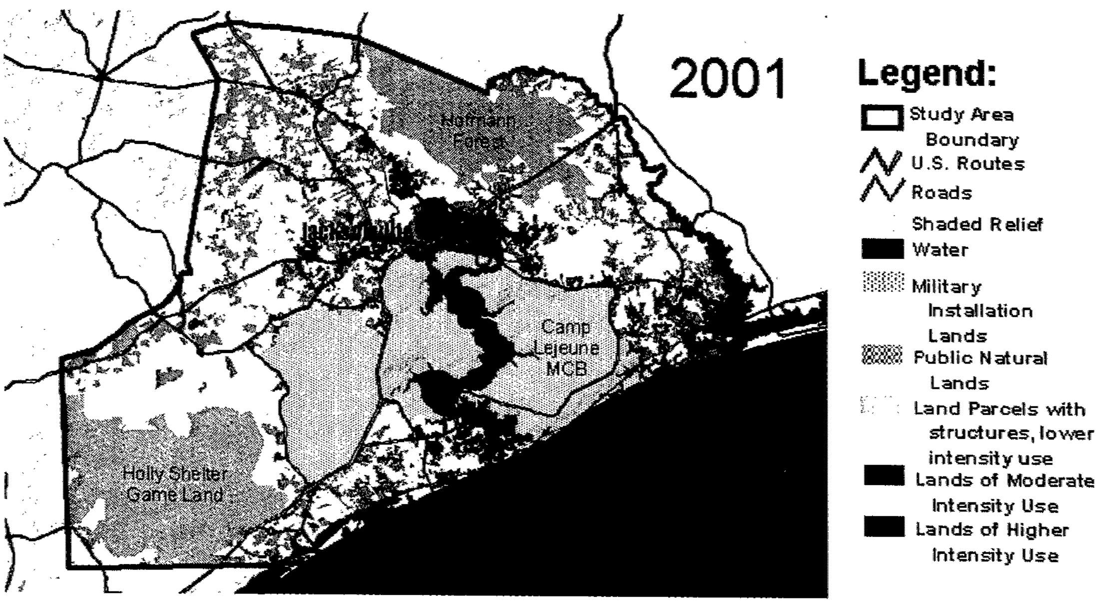

Figure 5. Animated illustration of growth within the study area over 60 years. If you have MS PowerPoint, double click on Figure.

* There is the suggestion that the Low Intensity Residential category is the highest sensitivity and therefore should be first in priority. The priority depends on the character of the study area. The priority depends on whether the Low Intensity category consists mostly of high- or low-cost housing. Generally, if it is mostly lower cost, then Low Intensity should be priority 3.

Figure 6. A zoomed in version of Figure 5 better showing the land use density variations. If you have MS PowerPoint, double click on Figure to animate it.

4 Encroachment Evaluations

ERDC/CERL's task was to generate a scientifically valid means of showing historical growth over time. Though this result is useful, the real question is, "How is this growth affecting the mission carried out at MCB Camp Lejeune?" Though this later question is not within the tasking of this particular project, it was considered necessary to illustrate that the data generated as part of this effort has more versatility than that resulting from the generation of a simple graphic. Further, it leads toward the answers to the next logical questions:

1. How will future growth affect the mission carried out at MCB Camp Lejeune in 2010 or 2020?
2. As new responsibilities for the installation emerge for Marine training and defense readiness, will the land-base upon which the installation sits be capable of fulfilling those responsibilities?

General Encroachment Example

First, let us examine the question of general encroachment around Camp Lejeune. What has happened near the Camp Lejeune installation since it was established in 1941? The graphics in the previous chapters have dealt with the entire study area. However, a parcel being developed into a more intense use in the northern portion of Onslow County will probably not be affected by Camp Lejeune training activities and visa versa. To really see what is happening near Camp Lejeune, we chose to define a buffer 1 kilometer wide surrounding the original installation and excluding non-developable areas such as water (Figure 7). (The Great Sandy Run training area was excluded so that a stable seven-decade growth trend could be developed.) One kilometer was considered a reasonable buffer within which the training activities would have the greatest influence and within which the concern of the civilian population would be the greatest.

Figure 7. One-kilometer buffer around Camp Lejeune (yellow) used to develop a seven-decade trend analysis [shown over the 1990s NLCD data.]

We extracted the parcel data within the buffer and derived the data in Table 2. Table 2 shows that as the decades pass, the land within the area directly adjacent to the original installation is being developed at an unevenly increasing rate and that currently over half of the available land has been developed. In fact, the situation is really much worse than the tabular data suggest. Figure 8 shows the rate of buffer development has been preferentially greater (roughly three times) adjacent to Camp Lejeune than in the rest of the study region. If this continues, all the available land will be used in much less than a decade. For Camp Lejeune, any proactive planning must occur in the next few years.

