HUMAN MIGRATION AND WATER QUALITY CHANGE
IN THE AUSTIN-SAN ANTONIO CORRIDOR OF CENTRAL TEXAS

DISSERTATION

Presented to the Graduate Council of
Southwest Texas State University
in Partial Fulfillment of
the Requirements

For the Degree of

Doctor of Philosophy

By

Paul D. Sutton

San Marcos, Texas
December, 2001

To My Family

ACKNOWLEDGEMENTS

I would like to thank the following people for their individual contributions to my education and this dissertation: Dr. Richard Earl, Dr. John Tiefenbacher, and Dr. Charles Johnson, each of whom as committee member played an important role in shaping the document in front of you; Dr. Craig Colten, who patiently guided me through the proposal stage of this project; and my friend Dr. Fred Day, who took over Dr. Colten's position as committee chair and provided the guidance and encouragement to ensure that this project was finished. I would also like to thank my parents, Tommy and Sara Sutton, who freely offered their emotional and financial support whenever needed and, more importantly, taught me to make good decisions based on a sound set of core values. Finally, I would like to thank my daughters, Hannah and Carolyn, and my wife, Susanne, for their love and patience throughout the research and writing of this dissertation.

This dissertation was submitted to my dissertation committee on September 10, 2001.

CONTENTS

Page

LIST OF TABLES ix

LIST OF ILLUSTRATIONS xi

ABSTRACT. xiii

Chapter

1. INTRODUCTION 1

Significance of Research 4

Dissertation Organization 7

2. FOUNDATIONS OF RESEARCH 9

Population and Environment 10

Water Quality 19

Summary 30

3. METHODOLOGY AND DATA 32

Quantitative Methodology 33

Descriptive Case Study Methodology. 34

Spatial Units of Analysis 36

Data 39

Chapter Page

4. STUDY AREAS 42

The Austin-San Antonio Corridor Study Area 42

Focus Watersheds 50

5. QUANTITATIVE RESULTS 58

Overview of Demographic Data 58

Results 59

Summary 71

6. CASE STUDIES: POPULATION AND CHANGE 72

Onion Creek 72

Plum Creek 92

Population and Demographic Change in Review 110

7. CASE STUDIES: WATER QUALITY AND RELATIONSHIP TO POPULATION CHANGE 113

Onion Creek 114

Plum Creek 137

Water Quality Change in Review 148

8. CONCLUSIONS 152

Review of Research Findings 153

The Hypothesized Model in Light of Research Findings 155

Other Observations and a New Model 157

Final Thoughts 159

Appendix Page

WATER QUALTIY AND NONPOINT SOURCE POLLUTION CONTROL 161

WORKS CITED 164

LIST OF TABLES

Table Page

5.1 Demographic Characteristics and Percent Change in Mean Water QualityIndicators for Watersheds in the Austin-San Antonio Corridor, 1980-1990 66

6.1 Platted Subdivisions in the Onion Creek Watershed by Size and Year Platted 74

6.2 Household Income in the Onion Creek Watershed, 1990. 78

6.3 Educational Attainment in the Onion Creek Watershed, 1990 79

6.4 Race and Hispanic Origin in the Onion Creek Watershed, 1990 81

6.5 Population Age Structure by Subunits in the Onion Creek Watershed, 1990 83

6.6 Place of Residence in 1985 in the Upper Onion Creek Watershed, 1990 87

6.7 Birth Place of Residents in the Upper Onion Creek Watershed, 1990 89

6.8 Place of Residence in 1985 in the Lower Onion Creek Watershed, 1990 91

6.9 Household Income in the Plum Creek Watershed, 1990 95

6.10 Population Age Structure by Subunits in the Plum Creek Watershed, 1990 97

6.11 Race and Hispanic Origin in the Plum Creek Watershed, 1990. 99

6.12 Educational Attainment in the Plum Creek Watershed, 1990. 101

6.13 Summary of Demographic Change in Caldwell County between 1980 and 1990. 104

Table		Page

6.14	Place of Residence in 1985 in the Plum Creek Watershed, 1990	106
6.15	Occupied and Vacant Housing Units in the Plum Creek Watershed, 1990 . .	108
6.16	Housing Units in the Plum Creek Watershed by Year Structure Built, 1990.	109
7.1	Agricultural Land Use in Hays County	123
7.2	Annual and Mean Precipitation for Austin and San Antonio, 1970-1993.	127
7.3	Platted Subdivisions in the Lower Onion Creek Watershed.	128
7.4	Platted Subdivisions in the Upper Onion Creek Watershed.	136
7.5	Agricultural Land Use in Caldwell County	145
7.6	Water Quality Data from Secondary Monitoring Stations in the Plum Creek Watershed	146
7.7	Precipitation at Selected Cities in the Austin-San Antonio Area: September 7-8, 1987	149

LIST OF ILLUSTRATIONS

Figure		Page
1.1	Conceptual Model Linking Migration and Water Quality.	3
4.1	Counties of the Austin-San Antonio Corridor	43
4.2	Physical Geography of the Austin-San Antonio Corridor.	45
4.3	Population Distribution in the Austin-San Antonio Corridor, 1990.	49
4.4	Population Growth Rates in the Austin-San Antonio Corridor, 1980 to 1990	51
4.5	Locations of the Onion and Plum Creek Watersheds within the Austin-San Antonio Corridor	52
4.6	Onion Creek Watershed.	54
4.7	Plum Creek Watershed	56
5.1	Mean Population Density Change for Watersheds in Analysis between 1980 and 1990.	60
5.2	Population Density for Watersheds in Analysis in 1990	61
5.3	Population Density for Watersheds in Analysis in 1980.	62
5.4	Number of In-migrants per Square Mile for Watersheds in Analysis between 1975 and 1980	63
5.5	Number of In-migrants per Square Mile for Watersheds in Analysis between 1985 and 1990	64
6.1	Census Divisions in the Onion Creek Watershed	76
6.2	Census Divisions in the Plum Creek Watershed.	94

Figure | Page

7.1 Land Use and Cover in the Onion Creek Watershed 116

7.2 Annual Mean Dissolved Oxygen Concentrations in the Lower Onion Creek Watershed 118

7.3 Annual Mean Concentrations of Nitrogen as Ammonia Nitrate in the Lower Onion Creek Watershed 119

7.4 Population Growth and Annual Rate of Change for Hays County, 1970 to 1996 120

7.5 Annual Mean Fecal Coliform Concentrations in the Lower Onion Creek Watershed 125

7.6 Annual Mean Dissolved Oxygen Concentrations in the Upper Onion Creek Watershed 131

7.7 Annual Mean Fecal Coliform Concentrations in the Upper Onion Creek Watershed 132

7.8 Annual Mean Concentrations of Nitrogen as Ammonia Nitrate in the Upper Onion Creek Watershed 133

7.9 Annual Mean Dissolved Oxygen Concentrations in the Plum Creek Watershed 139

7.10 Annual Mean Fecal Coliform Concentrations in the Plum Creek Watershed 141

7.11 Annual Mean Concentrations of Nitrogen as Ammonia Nitrate in the Plum Creek Watershed 142

7.12 Population Growth and Annual Rate of Change for Caldwell County, 1970 to 1996 143

ABSTRACT

This study of the role of human migration in surface water quality change contributes to the much larger body of literature pertaining to the role of population in changing the environment. This research tests a hypothetical model linking migration and changes in population composition (e.g., age, income, race/ethnicity) to water quality change. Collectively the new population may act differently including the way in which they use land. Finally, a modified system of land use will be reflected in changes to water quality.

The study utilizes a multi-method research design using a quantitative approach for addressing the basic question of whether a relationship exists between various demographic characteristics and water quality indicators such as dissolved oxygen, nitrogen, and fecal coliform. The second part of the research design revolves around two descriptive case studies of watersheds within the larger Austin-San Antonio Corridor. The case studies were designed as a framework for collecting evidence concerning the existence of the hypothesized linkages between migration, demographic change, land use, and water quality.

The quantitative portion of the research identified significant relationships between several different combinations of demographic and water quality variables. A U-shaped relationship existed for several variables, with both the most and least demographic

pressure resulting in better water quality and moderate pressure tending to lead to the worst water quality. Overall, the findings for the case studies were limited, primarily because of the inconsistent reporting of water quality data and the scale at which the most detailed census data was available. One notable unexpected finding was that land speculation appears to affect agricultural land use patterns and therefore seems to have been an important factor in water quality change in the study area.

Keywords: population-environment interaction, water quality, Central Texas

CHAPTER 1

INTRODUCTION

The National Research Council's (NRC) 1999 report, *Human Dimensions of Global Environmental Change,* identifies several broad areas of interdisciplinary environmental research for the next decade. One such area of research focuses on the search for the social processes, such as population dynamics, that underlie human relationships to the environment. More specifically, the NRC put forward a number of questions that need to be addressed in the coming decade, including: "What are the linkages among land use, migration, political and economic changes, cultural factors, and household decision making?" and "What are the interrelations between [human] migration and environmental change?" (National Research Council 1999, 58). In my dissertation research I address aspects of both of these questions using a multi-method research design to explore the linkages between migration and water quality in the rapidly urbanizing nine-county Austin-San Antonio Corridor of central Texas.

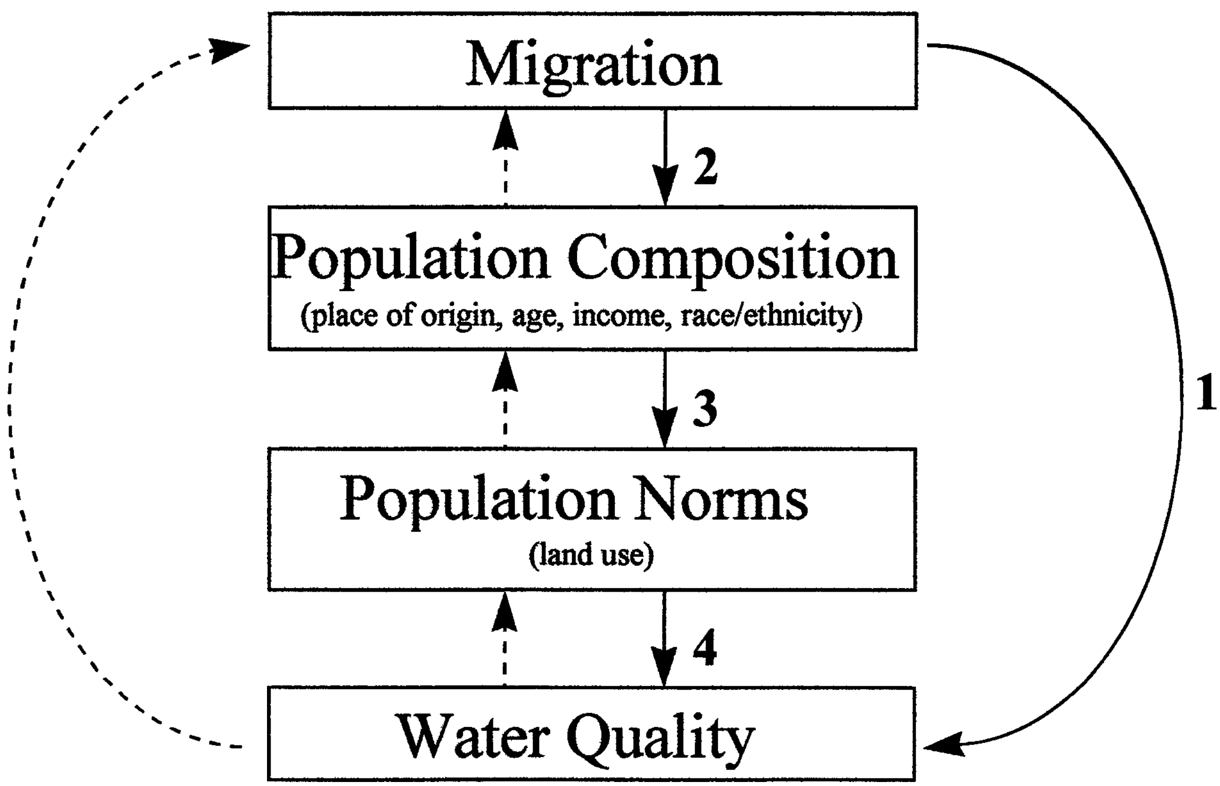
This research adds to the larger scholarly debate on the relationship between human population and the environment by testing the commonly held theory that human population growth degrades the environment. From the modern genesis of this debate, Thomas Malthus' *An Essay on the Principle of Population* (1798), scholars from a variety of academic fields have made significant contributions, often working at the periphery of their own disciplines. Geography, however, brings a long tradition of study in the area of "man-land" (human-environment) interactions. Geographers have not always responded to the opportunity to take a central role in advancing knowledge of the relationship between the population and environment, preferring in the recent past to focus on the organization of space instead (Kates 1987). This does not mean, however, that geographers have been absent from the debate; they made their mark in the context of influential works such as *Man and Nature* (Marsh 1864), *Man's Role in Changing the Face of the Earth* (Thomas 1956), and *The Earth as Transformed by Human Action* (Turner et al. 1990). This study continues research into the human-environment relationship per Kates' (1987) call.

Specifically the goal of this research is to expand our understanding of the relationship between population and the environment by exploring the idea that migration does more than simply increase the number of people. It also changes the demographic composition of that population. The changing composition of the population may in turn be reflected in land use change that can have significant impacts on water quality (figure 1.1). The hypotheses for this investigation are:

1. There is a significant relationship between migration and water quality.
2. Migration creates significant changes in the demographic and socio-economic composition of a population.
3. Changes in the population composition create significant changes in land use patterns.
4. Changes in land use significantly affect water quality.

FIGURE 1.1

Conceptual Model Linking Migration and Water Quality



Note: Solid lines reflect linkages specifically examined in this research, while dashed lines acknowledge the possible existence of relationships operating in the opposite direction.

Significance of Research

A long history of scholarly work on the relationship between the population and environment provides the basis for expanding our understanding of that relationship. This research examines the role that human migration plays in modifying the environment. Migration is often cited as one of several variables that modify the relationship between population and environment, however little research has been undertaken to study this systematically. Research efforts that have explicitly examined migration have tended to focus on it as a response to environmental change rather than a dynamic component of the forces causing change. For example, migrants' decisions to move should be viewed in the context of "environmental stress" (broadly defined as social, economic, and physical environmental stress) in the current place of residence and the migrants' threshold for stress (Wolpert 1966). More recently the relationship of physical environmental degradation to violence and "environmental refugees" has been examined (Homer-Dixon et al. 1993; Homer-Dixon and Levy 1995). The relationship between migration and the environment should be addressed not from the perspective of what caused the migration, but rather the impact of the migrants on their destination.

Examining the relationship of migration to environmental change requires considerable amounts and types of data. At the most basic level, good migration and environmental data are required. There are two alternatives to meet this need. One option is to collect data using surveys to monitor change over time. Another option is to study a location where the data are available. Constraints of time and money make the first option less attractive. Demographic and environmental data collection and maintenance are challenging and expensive tasks that only the wealthiest and most developed countries have performed consistently, limiting convenient study sites.

Virtually all efforts to examine the interplay between population and environment have been conducted in less developed areas of the world, such as the Dominican Republic (Sambrook, Pigozzi, and Thomas 1999), Benin (Agbo et al. 1993), Indonesia (Brechin et al. 1993), and Zambia (Lassilly-Jocob 1999). This research is an opportunity to examine the relevance of common conceptual approaches to population-environment relationships in the context of a more developed region, and to critique the classic assumption that there is a direct relationship between population and environment, best exemplified in the Malthusian perspective. In addition, the possibility of the relationship being mediated by intervening variables will be examined.

This research focuses on the broader population and environment debate testing the neo-Malthusian assumption that increased population pressure from migration degrades water quality. The notion that population growth is inherently "bad" for the environment is a common idea seen in the mission statements of environmental organizations such as Zero Population Growth (2000), Californians for Population Stabilization (2000), and Alternatives to Growth Oregon (2000). These organizations are not basing their objectives on fringe ideas, but rather on mainstream ideas taught in most population, economic, and environmental textbooks, such as Hardin's Tragedy of the Commons and Ehrlich's oft-mentioned equation (I)mpact = (P)opulation x (A)ffluence x (T)echnology (e.g., Berry, Conkling, and Ray 1993; Weeks 1999). I assert that migration-driven population growth is inherently different than traditional growth based on differential fertility and mortality rates and may eventually be reflected in the environment in unexpected ways. The selective process of migration, particularly in very rapidly growing areas can lead to a vastly different population structure in terms of social, economic, age, racial, and ethnic characteristics. This new population structure will, in turn, be reflected in land use patterns as different ideals and constraints operate within the new population. Thus migration may prove to both exacerbate and moderate classic notions of population pressure based solely on the number of individuals. To examine the broad concept of environmental impacts I have chosen to focus exclusively on water quality, a critical component of the environment. This has several important advantages. First, all surface fresh water exists in a watershed which is a definable geographic area with static boundaries providing an appropriate analytical unit. In addition, water quality is monitored relatively easily and has been an important issue for a long enough period that good data are available.

Quality data and clearly defined analytical units are important elements for successful quantifiable research, but are often difficult to obtain in studies using a combination of demographic and environmental data. Air quality is relatively easy to monitor, but is not confined to clearly defined spatial units. Studies of soil loss can be attributed to specific areas, but are not measured with great accuracy. In the case of soil erosion, researchers often estimate soil loss based upon certain parameters, but these formulae are often of questionable validity as they are derived in environments vastly different from where they are being applied (Wischmeier 1976; Stocking 1987). Studies involving deforestation as a form of environmental degradation are perhaps the most common in the literature (Myers 1990; Schmink 1994; Sambrook, Pigozzi, and Thomas 1999). There is good reason for this emphasis on deforestation beyond the importance of the resource itself: deforestation, even more than surface water, is easily measured (using aerial photography, satellite imagery, historic maps, or even oral description by locals) and can be calculated for any number and size of spatial unit.

Research pertaining to humans as agents of environmental change has value for both basic science and environmental policy decisions (NRC 1999). This research will contribute to the advancement of both basic and applied science. This study will help to better understand the relationship between migration and water quality by testing the common idea that population growth degrades water. This research also seeks to improve our understanding of the relationship between population and environment by focusing on the impact of migration on the environment. Improving this understanding will guide environmental policy and planning decisions related to water quality, particularly in areas where migration is the principal process behind rapid population growth.

Dissertation Organization

This dissertation essentially can be divided into four sections: introductory chapters (1 through 4), quantitative results (Chapter 5), descriptive case study results (Chapters 6 and 7) and conclusion (Chapter 8). In Chapter 2 the literature pertaining to the interaction between population, the environment, and water quality is reviewed. In Chapter 3 the research methodologies are outlined. The discussion of methodology covers both the quantitative that test for significant relationships between several demographic and water quality variables (results reported in Chapter 5), and the case studies that examine the hypothesized causal chain linking migration to water quality change (results reported in Chapters 6 and 7). Issues pertaining to the primary data set are also examined in Chapter 3. Chapter 4 provides an overview of the entire Austin-San Antonio Corridor study area, in addition to a more detailed description of the Plum and Onion Creek Watersheds (the two case study watersheds). Chapter 5 begins the presentation of research analysis. In Chapter 5, the results based on the quantitative methodology are presented, highlighting significant relationships between demographic and water quality variables. Chapters 6 and 7 are the product of the case study methodology. In Chapter 6 the 1990 demographic characteristics of Plum and Onion Creeks are examined in great detail. Chapter 6 continues with a discussion of the changes in population since 1980 that created the 1990 patterns, focusing on the role of migration in the change process. In Chapter 7 the demographic portrait of each of the watersheds developed in Chapter 6 is used as backdrops against which changes in water quality are interpreted. In the conclusion (Chapter 8) the results of each of the methodological approaches are reviewed and reinterpreted in the context of the combined results as well as other observations made in the course of conducting this research.

CHAPTER 2

FOUNDATIONS OF RESEARCH

In an examination of the relationship between population and the environment, and more specifically the relationship between migration and water quality, several themes within the literature seem to be relevant. Most important are those themes that regard the interaction between population, the environment, and water quality. In addressing these themes the first task is to place this research within the larger body of literature pertaining to the impact of population on the environment. The focus of the literature review then turns some of the specifics of how migration as a component of population change might impact the environment. The primary focus in this section is the cultural conflict and change that can occur when large numbers of migrants enter a new community.

The larger area of interest in this research is the relationship between population and the environment, but the specific question asked here is the role of migration in water quality change. It is essential then that a solid understanding of water quality and major forces contributing to water quality are addressed. With this in mind the basic characteristics of water quality are discussed. The discussion of water quality is divided into several section to help simplify what is in fact a large and complex body of literature. The physical, biological, and chemical characteristics of water quality are first discussed in individual sections. These three sections are followed by a brief review of issues pertaining to water quality measurement. Recognizing the importance of land use in determining water quality the chapter ends with a discussion of the relationship between land use and water quality.

Population and Environment

Positions in the Population and Environment Debate

The relationship between human population and the environment has been a topic of scholarly debate for at least 200 years. In 1798, in the first edition of *An Essay on the Principle of Population*, Thomas Malthus warned of a tragic sequence of death and destruction as population growth pressed against the Earth's ability to meet its most basic needs. Widely distributed works including *The Population Bomb* (Ehrlich 1968) and *The Limits to Growth* (Meadows et al. 1972) brought Malthus' ideas into modern debate. According to many, population growth has been a (or *the*) major cause of environmental problems (e.g., Ehrlich and Ehrlich 1990; Kates 1996; Smail 1997). Neo-Malthusians, including Ehrlich, began coming under attack in the 1970s as opposing ideas shifted blame for environmental degradation from population growth to technology (Commoner 1972), or exhorted the ingenuity of humans to overcome difficulties regardless of their cause (Simon 1981). The problem with these and other views of the population-environment question is that they have tended to take vastly different viewpoints regarding the role of population pressure in environmental change. Those that do consider population pressure one of the driving forces in environmental change make only limited attempts to examine variations in population composition that may determine the eventual impact of that group of people on the environment.