Table 2. Developed parcels within the 1-kilometer buffer and study area.

	1 Kilometer Buffer Changes					Changes Over Entire Study Area		
	Total Acres in buffer = 14,358.40					Total acres in study area = 665,893.16		
Decade	# Parcels Developed	Cummulative Parcels	Acres	Cumulative Acres	% Land Used in Buffer	Acres	Cumulative Acres	% Land Used in Region
1930s	103	103	754.97	754.97	5.26	16,810.73	16,810.73	2.52
1940s	608	711	745.16	1,500.13	10.45	9,455.88	26,266.61	3.94
1950s	513	1224	783.58	2,283.71	15.91	14,522.18	40,788.79	6.13
1960s	495	1719	538.53	2,822.24	19.66	19,488.88	60,277.67	9.05
1970s	678	2397	1,326.90	4,149.14	28.90	16,217.51	76,495.18	11.49
1980s	1277	3674	1,615.73	5,764.87	40.16	13,645.00	90,140.18	13.54
1990s	1375	5049	1,605.98	7,370.85	51.34	19,563.40	109,703.58	16.47

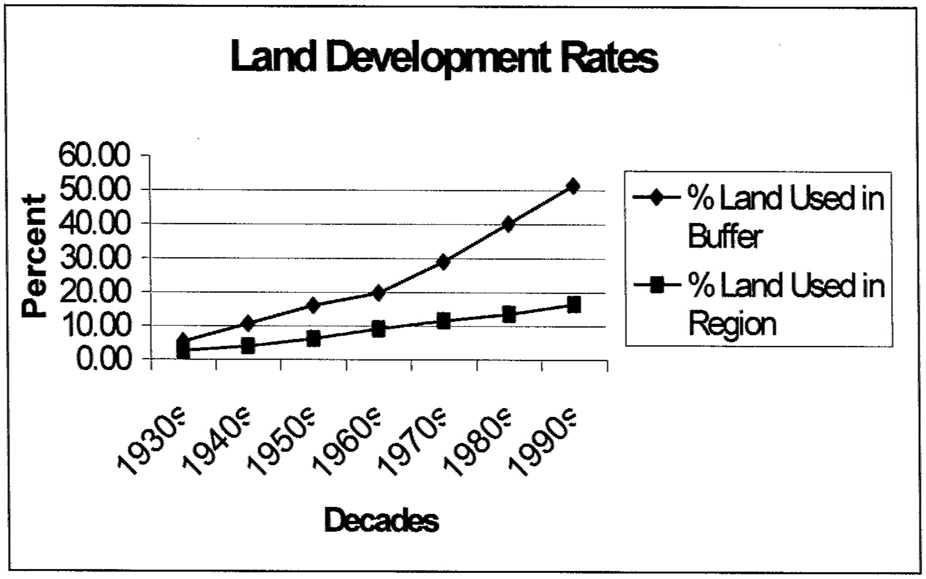

Figure 8. Land development rates in the study area vs within the 1-kilometer buffer.

Figure 9 shows the spatial pattern of the developing land. It shows that parcels directly adjacent to the installation boundary are preferably developed. Thus, an analysis similar to Table 2 but using a narrower buffer would show an even more intense degree of encroachment. Therefore, independent of the buffer width selected, the general conclusion is the same: land near the installation (i.e., land most likely to be involved in encroachment conflicts) is well over half developed and will preferably and increasingly be developed as this trend continues. Certainly there is no indication the pressure will decrease. This observation suggests that Camp Lejeune staff need to coordinate with at least county and city agencies to ensure the most positive land use, zoning regulations, and ordinances are enacted to help the installation carry out its training and readiness missions.

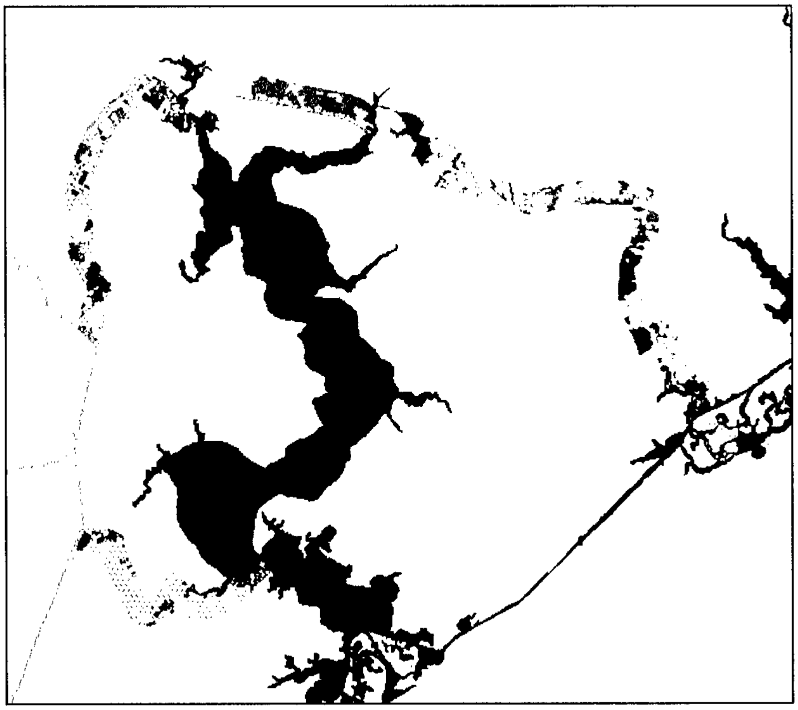

Figure 9. Spatial pattern of the developing land.
Darker shades of red indicate more recently developed land while the speckled areas are those yet to be developed.

Noise Example

The general example in the last section shows the trend, but not the specifics of how development can encroach on the military training and readiness mission. Noise is often a consequence of military training. Military aircraft have loud engines; artillery training is associated with the bursts from firing and the sound of ordnance exploding on impact. Several studies of noise at the installation have been carried out in the past several years, the most recent of which is the *Range Compatible Use Zone (RCUZ) Study for MCB Camp Lejeune, North Carolina* (2002). To specifically show the relation of noise to land use, one of the many studies contained within that report (Figure 5-2 on page 5-8, G-10 RCUZ Zones) was scanned, georeferenced, and digitized. It is based on the Day Night Level (DNL) noise contours for the busiest month of the year for the training area called G-10. The RCUZ map was overlaid on the NLCD data (Figure 10).

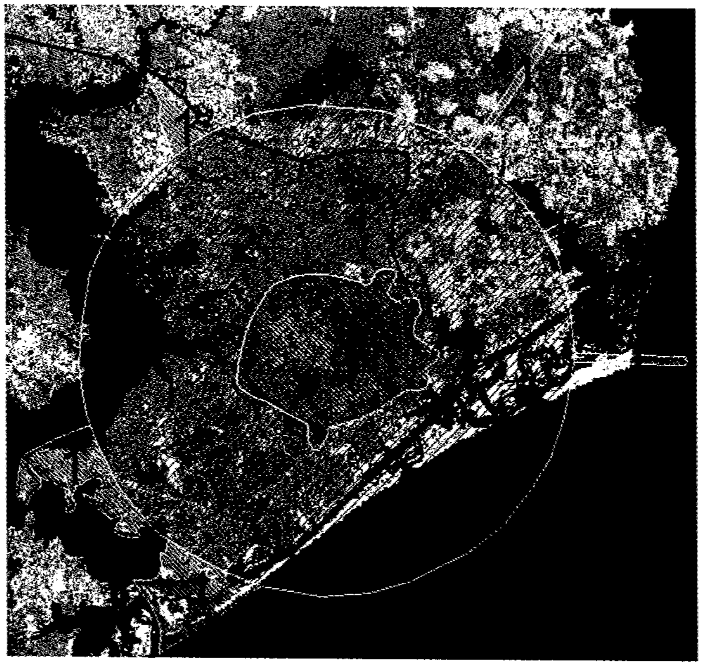

Figure 10. RCUZ noise zones laid over the NLCD in area G-10.

The question now asked was, “What types and amounts of different land uses off installation are being affected by these noise zones?” To find out, we identified those areas within a RCUZ but off the installation (Figure 11). These are the areas that are in private ownership and where a structure was built. From the parcel data, we extract the area data shown in Table 3.

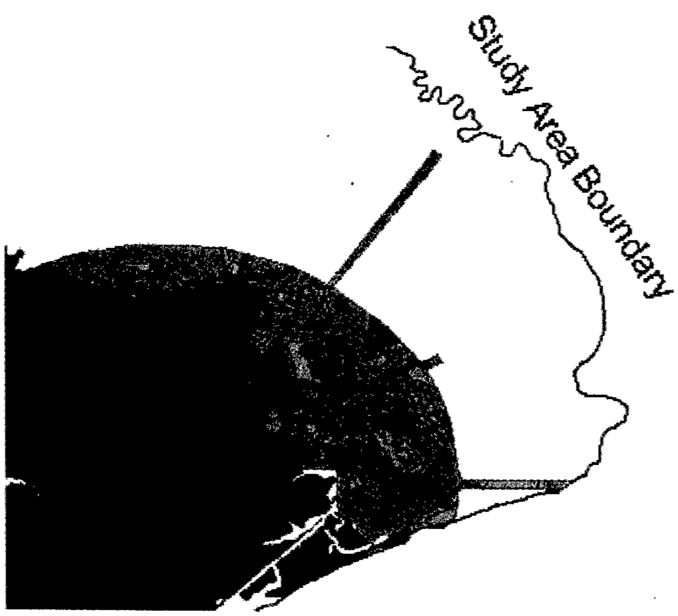

Figure 11. Built-upon parcels (to 2001) within the G-10 RCUZ area.