Beginning in the late 1980s, scholars began moving beyond the more extreme views of population-environment relationships. Research specifically addressed several aspects of the population-environment, including land-use change (Meyer and Turner 1994), land degradation (Blaikie and Brookfield 1987), and deforestation (Schmink 1994). In the 1990s scholars began shifting the focus towards a more complex view of the relationship. It has become apparent to a growing number of researchers that a simple relationship does not exist between population and the environment, and that research has focused too much on the numbers of people (Sage 1994). This development has prompted calls for research to examine the interrelationship of variables that modify the relationship between population and the environment. Variables that mediate the relationship between the population and environment fall into several broad categories, including: technology, economics, policy, socio-political boundaries, and culture (Ness, Drake, and Brechin 1993).

The NRC notes that some progress has been made in understanding broader population-environment relationships; however, in the future, migration rather than changes in fertility and mortality, will be the most important demographic link between population and environmental change (NRC 1999). While it has been found that environment influences migration, particularly in the context of environmental refugees (Homer-Dixon and Levy 1995), little specific research has focused on how migration leads to changes in the environment.

The study of how migration modifies the physical environment has not yet become an important area of research. Two aspects of the migration process, however, are potentially important here. The first is the classic assumption that larger populations will place pressure on the physical environment ultimately resulting in environmental degradation (Ehrlich 1968; Ehrlich and Ehrlich 1990; Ehrlich, Ehrlich, and Daily 1993). The second aspect, and the critical element in this research, is the notion that migration not only increases the number of people in a given place, but also changes the socio-economic composition of that population.

Population Growth and the Environment: Classic Notion/Limited Research

From the time of Malthus, population research related to the environment has been enmeshed in a larger literature on population growth and economic development in less-developed countries. Because of this combined focus on development, environment, and population growth much of the literature has focused on one demographic variable (population growth), availability of natural resources (i.e., food and energy), and almost exclusively worked in the context of the developing world (Pebley 1998).

The first modern era of environmental concern in population research, during the 1940s and 1950s, focused on limited natural resources (Ruttan 1993). During this era a new concern for limited natural resources brought about a significant change in how researchers thought about population and economic development. Before World War II, population researchers believed that long-term changes in fertility and mortality were brought about by the economic and social change accompanying industrialization (Davis 1945; Kirk 1944). Researchers were surprised when shortly after the war, population growth rates in many developing countries began to increase rapidly as a result of declining mortality. What was particularly interesting was that the increases were caused by external forces such as the introduction of medicines and public health programs, rather than internal social and economic change. Researchers became concerned that the rapid increases in population were slowing the economic development that might lead to fertility declines (Demeny 1988). Out of these observations emerged a new orthodoxy: that the extreme rates of population growth in developing countries could slow development and exhaust natural resources, and as a result fertility control programs were necessary to counter rapidly declining mortality (Hodgson 1988).

For many population researchers, early evidence that population growth might slow development and exhaust resources led not to further research on these issues but instead to extensive research on how to reduce fertility (for a review see, Donaldson and Tsui 1990). Research on population, development, and resources continued through the 1990s (Panayotou 1996; Repetto 1987; Ridker 1972). Despite this research little direct scholarly attention had been given to the relationship of population and resources specifically and population and the environment more generally by population researchers. However, the reason for this neglect was not that it was deemed unimportant, but rather that its importance was taken for granted and attention was focused instead on the need for fertility control instead (Davis 1991).

In the late 1970s the basic assumption that population growth hindered economic growth and led to severely degraded natural resources was attacked by Julian Simon (1977; 1981). Simon believed that moderate population growth would lead to technological innovation and that substitutes for limited resources would be found. Partly as a result of the popularity of Simon's views of the relationship between population and environment, the National Academy of Sciences (NAS) formed the working group on Population and Economic Development. The working group's report concluded that population growth can have negative environmental outcomes, not just in terms of limited resources, but it can also contribute to pollution, climate change, and decreased species diversity. The existence and size of these effects, however, depends on the social institutions that control the use of resources (National Academy of Sciences 1986).

Since the NAS report appeared in 1986, there has been a significant increase in the attention that population researchers have given environmental issues. Other factors contributing to this increase are the increasing scientific evidence about global environmental effects and growing popular concern about the environment. Papers by social scientists and population researchers have appeared as a result of international conferences and working groups, however the number of studies remains small (for a review see: Palloni 1994; Preston 1996).

Since the emergence of environmental awareness in population research in the 1940s and 1950s researchers have, as discussed in detail earlier, assumed the importance of population growth to environmental quality and focused most efforts on controlling fertility and population. This has been the most obvious reason for limited research in the area of population and the environment, but not the only one.

Pebley (1998) identifies two other reasons that have contributed to the limited amount of research specifically on the population-environment interaction by population specialists. One of these reasons is that some population researchers have come to the conclusion that the central causes of environmental problems are not demographic and are therefore not principally within the realm of demographic research (McNicoll 1990; Panayotou 1996). This conclusion is obviously opposite of the dominate paradigm which assumes the importance of population. These researchers base this conclusion on two documented ideas. First, factors such as social institutions, markets, and technology are at least as important as population growth in modifying the environment. And second, if any direct impact of population growth does exist, it is probably muted by feedback from growth-induced technology (Boserup 1965,1981; Simon 1981) or fertility reduction (Lee 1987, 1997).

Another reason for the lack of detailed research on population and the environment is that it requires expertise not only in population studies (a social science), but also in one or more natural sciences disciplines such as chemistry, biology, agronomy, or climatology. Some efforts have been made to solve this problem through interdisciplinary collaboration (e.g., Gaffin, O'Neill and Bongaarts 1996). Relatively few of these collaborative efforts including population researchers and natural scientists have been attempted, however, as significant differences in approach and basic assumptions exist between the two groups (Pebley 1998). Social scientists are often frustrated by natural scientists who according to Preston (1994, 90) are "too wedded to the primitive, biological model of human beings, whereby humans are distinguished from ants or seagulls only by their greater capacity for ecological destruction." Natural scientists undoubtedly have similar complaints about population researchers.

Migration, Culture Change, and the Environment

A guiding idea in this dissertation is that there is a link between changes in population that extends beyond mere numbers of people. This alternative link between population and environmental change is culture, particularly as it manifests itself in actions and lifestyles that impact the environment. There is a long tradition, particularly in the fields of anthropology and conservation philosophy, teaching that culture strongly influences how people use their land (Rockwell 1994). While not questioning that culture might have played a role in determining how people used the land in the past, some have questioned whether culture still plays a role in a modern complex society where no clear society-wide culture exists (Kay 1985; Tuan 1968). While true that it is difficult to identify a singular culture in today's American society, it does not seem to follow that a single culture is required for it to play a role in determining how people use their land. For example, one of the most obvious reflections of a culture is its laws, which at least in a democratic society require only a majority of the voting population to create (Rockwell 1994). It seems to follow then that in a complex modern society culture can still play a profound role in determining land use by granting the ideas of certain cultural groups legal status. The mix and power of the competing cultural groups will, at least in part, determine land use.

The essential argument is that migration not only modifies the number of people living in a given place, but the composition of the population as well. Migrants or "newcomers" often differ from the locals or "long-term residents" in terms of age, wealth, race, educational attainment or of other demographic characteristics. Newcomers also likely have attitudes and beliefs which differ from the long-term residents about a variety of issues including environmental concerns. A number of studies about the urban-to-rural population turnaround of the 1970s noted value differences and conflict between long-term residents and newcomers. Examples of such conflicts include environmental preservation and growth issues in Maine (Ploch 1978), growth issues in Wyoming (Cockerham and Blevins 1977), growth and preservation issues in Colorado (Graber 1974), and housing codes in California (Sokolow 1977). The theoretical rationale behind these conclusions is that newcomers of urban origin bring particular sociocultural identities to the rural communities to which they migrate. This identity and related values differ from those held by longer-term residents (Smith and Krannich 2000). Price and Clay (1980) referred to this difference as a "culture clash" between newcomers and longer-term residents.

Several theories exist for explaining why conflict over land use and environmental issues emerge between newcomers and longer-term residents, particularly in more rural settings. One theory for the conflict in less urbanized areas that are growing at least partly due to amenity attractions is that newcomers are reported to be particularly concerned about future growth and development "destroying" the amenities (including the environment) of their destination community. In this theory, sometimes called the "last settler" syndrome, newcomers are thought to be fleeing the results of growth in their previous place of residence. As a result the primary interest becomes stopping the same type of growth and change in their destination. Newcomers are more likely to support environmental protection and to oppose growth and development than are longer-term residents, who have never experienced the impacts of rapid urbanization (Ploch 1978).

Another theory seeking to explain the emergence of conflict over land use and environmental issues argues that urban-to-rural migrants tend to have common traits as a result of the selective nature of migration. It tends to support participation in social movements including environmental activities. Of these traits, higher levels of educational attainment has a particularly strong (though not perfect) relationship with higher levels of environmental awareness and support for environmental protection (Graber 1974; Schnaiberg 1986).

Finally, newcomers to a more rural environment may also support environmental protection because they are employed in fields divorced from the traditional occupations of the new community (Smith and Krannich 2000). For example, in many rural areas potentially environmentally destructive activities such as agriculture, ranching, and especially mineral extraction are the backbone of the traditional economy. New residents not tied to these traditional economic activities are often more supportive of efforts to curtail these activities than are longer-term residents with direct ties to these economic activities. In addition, newcomers attracted for outdoor recreation opportunities are also more likely to exhibit more pro-environmental attitudes than are longer-term residents (Theodori, Luloff, and Willits 1998).

In each of these three theories about cultural conflict between the newcomer and long-term resident, the newcomer has played the role of the environmentalist (regardless of the motivation). Interestingly, there is evidence that despite exhibiting more pro-environment attitudes, newcomers' activities actually often consume more resources than those of the longer-term residents (Fuguitt, Heberlein, and Rathbun 1991). In some situations, the contradiction between newcomers' environmental attitudes and their level of resource consumption fuels the cultural conflict between newcomer and long-term resident.

Further differences and potential tensions between newcomers and long-term residents can be found in smaller established communities and urban sprawl at the edge of large cites. Much of this discussion has focused on differences and tensions between newcomers and long-term residents in smaller but well established communities. The situation is different in rapidly growing suburbs of a large city, where indeed no long-term residents exist. It seems clear here that little conflict is likely to occur since all are relatively new residents responding to similar forces pushing them to and/or pulling them to the suburbs (Rome 2001).

Water Quality

Water quality is the focus of this study. Whether water is determined to be "good" or "bad" quality depends upon its intended use. For example, biological and chemical measures may indicate that a particular body of water is not suitable for use as a public water supply, however, that same water might be acceptable for use as industrial cooling water. Thus water quality can only truly be assessed relative to a given use. Water quality is measured through a composite assessment of the chemical, biological, and physical properties of the water. Each of these aspects of water quality can be affected by changes in human activities, originating from either population changes or by modifications in the way the water is used.

Water Quality Characteristics and its Measurement

Physical Characteristics of Water

Physical characteristics of water include: total suspended and dissolved solids, turbidity, color, taste, odor, and temperature. Many of these physical properties result from or impact the biological and chemical components of water quality. Of all physical characteristics of water quality, suspended solids and sedimentation are among the greatest problems today. Sediment, such as clay particles, silt, sand, and even gravel, is nationally the most common pollutant affecting rivers and streams and the third most significant pollutant of lakes and ponds (USEPA 2000a).

Sedimentation and siltation can severely alter aquatic communities. Sedimentation may clog fish's gills, suffocate eggs and insect larva on the bottom, and fill in the space between rocks on the bottom where fish lay eggs. Suspended silt and sediment interfere with recreational activities and aesthetic enjoyment at water bodies by reducing water clarity and filling in water bodies. Sediments may also carry other pollutants into water bodies. Nutrients and toxic chemicals may attach to sediment particles on land and ride the particles into surface waters where the pollutants may settle with the sediment or detach and become soluble in the water (USEPA 2000b). Sediment-quality guidelines for organochlorine pesticides were exceeded in 36 percent of urban streams sampled by the U. S. Geological Survey (USGS) as part of the National Water-Quality Assessment (USGS 2001).

Human land use can cause sedimentation of water bodies. Rain washes silt and other soil particles off of plowed fields, construction sites, logging sites, urban areas, and strip-mined lands. Eroding streambanks also deposit silt and sediment in water bodies. Riparian vegetation removal can accelerate streambank erosion.

Other physical characteristics of water are taste, odor, and temperature. Taste and oder are often associated with vegetative decay and thus are important indicators of water quality. Decreases in water clarity can result from decay as well, but can also come from dissolved chemicals. Temperature is an important variable in determining whether a particular species can or can not live in a given body of water. Temperature will fluctuate naturally during the course of the year, but unusual increases or decreases can be an important sign of human impacts (Dzurik 1996).

Biological Characteristics of Water

A variety of biological factors contribute to water quality. Life that commonly exists in water bodies can range from large fish and aquatic plants to microscopic organisms. A sure sign of a severely polluted water body is the absence of life. By contrast, species diversity can provide an indication of the overall water quality since different organisms respond differently to changes in water quality. While the presence of most aquatic organisms is a indicator of good water quality the appearance of disease-causing organisms is not an indicator of good quality. The presence of these life forms decreases the water quality for human use.

Some waterborne bacteria, viruses, and protozoa cause human illnesses that range from typhoid and dysentery to minor respiratory and skin diseases. These organisms may enter waters through a variety of routes, including inadequately treated sewage, storm water drains, septic systems, runoff from livestock pens, and sewage dumped from boats.

Because it is prohibitive to regularly test water for every possible disease-causing organism, states and other jurisdictions usually measure indicator bacteria that are found in great number in the stomachs and intestines of warm-blooded animals including humans. The presence of indicator bacteria suggests that water may be contaminated with untreated sewage and that other, more dangerous, organisms may be present. States, tribes, and other jurisdictions use bacterial criteria to determine if waters are safe for recreation and shellfish harvesting (USEPA 2000b).

Pathogens represent the second most common pollutant in the nation's rivers and streams (USEPA 2000a). It might seem logical to assume that since agriculture is the leading polluter of streams and rivers that biological pollutants from intensive livestock operations would be major contributors to biological pollution. This logic might be extended to conclude that biological pollution might be less likely to be a problem in urban watershed. This logic, however, is not supported by the data that indicate that concentrations of fecal coliform bacteria is a greater problem in urban watersheds. Sources of biological pollution in urban watersheds include inadequately treated sewage, septic systems (USEPA 2000b), and pet wastes which are strongly correlated to human population (Waite 1984).

Chemical Characteristics of Water

The chemical quality of water pertains primarily to water's ability to dissolve many other materials. This includes a variety of salts and minerals, that contribute to water "hardness." Dissolved salts and minerals present in most water affect the smell and taste of the water. Excessive salt content can make water unsuitable for many uses. Water also contains dissolved gases, such as oxygen and carbon dioxide. Oxygen is of particular importance in water and is required for aquatic life. As a rule higher levels of dissolved oxygen indicate a "healthier" water body. Very low dissolved oxygen levels can indicate that pollution by organic material is consuming the oxygen in the water as it decomposes. The actual amount of dissolved oxygen will, however, fluctuate depending on the time of day and temperature. Cold water can hold more oxygen than warm water and the photosynthesis of aquatic plants will cause oxygen levels to increase over the course of the day and then decline over night as plants stop producing oxygen aquatic life uses some of the balance.

One of the most important categories of chemical pollution in terms of its impact on the nation's water is nutrients. Nutrients are an essential building block of aquatic communities, but excessive nutrients (especially nitrogen and phosphorus) create excessive growth of aquatic plants, especially algae. This excessive growth of aquatic plants interfere with swimming and boating, and competes with more desirable aquatic vegetation. When, this extra vegetation decomposes, it consumes large amounts of oxygen, which can lead to fish kills, foul odors and taste, and increased water-treatment costs (USGS 1994).

The two most important nutrients in terms of water quality are nitrogen and phosphorus. Of these two nutrients phosphorus is a greater problem in urban watersheds, in part due to effluent from wastewater treatment plants (USGS 1999a). Phosphorus levels have been on the decline with improved treatment and growing numbers of states banning detergents containing phosphorus (USGS 1999b). In rural areas nitrogen is the more serious problem of the two major nutrients originating from fertilizer and manure (USGS 1994).

Nutrients are difficult to control because lake and estuarine ecosystems recycle nutrients. Instead of leaving the system, the nutrients cycle between algae and plant tissue, and bottom sediments. For example, algae may temporally remove much of the nitrogen from the water only to be returned when the algae die and decomposes. Therefore, gradual inputs of nutrients tend to accumulate over time rather than leaving the system (USEPA 2000a).

Two other important categories of chemical characteristics of water are toxic organic chemicals and metals. Toxic organic chemicals are carbon-based synthetic compounds such as PCBs, dioxins, and DDT. These synthesized compounds often persist and accumulate in the environment because they do not readily break down in natural ecosystems. Many of these compounds have been shown to cause cancer and/or birth defects in both humans and animals (USGS 1999a). Metals occur naturally in the environment, but industrial activities and mining have significantly changed their distribution in the environment. Metals tend to accumulate in animals as you climb the food chain (USEPA 2000b).

Chemical compounds that negatively impact water quality can be introduced by both human and non-human activity. However, the rate of the human-induced contamination is often many times the rate of natural geologic process for heavy metals such as mercury, copper, lead, and tin (Mason 1991). One method for human modification is the addition of pollutants into water draining into a river, stream, or lake. Researchers have examined the implications of transport and dispersal of chemical pollutants. For example, Graf (1985a; 1985b) examined the implication of increased salinity, and the presence of heavy metals and radioactive materials on water quality in the Colorado River Basin, and Marcus (1987) assessed the dispersal of copper in ephemeral streams. Phillips (1988; 1989) attempts to integrate watershed-level targeting with quantitative risk assessment to develop a model for evaluating the influence of smaller contributing areas on water quality in the larger watershed or basin. These studies of chemical pollutants shy away from discussions of the human systems leading to the introduced of the pollution into the stream, preferring instead to focus on the movement of the pollutants once in stream systems. Others have examined water pollutants of human origin, but have tied the source of the pollution to an immediate and obvious source such as urban runoff (Pope 1980; Carpenter 1999) rather than the human processes.

Water quality measurement

The ideas of "quality" and "use" are inseparable in the context of water quality management. Uses for water cover a range of activities, including: drinking, sanitation, industry, agriculture, navigation, and recreation. Recently, biotic diversity has emerged as an important non-human "use" (Perry and Vanderklein 1996). Each of these uses has different water quality requirements and consequently different combinations of physical, chemical, and biological characteristics will be important depending on the designated uses of the water. This aspect of water quality measurement and assessment has led to an array of techniques for the measurement and assessment of water quality (Barbour et al. 1995). Classical approaches to water quality assessment select a single attribute that refers to a narrow range of conditions. For example, reduced dissolved oxygen, biological oxygen demand, or specific toxins have been used (Karr 1991). Interest in the 1980s and 1990s shifted to more sophisticated measures of water quality that attempt to provide a better indication of all forms of degradation, including complex cumulative impacts (Karr 1991). These indices of water quality are called "multimetric approaches," since they attempt to incorporate not just one, but many different variables relevant to water quality. The Index of Biotic Integrity (IBI) was the first successful use of the multimetric concept (Karr 1981). Like other multimetric approaches, the IBI is useful but requires a large array of data. The extensive data requirement makes the IBI more appropriate for longitudinal studies of small areas. Because of this, extensive assessment efforts will continue to use single indirect indicators of water quality.

Human Factors in Water Quality: Land Use

In a study of the history of pollution in the Illinois River Colten (1992) observed that the passage of environment minded legislation alone would not ensure improvements in the water quality. Rather, Colten observed, it was the slow-moving public policy apparatus which largely determined the course of water quality improvement initiatives. Public policy definitely began to change in the 1970's. Largely as a result of the Clean Water Act of 1972 gross pollution of the nation's water by sewage and industrial waste is essentially a thing of the past. Aquatic organisms have returned to rivers, lakes, and estuaries where they had once all but vanished. Recreational waters that had been closed for health concerns have reopened (Griffin 1991). Despite these and other successes, approximately a third of the nation's rivers, lakes and estuaries are not safe for basic uses such as swimming and fishing (USEPA 1996b). In fact from 1972 until 1987 when the

Clean Water Act was amended, efforts to improve water quality focused primarily on addressing the obvious problems of municipal and industrial discharges of so called "point sources" of pollution (USEPA 2000b). The 1987 amendments to the Clean Water Act (see appendix for more detailed review of water quality legislation), known as the Water Quality Act, specifically set standards for "nonpoint source" runoff, that is the diffuse runoff pollution that does not enter streams from specific effluent discharge "points."

Today, nonpoint source (NPS) pollution is the principle cause of water quality problems. NPS pollution is a hard to manage problem because it is difficult to precisely identify the pollution source. Agriculture, forestry, grazing, septic systems, recreational boating, road surface, and construction are all potential sources of NPS pollution. Of these sources of NPS pollution agriculture is the leading contributor to water quality problems in all regions but estuaries where urban point and nonpoint sources become the greatest problems (USEPA 2000a). While agriculture and urban runoff are the two most important sources of NPS pollution all land uses can have impacts on water quality (USEPA 1996a). In the following section land use is examined as a factor in water quality.

Land Use and Water Quality

Land-use and land-cover change can have four major impacts on the hydrologic cycle and water quality: they can cause floods, droughts, changes in river and ground water regimes, and they can affect water quality. Of these impacts three primarily concern water quantity; for example clear cutting of forests can cause localized flooding. Land cover disturbances can also make less water available for groundwater recharge. Base flow of perennial rivers can in turn be diminished by reduced ground water flows to river systems. Less water recharging groundwater combined with reduced groundwater return to the river will concentrate flow at flood and peak periods and diminish flow during dry periods. Another consequence of these impacts on water quantity is the addition or removal of material from rivers and streams. Changes in land cover increasing flooding can also increase the amount of sediment reaching rivers and streams. Excessive sediment increases turbidity, which reduces the amount of sunlight reaching aquatic plants; covers fish spawning areas and food supplies; and clogs the gills of fish. In addition, other pollutants like phosphorus, pathogens, and heavy metals are often attached to the soil particles and end up in the water bodies with the sediment (USEPA 1996c).