Table 3. Parcel changes in 30 years.

Total Acres within G10 RCUZ outside of Installation = 16,881

Year	Number of Parcels	% Growth	Acreage	% Growth	% Total Area
1970	457		1,764		10
2001	2,489	545	4,487	254	27
2030 Proj	13,556		11,413		68

From the analysis in Table 3 it is clear that both the number of active owners (i.e., those that are buying land and building structures) and the area being used have increased dramatically (by 545 percent and 254 percent, respectively) over the past 30 years. A simple straight-line projection using these trends indicates that in 30 years over two-thirds of the land within this RCUZ off-installation area would be occupied.

Next we did an analysis of the types of land uses in this off-installation crescent (Figure 12). Table 4 shows that within the area encompassed by the noise zones off installation, the amount of "natural type" land uses have decreased slightly over the 30-year period while the amount of more urban uses has stayed the same or decreased slightly. This is a very fortunate situation and probably also reflects some very careful planning by the installation staff so that the training exercises have minimal off-installation impacts. As the rest of the land is developed, it will be increasingly difficult to avoid off-installation noise impacts.

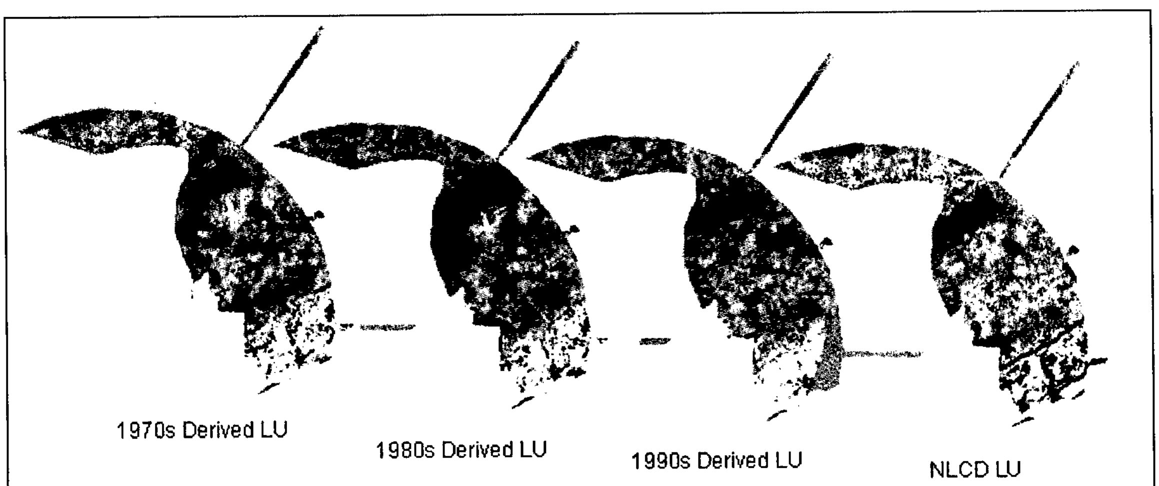

Figure 12. Off-installation land uses within RCUZ derived from the NALC images for the period 1970 to early 1990s and the NLCD data (most right) for the same area.

Table 4. Changes in land use groups over three decades per RCUZ in which they reside.

	1970s			1980s			1990s		
Class Name	% RCUZ 1	%RCUZ2	%RCUZ3	% RCUZ 1	%RCUZ2	%RCUZ3	% RCUZ	%RCUZ2	%RCUZ3
Forested & Marshes	2.5	64.7	0.1	2.7	64.0	0.2	2.5	61.9	0.1
Decade Total Percents			67.3			66.8			64.5
	1970s			1980s			1990s		
Class Name	% RCUZ 1	%RCUZ2	%RCUZ3	% RCUZ 1	%RCUZ2	%RCUZ3	% RCUZ	%RCUZ2	%RCUZ3
More Developed	0.0	2.7	0.0	0.0	1.8	0.0	0.0	1.7	0.0
Decade Total Percents			2.7			1.8			1.8