Human activities introduce many other pollutants into the aquatic ecosystem. Some degree of success has been achieved in controlling point source pollution, however, many types of pollutants originate primarily from NPS. For example, a U. S. Environmental Protection Agency (USEPA) report estimated that 90% of both fecal coliform and nitrogen in the nation's water comes from NPS rather than point sources. Most pollutants originate from nonpoint sources (USEPA 1984). Agriculture and forestry are the two major sources of NPS pollutants, but urban storm runoff and combined sewer overflows are also major contributors (Rogers 1994).

Every land cover type impacts the hydrology and water quality of the region in a different way. For example, evidence indicates that more moisture reaches the ground either from more rain or drips from leaf condensation in forested areas than in similar places where the forest has been removed (Parsons 1960; Pereira 1973). However, while more water may reach the ground, forest litter and deep root systems help to transmit water to the soil by infiltration and thus help to control excess runoff and flooding during heavy rain events (Pereira 1973; Rogers 1994).

Grasslands like forest can have substantial impacts on the hydrologic cycle. The actual impact of any given grassland can vary substantially depending upon how it is managed. Grasslands with minimal compaction of the soil from grazing and dense cover can do an excellent job at controlling flood and erosion damage without reducing water yield of the watershed as much as forest (Ives and Messerli 1989).

Agricultural and residential land uses where humans have more aggressively modified the land cover tend to have greater negative impacts on hydrology and water quality than other land uses. Tarr and Ayres (1993) observed in a historical study of the Hudson-Raritan basin that water quality was most severely degraded between 1880 and 1970. The Hudson-Raritan basin was characterized by intense agriculture and rapid industrialization during those decades.

Agriculture is generally recognized as the leading source of NPS pollution. Several aspects of agricultural land use are important for understanding why it is the leading source of NPS pollution. First, planting and harvesting crops leaves the soil unprotected and as such more vulnerable to erosion. Second, agriculture often brings large groups of animals (e.g., cattle, pigs, or chickens) to very small areas. High densities can present serious problems for water quality if not managed properly in terms of their waste and increased erosion. Another, obvious and very important, contributor to water quality problems is the quantity of fertilizers and pesticides used.

Urban settlement represents the most striking human modification of a watershed and is another important source of NPS pollution in the nation's water bodies (USEPA

2000c). While urban land use places it behind agriculture as a source of NPS pollution, urban point sources of pollution (such as industry) increasing the potency of urban runoff (Rogers 1994).

Due to increased impermeable cover, urban development changes hydrologic patterns decreasing ground water recharge, increasing surface runoff and decreasing evapo-transporation. (Organization for Economic Cooperation and Development 1986). This increased runoff in the form of storm sewer flows has the effect of washing pollutants from streets, parking lots, and yards creating a spike in pollution load of stormwater at the beginning of the storm. This spike called the "first flush" washes automobile fluids and salt from roads, and pesticides and fertilizers from yards. Even rooftops often considered sources of relatively clean water can contain harmful metals (Good 1993).

Summary

This chapter was intended to serve two primary functions in this dissertation. The first was to place this research concerning the role of migration in water quality change within the larger body of research on the relationship between human populations and their environment. I began by focusing on the major philosophical position concerning population and environment, including: neo-malthusian perspectives such as Ehrlich's (1968) and more complex schemes such as Blaikie and Brookfield's (1987) political ecology. Moving from the discussion of positions within the debate it was observed that little empirical research existed, prior to the early 1990s, concerning the true nature of the relationship between population and the environment. It appears that the absence of research largely resulted from the pervasive notions that the role of population was a given fact or, in sharp contrast, that migration was one of many factors that modified the role of population beyond recognition.

The second function of this chapter was to introduce topics that will be important in conducting this research and interpreting the results. The objective of this research is to examine the role of migration driven population change in modifying water quality. Rural sociologists, among other researchers, have suggested that differences between newcomers and long-term residents in small towns do often exist and that tensions can and do often arise. In the context of this dissertation it is felt that the differences, that will be measured in terms of demographic change, between the long-term residents and in-migrant (newcomers) might result in meaningful changes in water quality. Since land use is a driving force behind surface water quality change, a basic review of the role of land use in this process was also presented.

CHAPTER 3

METHODOLOGY AND DATA

Two different methodological approaches are used in this dissertation. Ideally the research question and related hypotheses could be addressed using a single methodology; however, limitations of the data made it difficult to design a single quantitative methodological approach capable of addressing all the hypotheses. This multi-method approach was chosen to maximize the value of the available quantitative data while employing a more qualitative case study approach to questions that could not be addressed purely quantitatively with the available data.

The quantitative portion of the analysis and the descriptive case studies are designed so that together the research question and each of the related hypotheses can be addressed. The quantitative analyses use the available data to establish whether-or-not a significant relationship exist between various aspects of population (i.e., population change, absolute density, and number of in-migrants) and water quality. The chain of relationships whereby migration changes the socio-economic composition of the population which, in turn modifies land used and therefore water quality is examined using the case studies in Chapters 6 and 7 of this dissertation. Each of the two methodological approaches and their results could stand on their own, however, both were undertaken in order to more fully probe the larger research question concerning the relationship between migration and water quality change.

In the second half of this chapter other issues which are pertinent to both methodological parts of the research are discussed. The first of these issues is the watershed as a unit of analysis. In the quantitative portion of this research project demographic and water quality data are matched to the watersheds in the Austin-San Antonio Corridor. For the case study specific watersheds are chosen for a more qualitative and descriptive analysis. The remainder of this chapter focuses primarily on issues concerning the primary data sets used in both parts of this research most notably the demographic data from the census and water quality data from the Texas Natural Resource Conservation Commission (TNRCC).

Quantitative Methodology

Most variables related to water quality have significant volatility over the short term, making the identification of trends difficult for shorter periods of time. Ideally water quality data for all variables would be available for all stations over a long time period (20 years or more). Unfortunately, environmental data often lack consistency in the variables measured and stationed monitored. For example, of the over 400 monitoring stations only 109 have water quality data covering the period 1980 to 1990. This ten-year period is likely too short to identify meaningful trends in many variables related to water quality since the natural fluctuation is often greater than the perceived trend. When the time period of the study is extended over fifteen years (1975 - 1990) or twenty years (1975 - 1995) the number of available stations drops to 67 and 48 stations respectively. Even the number of stations reported for each of the time periods just mentioned are somewhat misleading since data for all variables are not collected at every station. No attempt was made to identify a single time period, be it ten, fifteen or twenty years, which best balanced the need to maximize the number of stations and ensure that water quality trends were real and not a result of natural fluctuation. Rather, the analyses were conducted at each of the three time periods (1980-90, 1975-90, and 1975-95).

Once the data had been matched to watershed geography, the watersheds were classified based on number of immigrants (1975-80 and 1985-90), population density (1980 and 1990), and percent change in population density (1980-90). In each of these cases 0.5 standard deviations above and below the mean were used as breaks for dividing the watersheds into three groups. A Kruskal-Wallis H test, which is a nonparametric version of an ANOVA, was used to test for significant differences in the water quality change in the groups of watersheds for each of the three measures of water quality. Finding significant differences in water quality change would support the hypothesis that water quality and migration are related. For the purpose of this study the relative relationships between the groups of watersheds are the most important. Therefore statistical significance as low as 0.25 are reported in the results.

Descriptive Case Study Methodology

The quantitative methodology test the basic hypothesis that migration and water quality change are related, and may cast some light on the ways that migration-driven population change lead to differential changes in water quality. The previous methodology did not have the ability to connect the individual links into a process. Here a descriptive case study approach is used to examine the hypothesized chain of events resulting in differential impacts on water quality. Specifically, two watersheds are selected for a more detailed look at the hypothesized chain of linkages. This serves not only to tie the links examined in the quantitative analysis together, but also to examine the final hypothesis that changes in attitudes and land use decisions resulting form migration are the final link between water quality change and migration.

The analysis follows an explanation-building strategy whereby a phenomenon is "explained" by stipulating a set of logical causal links about it (Yin 1989). The phenomenon examined here is the relationship between water quality and changes in population attributable to migration, including: density, racial composition, income levels, education and age structure.

In Chapter 6 the demographic changes in the Onion and Plum Creek watersheds between the 1970s and 1990 are examined in detail. This examination of demographic trends in the watersheds serves as an explanatory backdrop for changes in water quality outlined in Chapter 7. Water quality data from multiple monitoring sites within the watershed provides data to construct a picture of changing water quality between 1975 to 1995. These data permit the construction a narrative description of temporal changes in water quality supported by graphs and maps. Simultaneously, trends in water quality are examined against changes in the population detailed in Chapter 6. Temporal correlation between changes in population and water quality are examined for evidence of a relationship.

Evidence supporting logical connections between temporanous changes in demographic and water quality variables can come from a variety of sources (Trimble and

Cooke 1991; Colten 1993). Information from several different sources is used to construct logical links between changes in the population and water quality. Evidence supporting the links is taken from personal interviews, subdivision plat data, land-use maps, and the agricultural census.

Spatial Units of Analysis

Watersheds serve as the analytical units for this research. While many human decisions and administrative activities operate in different spatial frameworks, individual activities that affect water quality occur by definition in a watershed. Watersheds thus provide a framework for confining specific activities and conditions that impact water quality. Unfortunately most human data (demographic, social, and economic) units seldom match physical units. For this study the census block group (the smallest geographic unit at which data is still not suppressed by the Census Bureau) is combined in a way to approximate watershed boundaries. By working from the block groups and constructing larger composite units it has been possible to closely match human data to watersheds.

Watersheds as Management and Research Tools

Watersheds can range in size from a few acres to thousands of square miles (these are often referred to as river basins). Technically speaking, a watershed is nothing more than the area of land that supplies runoff to a central stream, river, lake, or other body of water (USEPA 1997). This description while simple, provides a framework to understand which aspects of watersheds are important to water quality management. A watershed is much more than just the water, rather it is the land from which the water drains. Watersheds thus provide a convenient natural division for monitoring and regulating human activities that contribute to changes in water quality. While these properties have been known for many years, it is only recently that policy makers in the United States have begun to introduce programs that take advantage of this.

The use of the watershed as a unit of organization and study is not a recent development. Organization of certain human activities along watershed boundaries can be found dating back thousands of years (Saha 1981). Drainage basins have also been proposed as units for "regional" studies and as divisions for regional government (Smith 1969). In hindsight it seems obvious that some of these uses for watersheds were doomed to failure as few of the human or larger natural systems fit neatly within this geography. More recent attempts at sub-dividing the Earth's surface include the ecosystem approach which provide a framework for structuring research, assessment, and management of all environmental resources. However, even the leaders in the development of ecosystem mapping concede that ecoregions may not be the best framework for any one particular resource (Omernik 1987; Bailey 1991; Bailey 1995; Omernik and Bailey 1997). It has become obvious that watersheds are not the ultimate geographic unit for management and research of all natural resources that some had proposed (Lotspeich 1980; Armitage 1995; Montgomery et al. 1995). However, it also seems clear that whenever the central focus of management or research is surface water quality and quantity that watersheds are the appropriate unit of analysis (Omernik and Griffith 1991; Omernik and Bailey 1997).

The Tennessee Valley Authority (TVA) represents one of the earliest efforts in the U.S. to utilize the inherent qualities of the watershed as a unit for integrating a host of economic, environmental, and social projects. Best known for its flood control, navigation, and power-generation programs, the TVA also developed pioneering programs in soil erosion management, reforestation, and economic development (Platt 1996). While not specifically focusing on water quality, TVA's integrative approach to river basin management has been important in the recent emergence of watersheds as a significant element of water quality management policy.

The current emphasis on watersheds in water quality policy dates to the 1970s. The Federal Water Pollution Control Act (FWPCA) of 1972 and its amendments, the Clean Water Act (CWA) of 1977 and Water Quality Act (WQA) of 1987, form the core of national water quality legislation in the United States. Current legislation mandates that both point and non-point source pollution must be considered in the management of water resources. This legislation also designated the USEPA as the federal agency responsible for establishing programs to achieve the mandates of the legislation. The USEPA in an effort to provide a structure for managing both point and non-point source pollution turned to a watershed-based management approach (Sidhu 1993). In 1991, the Texas legislature enacted the Texas Clean Rivers Act. This act established a program for the management of surface water quality based on USEPA guidelines (TNRCC 1997).

Watersheds as Operational Units of Analysis

Despite the benefits of working in the context of watersheds, water quality data in Texas has traditionally been collected based on stream segments. Stream segments are often not compatible with watersheds and often have breaks between segments in the middle of watersheds. Fortunately, all water quality monitoring sites have been referenced by the segment, and by latitude and longitude. The inclusion of grid coordinates in the data set facilitates the importation of the individual monitoring sites into a geographic information system (GIS) layer. A second GIS layer with watershed boundaries was overlaid on the coverage of monitoring sites to situate them in the appropriate watershed. This process resulted in some watersheds containing multiple monitoring sites. At this stage of it is preferable to use a single monitoring station located near the downstream limit of the watershed and with consistent data over the entire study period as the single indicator of water quality change for the entire watershed.

Data

The quantitative portion of this research draws upon U.S. Census data and water quality records of the TNRCC. This portion of the study will determine statistical relationships between migration and changes in water quality in the corridor region.

The core data for this analysis are migration data extracted from Census Summary Tape File Three (STF3) and detailed water quality data collected by TNRCC for use in monitoring both ambient and special situation water quality in the state of Texas. Census migration data based on the respondent's place of residence five years prior to the census is not as detailed as might be desired. However, census migration data represents a comprehensive and systematically collected source of migration information well suited to the task of establishing the scope of migration-driven population growth in the study area.

Good water quality data are also needed for this analysis. The TNRCC maintains a data base of surface water quality, the earliest records dating from 1968. This source includes data collected by TNRCC, and by other state and national agencies that routinely monitor water quality in the state of Texas, including the regional river basin authorities and the U.S. Geological Survey (Twidwell 2000). The earliest data have limited usefulness due to restricted coverage and inconsistencies. During the past thirty years, however, the water quality monitoring program in Texas has expanded coverage and improved data consistency. This has resulted in a water quality data set for the nine counties in this study including well over fifty thousand separate monitoring events at over four hundred monitoring stations. An average of ten different water quality variables were collected during each monitoring event resulting in a data set of over five hundred thousand records. Today water quality monitoring typically includes the core variables: conductivity, water temperature, dissolved oxygen, pH, secchi disk transparency, and total depth. In addition to these core variables, information on nutrients, fecal coliform, salinity, and other characteristics are available for certain locations. A comprehensive assessment of water quality requires all or most of this information since water pollution is not a single compound or specific conditions, but is rather a decline in the water's viability for certain uses. This complexity does not suit a statistical study calling for a single dependent variable (water quality).

To address the issue of measuring water quality three different measures of water quality are used: dissolved oxygen, nitrate, and fecal coliform. Rather than attempt to use or create a composite index of water quality the analyses are repeated with each characteristic as the dependent variable. These three water quality variables where chosen for several different reasons. Dissolved oxygen is generally considered one of the best indicators of water quality. Nitrate and fecal coliform were chosen because of their well documented connection to human population (USEPA 2000c; USGS 1994). Finally, they are among the most commonly collected variables and are useful as long-term water quality indicators.

As the final data set was constructed a significant amount of the water quality data had to be dropped because of multiple monitoring stations within a single watershed or because data were not collected at specific monitoring stations for a period long enough to make it useful. Further, the decision to not use the more specific measure percent saturation of dissolved oxygen instead of the simpler dissolved oxygen measures was based on data availability. Percent saturation of dissolved oxygen is a calculation that incorporates water temperature, as it determines the oxygen carrying capacity of water. Percent saturation of dissolved oxygen permits direct comparison of individual monitoring events regardless of water temperature. However, making this calculation requires water temperature which is not always recorded by the monitor. Thus using the percent saturation of dissolved oxygen would limit the data available for analysis. Since this study concerns itself with trends in water quality rather than individual monitoring events, the number of monitoring events in the data set was maximized and five-year averages around the beginning and end of the study periods were used to smooth out the fluctuations caused by differences in water temperature.

CHAPTER 4

STUDY AREAS

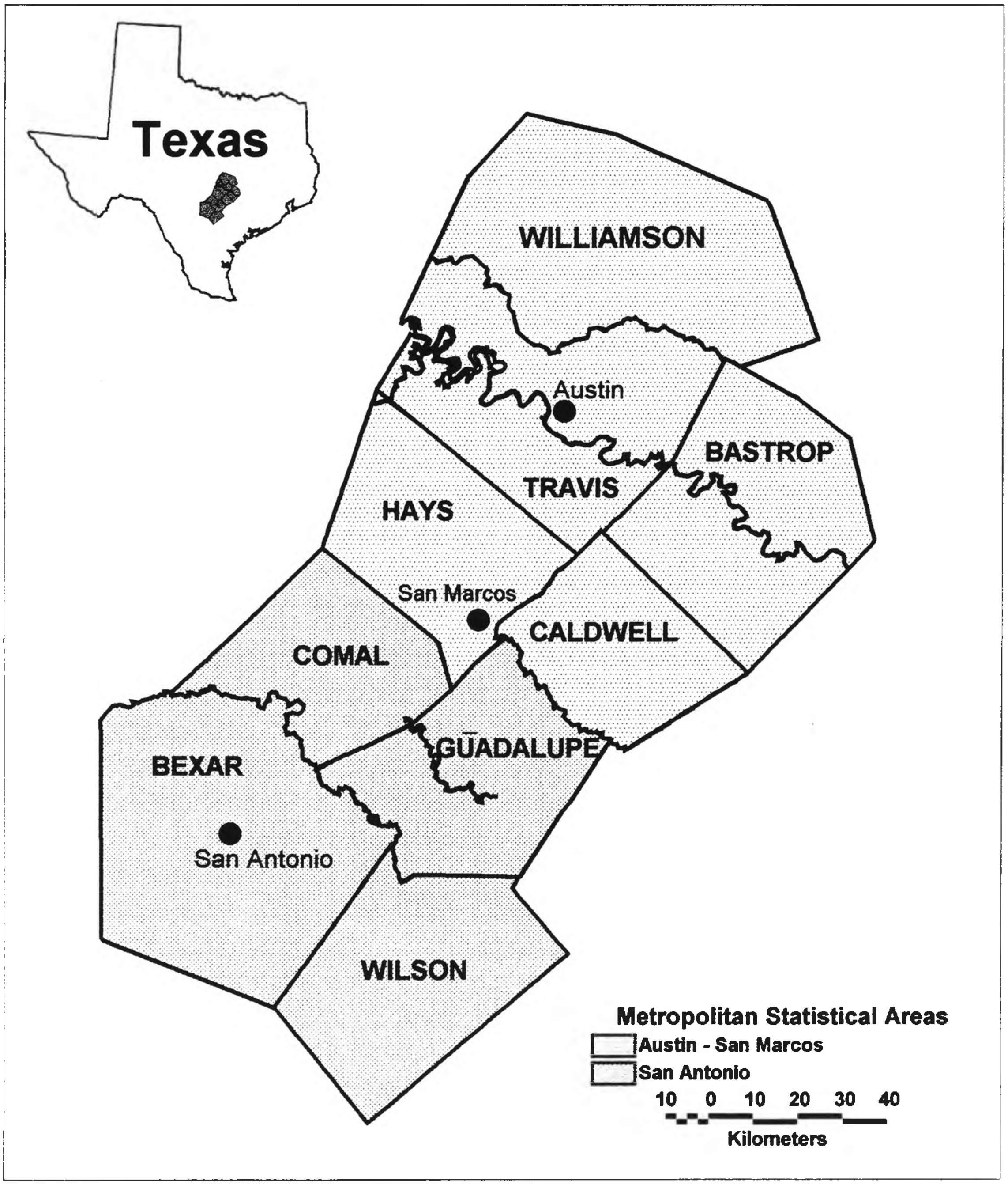
The study area for this dissertation is the Austin-San Antonio Corridor of central Texas. In this chapter the physical and human-demographic characteristics of the study area are discussed in detail. The second half of this chapter turns from the larger study area to the Onion and Plum Creek Watersheds which were chosen for more descriptive case studies.

The Austin-San Antonio Corridor Study Area

The study area for this research includes the nine-county Austin-San Antonio Corridor of Central Texas (Williamson, Travis, Bastrop, Hays, Caldwell, Comal, Guadalupe, Bexar, and Wilson counties) (figure 4.1). These nine counties correspond to the five counties forming the Austin-San Marcos and four counties of the San Antonio metropolitan statistical areas (MSAs) as defined in by the U.S. Office of Management and Budget, June 30, 1999. The region over the past fifteen years has experienced migration-driven population growth rates nearly three times the national average. Between 1990 and 1998, the Austin-San Marcos MSA grew by over 30 %, making it the seventh fastest growing MSA population in the county. The San Antonio MSA, while growing more slowly, ranked forty-ninth out of nearly 300 MSAs in the United States for the same time

FIGURE 4.1

Counties of the Austin-San Antonio Corridor



period with slightly over 16 % growth (United States Census Bureau 1999a; 1999b). If combined, the population of the region grew by nearly 22 % or what would have ranked as the twenty-fifth fastest growing MSA. These are extraordinarily high rates of growth for a region with a population of over two million; even more extraordinary if we consider that 70 % of those MSAs with more rapid rates of growth have less that a quarter of the population and several less than a tenth. This is one of the fastest growing regions in the United States.