5 Summary, Conclusions, and Recommendations

Summary

As with many other installations within the Department of Defense, Marine Corps Base Camp Lejeune, North Carolina, is experiencing increased pressure on its military mission activities due to the development and placement of land uses near the installation boundaries. The new land uses, often described as "urban encroachment," may in some way conflict with the on-going activities at an installation. To deal with this issue, it is useful to clearly establish the historical urban growth trends in areas surrounding the installation. In this study, development in each decade since the establishment in 1941 of MCB Camp Lejeune has been traced using growth information and recent advances in computer analysis techniques based on remotely sensed satellite imagery. The purpose was to establish a scientifically derived presentation of growth near the installation. Baseline information was extracted from historical USGS maps of the region. Parcel information was obtained from both the County of Onslow North Carolina and the City of Jacksonville North Carolina. This data was reformatted and combined with the information extracted from the USGS maps. Beginning in 1972, the LANDSAT series of satellites began taking images of the earth's surface. From these images the USGS and the Environmental Protection Agency (EPA) have generated a three-decade series of images (called the NALC Triplicates) for the early part of the 1970s, 1980s and 1990s at 60-meters resolution. Another program generated the National Land Cover Data (NLCD) at 30-meters resolution for the early 1990s. As part of its ongoing research program, ERDC/CERL has supported the development of a software package ("CellPicker" from Hunter College, CUNY) to use the NLCD as source data and derive from the NALC images associated land uses. The viability of the product resulting from this procedure can be validated statistically based on an evaluatory routine that is part of the package. The land uses (beginning with the first image in 1972) derived from the images were integrated into the GIS data base that supported this project primarily to show how those more concentrated, more urban land uses were distributed around the study area and particularly how these most critical land uses for encroachment concerns were beginning to encircle Camp Lejeune.

Conclusions

To show how the maps may be used for analysis of encroachment questions, two simple analyses were carried out. The first analysis looked at the general issue of what was happening within a 1-kilometer buffer around the original installation boundaries over seven decades. It shows that:

1. As the decades pass, the land within the area directly adjacent to the original installation is being developed at an increasing rate and that currently over half of the available land has been developed.
2. Land adjacent to the installation is being developed at a rate roughly three times greater than within the rest of the study area.
3. Parcels directly adjacent to the installation boundary are preferably developed. A narrower buffer would show a more intense degree of encroachment.

Independent of the buffer width, the general conclusion is the same: land near the installation (i.e., land most likely to be involved in encroachment conflicts) is well over half developed and will preferably and increasingly be developed as this trend continues. There is no indication that the pressure will decrease.

In the second analysis, the growth of used land within the RCUZ areas associated with Training Area G-10 was extracted. It was shown that built-upon parcels increased by over 250 percent in the three decades before 2001. It also showed that at the rate of change exhibited, two-thirds of all the land within this area would be in a more intensive use category before the end of the next 30 years. A comparison of the land use types to the noise levels illustrated that the affected intensive land uses have not changed greatly, suggesting very good planning on the part of the installation staff to mitigate the impact of encroachment on training activities. It will be difficult to avoid impacts as the rest of the land is developed.

The primary products of this study are:

- Set of LANDSAT satellite remote sensing images (1970s, 1980s, 1990s decades) showing images of changing land cover patterns. (Figure 9 is an example.)
- Set of land cover GIS data showing changes in each decade (1970s, 1980s, 1990s). (Figure 5 is an example.)
- Set of map style frames showing urban growth character. (Figure 9 is an example.)

Recommendations

In the Background in Chapter 1 it was stated:

To deal with these {encroachment} issues effectively, an installation planner needs to establish two "trajectories of change":

1. Clearly define the historical urban growth trends in areas surrounding a military installation,
2. Provide scientifically based projections of future growth and change.

This study provides a solid scientific and technological answer to the first issue. It provides a sound foundation upon which to embark on the second question. It is suggested that the next logical step for Camp Lejeune is to begin to focus efforts toward more clearly defining the direction and impacts of future growth within the region. To define the relation of Camp Lejeune to projections of future growth and change, two additional items need to be understood:

- Inside the fence: What are the likely training requirements at the installation over the next few decades? Although it is difficult to predict a single set, it is possible to set up different sets that incorporate the best knowledge at the installation, Marine Corps, and Department of Defense (DoD). These could be characterized as "Alternative Futures" for the installation's mission.
- Outside the fence: What are the likely land growth policies that the cities and counties (also the state) see are feasible over the next few decades? These policies influence the direction of land use growth. One set of policies is officially stated as the city, county, and/or state plans. However, others might include policies that encourage maximum development or policies that encourage highly restrictive growth regulations.

Once these requirements and policies are defined, it is possible to translate the training mission characteristics into land use distributions and the governmental growth policies into rules that distribute land uses based on those policies. It is not possible to say which land use will occur on a parcel of land; it is possible to say that the resulting general distribution of land use character for each combination of inside- and outside-the-fence scenarios will impact the installation's proposed missions in specific and predictable ways. ERDC/CERL is in the process of developing this capability for military installations and would be able to assist Camp Lejeune in this next step.

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Range Compatible Use Zone (RCUZ) Study for MCB Camp Lejeune, North Carolina. 2002. Prepared by the ONYX Corporation for the Atlantic Division of the Naval Facilities Engineering Command, Norfolk, VA.