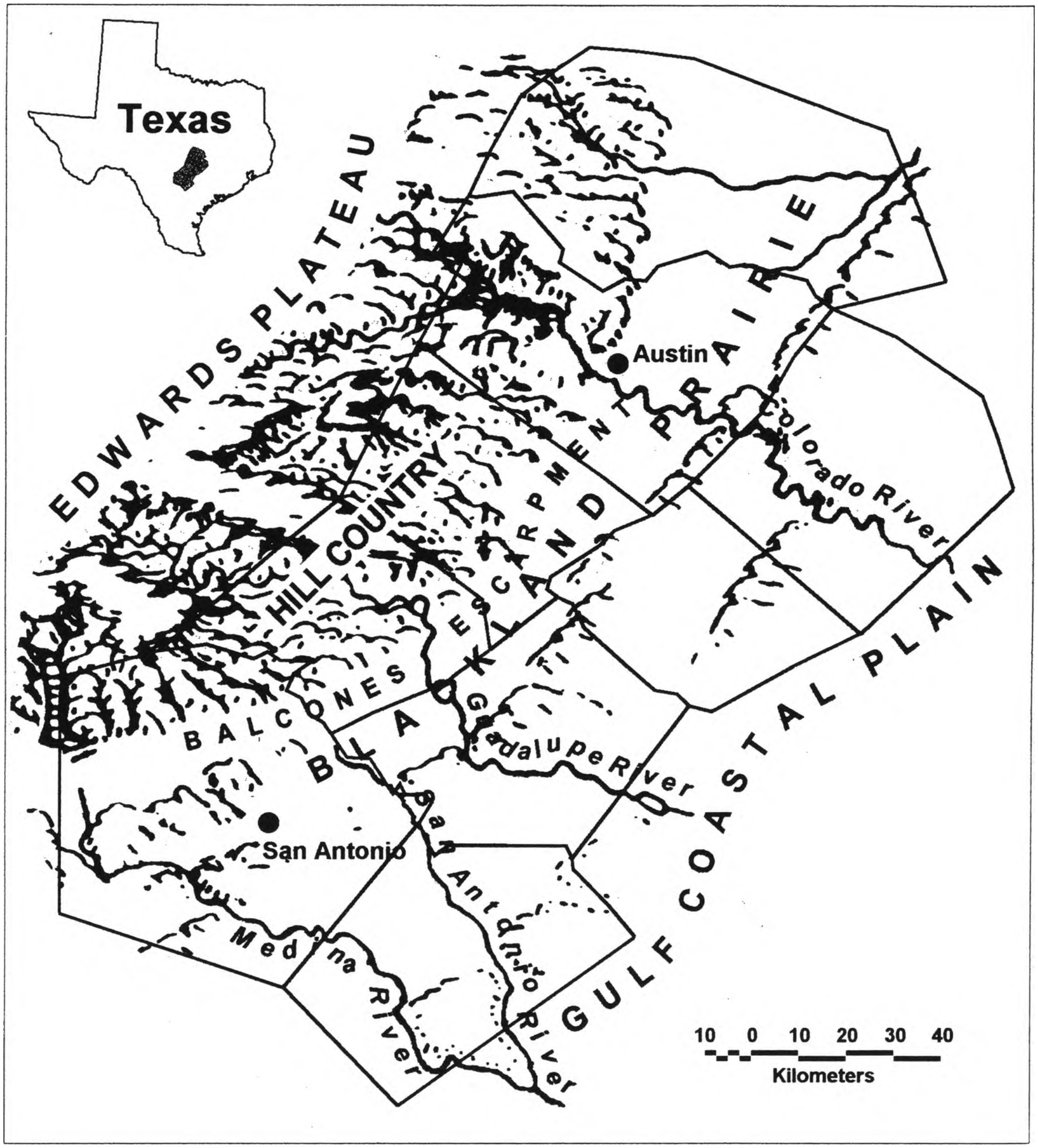
Because of its moderately dry climate, Central Texas governments have traditionally been more concerned about water quantity rather than quality. Water quality, however, is becoming a major issue within the region with over twenty streams polluted severely enough in 1999 to be included on the Clean Water Act mandated section 303(d) list (TNRCC 1999). The combination of very rapid population growth and the emergence of water quality problems make this an ideal study area for an analysis of the relationship between migration and water quality. An understanding of the basics of the geography of the study area is essential to appreciate the analysis to follow. In the next sections the physical and human geography's of the nine county Central Texas study area are examined in turn.

Physical Setting

Today the most prominent physical feature in the study area is the Balcones Escarpment (figure 4.2). During the early Cretaceous Period (140 - 97 million year ago) central Texas was covered by a body of water now known as the North American Seaway. Extensive sequences of limestone formed as limy mud was laid down over the floor of the

FIGURE 4.2

Physical Geography of the Austin-San Antonio Corridor



sea. During the Miocene Epoch (~25 million year ago) uplift along the Balcones Fault Zone occurred along a system of parallel normal faults resulting in a stepped lowering of fault blocks towards the modern Gulf Coast. By the time the period of uplift and faulting ended about 10 million years ago, a total of about one thousand feet of vertical offset in the strata on opposite sides of the fault line existed. The modern topographic relief at the escarpment only averages around 300 feet between the higher Edwards Plateau to the west and the lower Gulf Coastal Plains to the east as erosion has removed much of the uplifted layers. Rivers forming in and flowing through Central Texas have cut canyons into the Edwards Plateau creating the hills of the Texas Hill Country. The Balcones Escarpment forms a distinct boarder between the Hill Country to the west and the Gulf Coastal Plain to the east.

The hills of the Hill Country typically have stair-stepped sides caused by differential erosion of parallel layers of limestone and softer materiel. Exposed bedrock is common since almost no soil is produced as the local limestone erodes. Studies have shown, however, that some of the softer layers between the limestone can produce fair soils, but overgrazing, brush clearing for range improvement, and other human activities have resulted in considerable erosion from a landscape that has modest soil resources even in the best sites. The finest agricultural soils in the Hill Country occupy the floodplains common along many area streams and rivers. Larger rivers cutting through the Hill Country such as the Blanco and Guadalupe have broad valleys which historically have enticed settlers into an area otherwise unsuitable for agriculture.

Separated from the Hill Country and the Edwards Plateau by the Balcones Escarpment is the Gulf Coastal Plain. Caldwell, Guadalupe, and Wilson counties, three of the nine counties in the study area, are located entirely in the coastal plain. The coastal plain extends into portions of the other four counties as well. The Gulf Coastal Plain is characterized by low relief and low elevation and gently slopes towards the Gulf of Mexico. A broad belt of this region extending from the north into the study area is the Blackland Prairie, a zone of organically rich dark clayey soils. The Blackland Prairie has been a major agricultural region since the 1840s.

The Balcones Escarpment is not only the dividing line between the Hill Country and the Coastal Plain, it is an important feature of the region itself. Along the escarpment porous limestone layers, most importantly the Edwards Limestone, form the Edwards Aquifer. Because of the uplift along the Balcones, water drains generally eastward to form a line of artesian springs along the escarpment. Important examples of these springs within the study area are San Antonio Springs in San Antonio; Comal Springs in New Braunfels, and San Marcos Springs in San Marcos. The head waters of both the San Marcos and Comal Rivers lay in their respective springs.

Rivers such as the Comal and San Marcos which receive the majority of their flow from the springs along the fault line, are not the only or even most important rivers in the study area. The study area includes portions of five of the fifteen major Texas river basins. River basins represented in the study area are the Brazos, Colorado, Guadalupe, San Antonio, and Nueces. Surface water in Texas, and the region tends to flow from the northwest toward the Gulf Coast to the southeast.

The study area's climate can generally be described as the dry western margin of the humid subtropical climate region. Average annual precipitation is around 32 inches. Variations from the norm can be extreme, however, with actual annual rainfall ranging from 50 % to 150 % of the average. Temperatures regularly exceed 100 degrees in the summer. Very cold days, below 10 degrees, are rare. Prevailing air flow is south to southeasterly except during the winter when strong northerly flows can bring continental polar air into the region (Natural Fibers Information Center 1987).

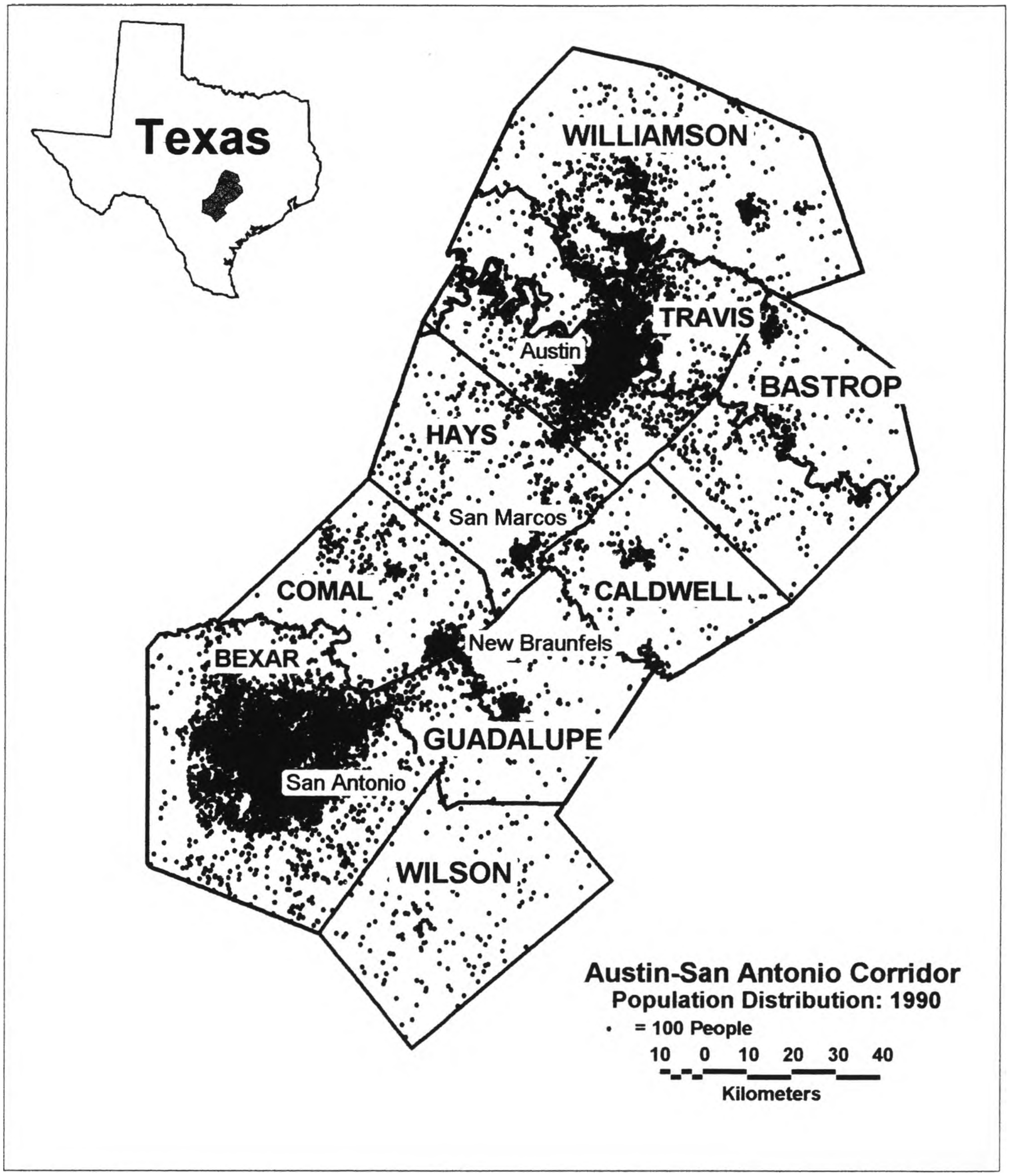
Demographic Setting

The physical setting has played a dominant role in the modern distribution of human settlement in the study area. Access to water has long been of primary concern to people settling Central Texas. The springs along the Balcones Escarpment were particularly attractive to early human inhabitants interested in reliable water sources. The modern settlement pattern bears this out with all of the largest population clusters (San Antonio, Austin, New Braunfels and San Marcos) in the study area located along the escarpment. A modern population distribution map of the study area clearly illustrates the close connection between settlement pattern, escarpment, and springs (figure 4.3).