Appendix A: Data Sources

Parcel data from:

Onslow County

Patricia Rouse, GIS Director, Information Technology Systems Department, Onslow County, North Carolina

City of Jacksonville

Brenda Livingston, GIS Specialist, City of Jacksonville, North Carolina

Population for City of Jacksonville, North Carolina:

City of Jacksonville

Glenn Harget, Manager, City of Jacksonville, North Carolina

USGS maps scanned, georeferenced, and digitized to provide additional data, particularly for Pender County:

Quadrangle Name	Size	Year	Format	Georeferenced?
Burgaw	15 min	1942	Tif	Yes
Hampstead	7.5 min	1970	Img	Yes
Hollyridge	7.5 min	1970	Img/tif	Yes/No
Hubert	7.5 min	1952	Img/tif	Yes/No
Jacksonville North	7.5 min	1975	Img/tif	Yes/No
Maple Hill	15 min	1948	Tif	No
Mooretown	7.5 min	1970	Img/tif	Yes/No
New River	15 min	1952	Tif	No
New River Inlet	7.5 min	1971	Img/tif	Yes/No
Rocky Point	15 min	1942	Tif	No
Scotts Hill	7.5 min	1970	Img/tif	Yes/No
Sneads Ferry	7.5 min	1971	Img/tif	Yes/No
Top Sail	7.5 min	1970	Img/tif	Yes/No

USGS NALC Triplicates, orderd from EROS Data Center, Sioux Falls, North Dakota

NLCD downloaded off the Internet from:

http://edcwww.cr.usgs.gov/programs/lccp/nationallandcover.html

Appendix B: Discussion of the CellPicker Procedure and Possible Limits for Camp Lejeune

The CellPicker procedure developed by Hunter College (CUNY) consists of a series of steps using a suite of image processing, GIS manipulations, and Java scripts to generate land cover maps for the 1970s, 1980s and 1990s. The "ground truth" data is the 1990s the National LandCover Data (NLCD). The 1980s and 1970s Land Use Data are grids derived from Landsat MSS Sensor images from the North American Land Characterization Project (NALC). The CellPicker process attempts to find NALC grid cells that have the same appearance over all three decades of NALC images. Grid cells with the same appearance over three decades are considered to be "ground truth" and are assigned the NLCD designation at the same location. The grids are developed via a supervised classification technique using sample cells from the CellPicker process. There are two types of input data:

- NALC triplicates: The NALC image quality for the defined study area (entirely contained within PathRow number 1536) ranges from excellent to fair (there existed a few low scattered clouds in the 1972 image). Minor horizontal registration errors exist (a characteristic of the source data). The 1970s pathrows do not completely overlap with the other two images (i.e., slivers of No Data between some pathrows exist).
- NLCD Landcover and Landuse maps from the early 1990s were derived from 1990s NALC images and auxiliary information. In some ways this is redundant and not independent.

Concerns that limit the reliability of the data, and how they were minimized in this study include:

- Original NLCDs claim 85 percent accuracy against reality. Since CellPicker attempts to replicate NLCD data in earlier decades, even a perfect fit will only be 85 percent accurate.
- NALC images only provided a single image per decade. A "leaf on" and "leaf off" image for each decade would provide better results. Two problems arise from using single image:

1. It becomes impossible to differentiate between Deciduous and Evergreen Forest (not a concern for the Camp Lejeune work since this was not a category used).
2. Low intensity residential is poorly defined with only a single image. There will be more mismatches between low intensity residential and various row crops or forested areas. (This is a concern for Camp Lejeune study. We minimized this by cutting out any cells that did not have a taxable structure present. To a very large extent, this eliminated row crops or forested areas.)

To minimize other potential issues, several assumptions were made within the Cellpicker software:

- Open water (category 11) must exist in the NLCD to be considered open water in the derived land use maps. This minimizes problems caused by streaks in original NALC triplicates. (Not a concern for the Camp Lejeune work.)
- Commercial & industrial (Category 23) must exist in the NLCD to be considered commercial & industrial in the derived land use maps. This minimizes mismatches. (Category 23 was used to derive land use intensity, so it is a concern for the Camp Lejeune work. However we minimized these problems by removing all areas that were not within a "built upon" parcel.)
- Medium intensity residential (Category 22) must exist in the NLCD as Category 22 or Category 23 to be considered medium intensity residential in the derived land use maps. (Category 22 was used to derive land use intensity, so it is a concern for the Camp Lejeune work. However we minimized these problems by removing all areas that were not within a "built upon" parcel.)
- Low intensity residential (Category 21) must exist in the NLCD as categories 21, 22 or, 23 to be considered low intensity residential in the derived land use maps. (Category 21 was used to derive land use intensity, so it is a concern for the Camp Lejeune work. However we minimized these problems by removing all areas that were not within a "built upon" parcel.)
- The original NLCD categories were compressed to better classify land cover due to the lack of "ground truth" land use data. Confusion matrices (Appendix C) comparing the generalized NLCD categories against the original categories for the 1990s decade were generated. (Not a concern for the Camp Lejeune work as the critical land use intensity categories – 21,22 and 23 – were not compressed.)
- Without any actual ground truth, we applied this technique to the 1990s NALC images as well as the 1980s and 1970s NALC images in order to perform cross-validation. By comparing cells not found by the CellPicker process in the 1990s NALC image against the NLCD, we can estimate the how error prone the model is. Confusion matrices comparing the 1990 derived land use categories against the combined NLCD categories were generated (Appendix C). These confusion matrices, assuming the 1970 and 1980 image is as clear as the 1990 image for

that pathrow, provide a good estimate of that pathrow's accuracy. In general, Appendix C matrices show acceptable to good results.

- Generalized classes in the 1970s and 1980s land cover grids were converted to the original NLCD classes if the 1990s NLCD class at a cell was a possible actual class. For example, suppose a cell in the 1970s grid contained class 40, which generalizes all NLCD forest classes. If, at that location, the NLCD grid contains deciduous forest, the 1970s grid cell is given the deciduous forest class. This assumption will be correct most of the time. However, it is possible that an evergreen forest existed at a location in 1970 but was actively managed to become a deciduous forest (a goal at several National Forests). Without ground truth data from the 1970s and 1980s, it is impossible to estimate the reduction in accuracy caused by this "increase in precision." (This is not a concern for the Camp Lejeune work because forest classes were not important in deriving the land intensity information.)

Appendix C: Confusion Matrixes from CellPicker Procedure

Results of assigning land uses to the NALC Images:

For the 1970s:

cnfus	11	16	21	22	23	31	32	33	41	42	43	81	82	85	91	92	OnRatio
11	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04516
16	0.31998	0.43917	0.00860	0.00214	0.00890	0.02341	0.00158	0.00414	0.01511	0.06437	0.01793	0.00395	0.01445	0.00173	0.07451	0.00005	0.00988
21	0.00000	0.00000	0.87213	0.04143	0.08644	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00323
22	0.00000	0.00000	0.00000	0.64374	0.35626	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00238
23	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00197
31	0.00608	0.00216	0.00014	0.00000	0.00095	0.97703	0.01162	0.00000	0.00081	0.00027	0.00041	0.00000	0.00054	0.00000	0.00000	0.00000	0.00099
32	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00034
33	0.00480	0.00463	0.00793	0.00190	0.00341	0.00066	0.00081	0.01493	0.07010	0.30845	0.07093	0.02583	0.14185	0.00154	0.34211	0.00011	0.36547
40	0.02744	0.02060	0.05654	0.01620	0.02764	0.00346	0.00287	0.06906	0.00000	0.00000	0.00000	0.11895	0.65723	0.00000	0.00000	0.00000	0.05447
41	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02414
42	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.11660
43	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02443
80	0.01057	0.00800	0.04464	0.01536	0.02766	0.00328	0.00184	0.00877	0.14562	0.36021	0.11793	0.00000	0.00000	0.01100	0.24473	0.00039	0.11149
81	0.00004	0.00003	0.00008	0.00001	0.00007	0.00001	0.00000	0.00001	0.00162	0.00101	0.00073	0.95932	0.03611	0.00001	0.00098	0.00000	0.02442
82	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.12767
85	0.00399	0.00342	0.00196	0.00032	0.00097	0.00062	0.00012	0.00235	0.03973	0.36055	0.05423	0.00697	0.01593	0.21804	0.29079	0.00000	0.00577
91	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.08153
92	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00008
GlRatio	0.05277	0.00807	0.01387	0.00498	0.00902	0.00199	0.00102	0.01025	0.06642	0.27223	0.06401	0.03943	0.21643	0.00306	0.23628	0.00016	

For the 1980s:

cnfus	11	16	21	22	23	31	32	33	41	42	43	81	82	85	91	92	OnRatio
11	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04615
16	0.27421	0.43700	0.00877	0.00221	0.00952	0.02269	0.00215	0.00281	0.01894	0.08073	0.02088	0.00514	0.02072	0.00244	0.09175	0.00004	0.00986
21	0.00000	0.00000	0.86162	0.03693	0.10145	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00257
22	0.00000	0.00000	0.00000	0.63743	0.36257	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00238
23	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00205
31	0.00616	0.00219	0.00014	0.00000	0.00096	0.97673	0.01177	0.00000	0.00082	0.00027	0.00041	0.00000	0.00055	0.00000	0.00000	0.00000	0.00098
32	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00041
33	0.00537	0.00506	0.01193	0.00321	0.00575	0.00080	0.00052	0.02136	0.05364	0.40849	0.06281	0.02161	0.10574	0.00216	0.29137	0.00017	0.27673
40	0.02665	0.02255	0.05478	0.01330	0.02298	0.00372	0.00257	0.04088	0.00000	0.00000	0.00000	0.12308	0.68949	0.00000	0.00000	0.00000	0.06596
41	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02820
42	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10777
43	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02787
80	0.01032	0.00626	0.03383	0.01155	0.01959	0.00278	0.00185	0.00996	0.16522	0.33052	0.13142	0.00000	0.00000	0.00848	0.26795	0.00027	0.13942
81	0.00004	0.00003	0.00008	0.00001	0.00006	0.00001	0.00000	0.00001	0.00151	0.00095	0.00068	0.96202	0.03371	0.00001	0.00091	0.00000	0.02642
82	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.14167
85	0.00399	0.00341	0.00196	0.00032	0.00097	0.00062	0.00012	0.00235	0.03969	0.36022	0.05418	0.00697	0.01591	0.21877	0.29052	0.00000	0.00583
91	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.11565
92	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00008
GlRatio	0.05357	0.00809	0.01395	0.00501	0.00911	0.00204	0.00102	0.01004	0.06654	0.26981	0.06411	0.03961	0.21760	0.00308	0.23626	0.00016	

For the 1990s:

cnfus	11	16	21	22	23	31	32	33	41
42	43	81	82	85	91	92	OnRatio		
11	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04387	
16	0.30001	0.40454	0.00828	0.00241	0.01018	0.01986	0.00309	0.00886	
0.02333	0.06023	0.02193	0.00716	0.03161	0.00216	0.09629	0.00004	0.00967	
21	0.00000	0.00000	0.84367	0.04585	0.11048	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00237	
22	0.00000	0.00000	0.00000	0.52804	0.47196	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00230	
23	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00142	
31	0.00720	0.00256	0.00016	0.00000	0.00112	0.97278	0.01377	0.00000	
0.00096	0.00032	0.00048	0.00000	0.00064	0.00000	0.00000	0.00000	0.00084	
32	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00050	
33	0.00710	0.00568	0.01262	0.00311	0.00565	0.00085	0.00049	0.02122	
0.05695	0.39366	0.06264	0.02514	0.13803	0.00172	0.26496	0.00019	0.20823	
40	0.02492	0.02370	0.05711	0.01413	0.02397	0.00399	0.00207	0.04638	
0.00000	0.00000	0.00000	0.12691	0.67680	0.00000	0.00000	0.00000	0.09039	
41	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03948	
42	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.15984	
43	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03930	
80	0.01307	0.00661	0.04466	0.01943	0.03193	0.00442	0.00208	0.01538	
0.16621	0.30915	0.12734	0.00000	0.00000	0.01476	0.24451	0.00044	0.08949	
81	0.00004	0.00003	0.00008	0.00001	0.00007	0.00001	0.00000	0.00001	
0.00168	0.00105	0.00075	0.95786	0.03740	0.00001	0.00101	0.00000	0.02376	
82	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.12643	
85	0.00393	0.00336	0.00193	0.00032	0.00095	0.00061	0.00011	0.00231	
0.03905	0.35435	0.05330	0.00685	0.01566	0.23149	0.28579	0.00000	0.00591	
91	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.15609	
92	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00008	
GlRatio	0.05171	0.00785	0.01388	0.00501	0.00908	0.00194	0.00102	0.01009	
0.06671	0.27218	0.06428	0.03958	0.21764	0.00307	0.23580	0.00016		

Acronyms and Abbreviations

CERL	Construction Engineering Research Laboratory
CUNY	City University New York
DNL	Day Night Level (noise)
DoD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
ERDC	U.S. Army Engineer Research and Development Center
GIS	Geographical Information System
GSRA	Great Sandy Run Area
MCB	Marine Corps Base
MSS	Multispectral Scanner
NALC	North American Land Characterization
NLCD	National Land Cover Data
RCUZ	Range Compatible Use Zone
TM	Thematic Mapper
USGS	United States Geologic Survey

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14. ABSTRACT

Marine Corps Base (MCB) Camp Lejeune, North Carolina, is experiencing increased pressure on its military mission activities due to the development or placement of land uses near the installation boundaries. The new land uses, often described as "urban encroachment," may in some way conflict with the ongoing activities at an installation. To begin to deal with this issue, it is useful to clearly establish the historical urban growth in areas surrounding a military installation. In this study, development in each decade since the establishment in 1941 of MCB Camp Lejeune has been traced using growth information and recent advances in computer analysis techniques based on remotely sensed satellite data to establish a scientifically derived baseline of growth near the installation.

15. SUBJECT TERMS
land management, satellite imagery, urbanization, Marine Corps, military training, military installation, encroachment, Camp Lejeune, NC

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