In 1990 the population for the nine counties in the study area was 2.2 million. The population 1990 represents a 30% increase over the 1980 population of 1.7 million. Different racial and ethnic groups have not contributed equally to the population increase. The Hispanic segment of the population grew by 36%, the most of any major ethnic group. While total population in all ethnic groups increased between 1980 and 1990 the particularly rapid increase in the Hispanic population was countered by a relative decline in the Black and to a lesser degree Anglo populations. As a percentage of the total population Hispanics increased from 35% in 1980 to 37% in 1990 compared to the

FIGURE 4.3

Population Distribution in the Austin-San Antonio Corridor, 1990



relative declines of 45% and 7.8% in 1980 to 38% and 7.77% in 1990 for the Anglo and Black population respectively.

Population growth has been spatially uneven across the study area. Travis County (Austin) has increased its relative share of the area's population from 22.7% in 1970 to 26.6% in 1990. Bexar County (San Antonio) while growing in absolute population declined proportionately from 63.9% to 54.6% between 1980 and 1990. The faster growth in the Austin than in San Antonio tends to apply to the surrounding suburban and rural counties as well. For example, all of the counties surrounding Travis except Caldwell increased their relative share of the study area's population (figure 4.4). In the cases of Hays and Williamson Counties this increase was particularly evident. The three counties adjoining Bexar County had very minor increases in their share of the population or were stable.

Focus Watersheds

The case studies entail a more detailed examination of the relationship of migration to water quality change in two watersheds in the larger Austin-San Antonio Corridor. Onion Creek located in northern Hays County and Plum Creek primarily in Caldwell County with headwaters in Hays County provide the setting for this more detailed examination (figure 4.5). Several factors were critical in choosing these two watersheds. First, both watersheds are located in the headwaters of their respective larger drainage basins. This simplifies the analysis since all modification to the surface water quality had to occur in the watershed, and is not the result of upstream events. Second, both watersheds have lengthy and continuous water-quality monitoring at a station located

FIGURE 4.4

Population Growth Rates in the Austin-San Antonio Corridor, 1980 to 1990

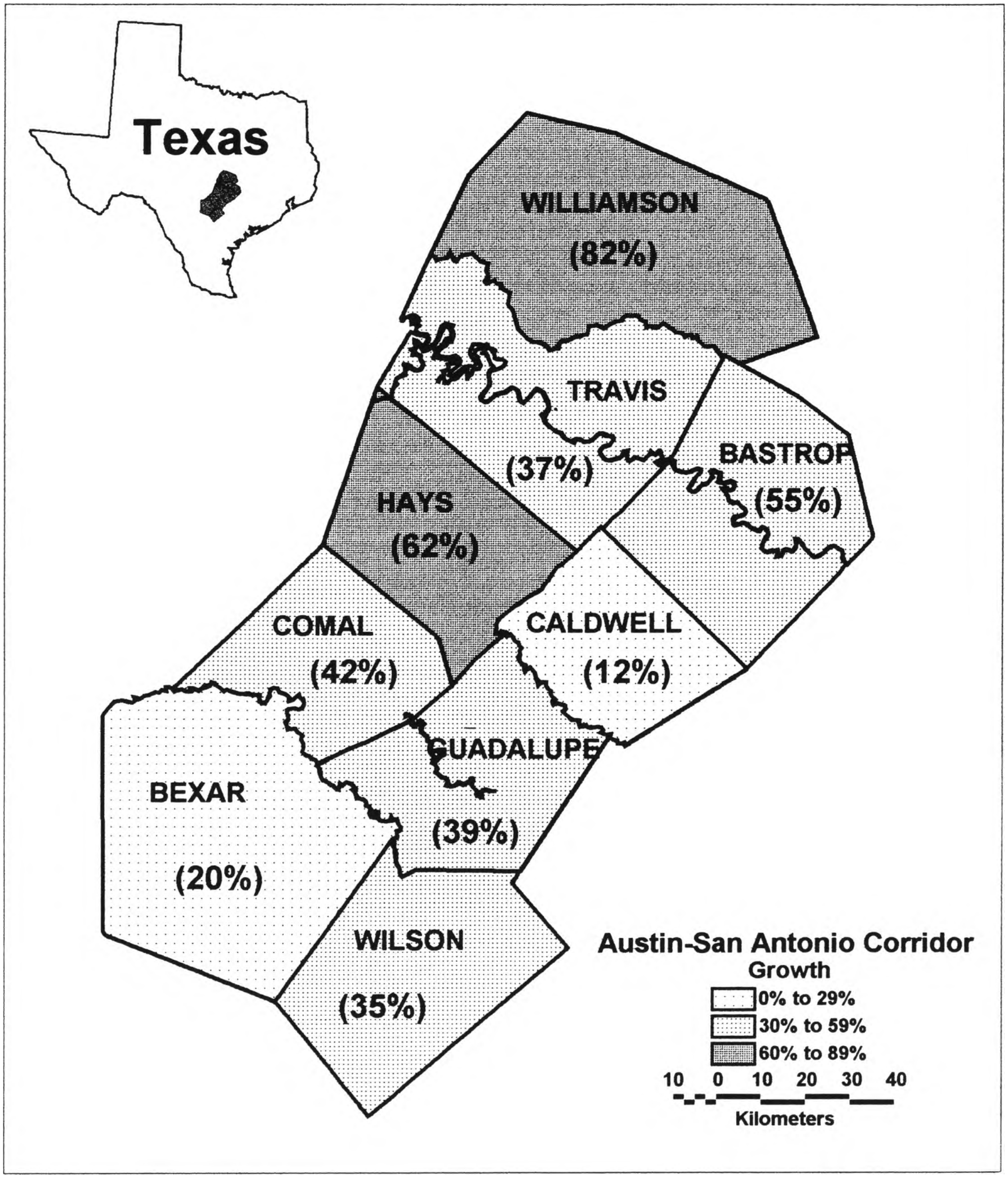
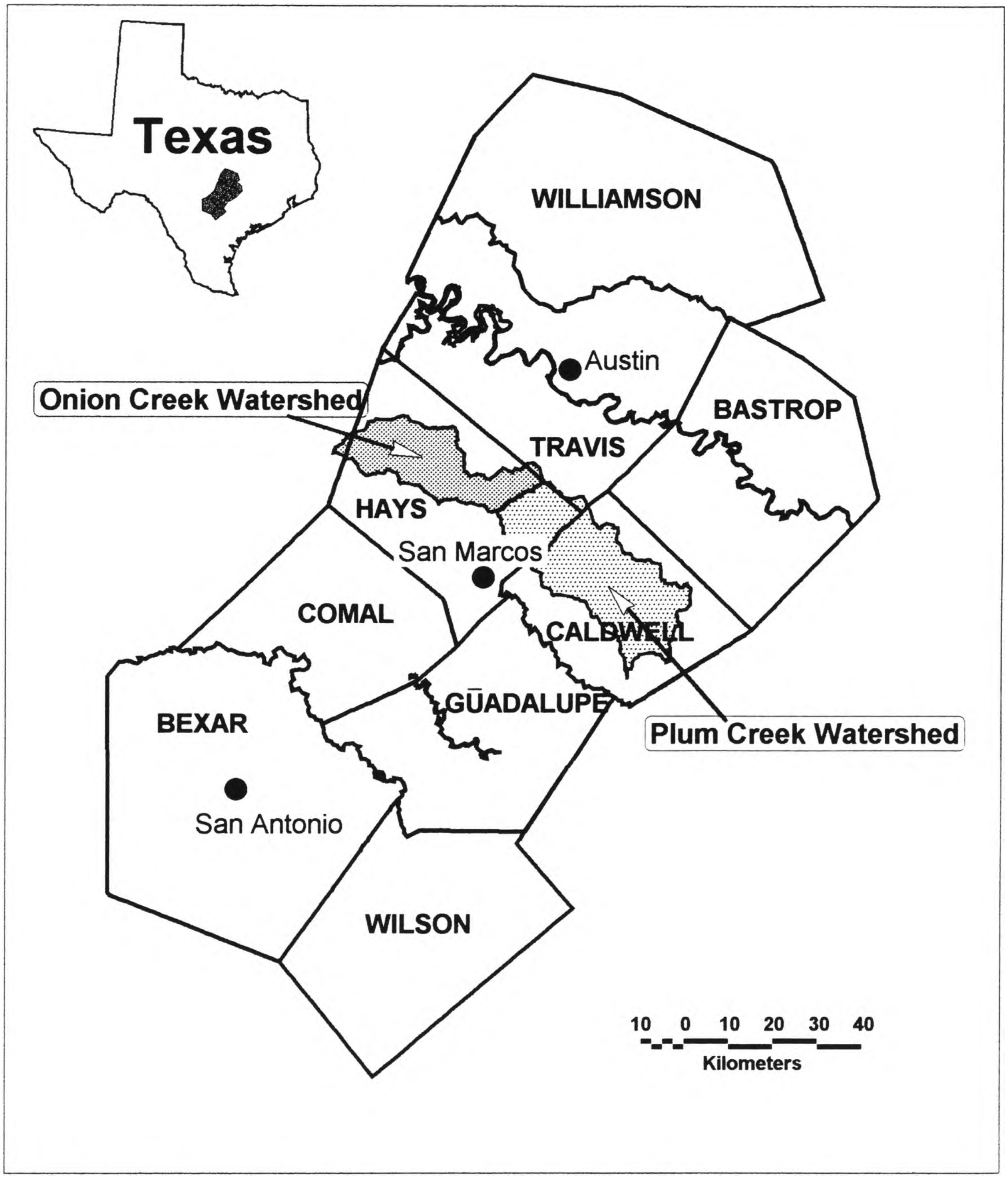


FIGURE 4.5

Locations of the Onion and Plum Creek Watersheds
within the Austin-San Antonio Corridor



close to the low point in the watershed. In addition, to this well positioned "primary" monitoring, several "secondary" monitoring stations are available. Often, the secondary monitoring location was not monitored over the entire period of the primary station, but adds valuable detail to the picture of water quality change in each watershed. Finally, each watershed represents different, but representative, pictures of the larger study area.

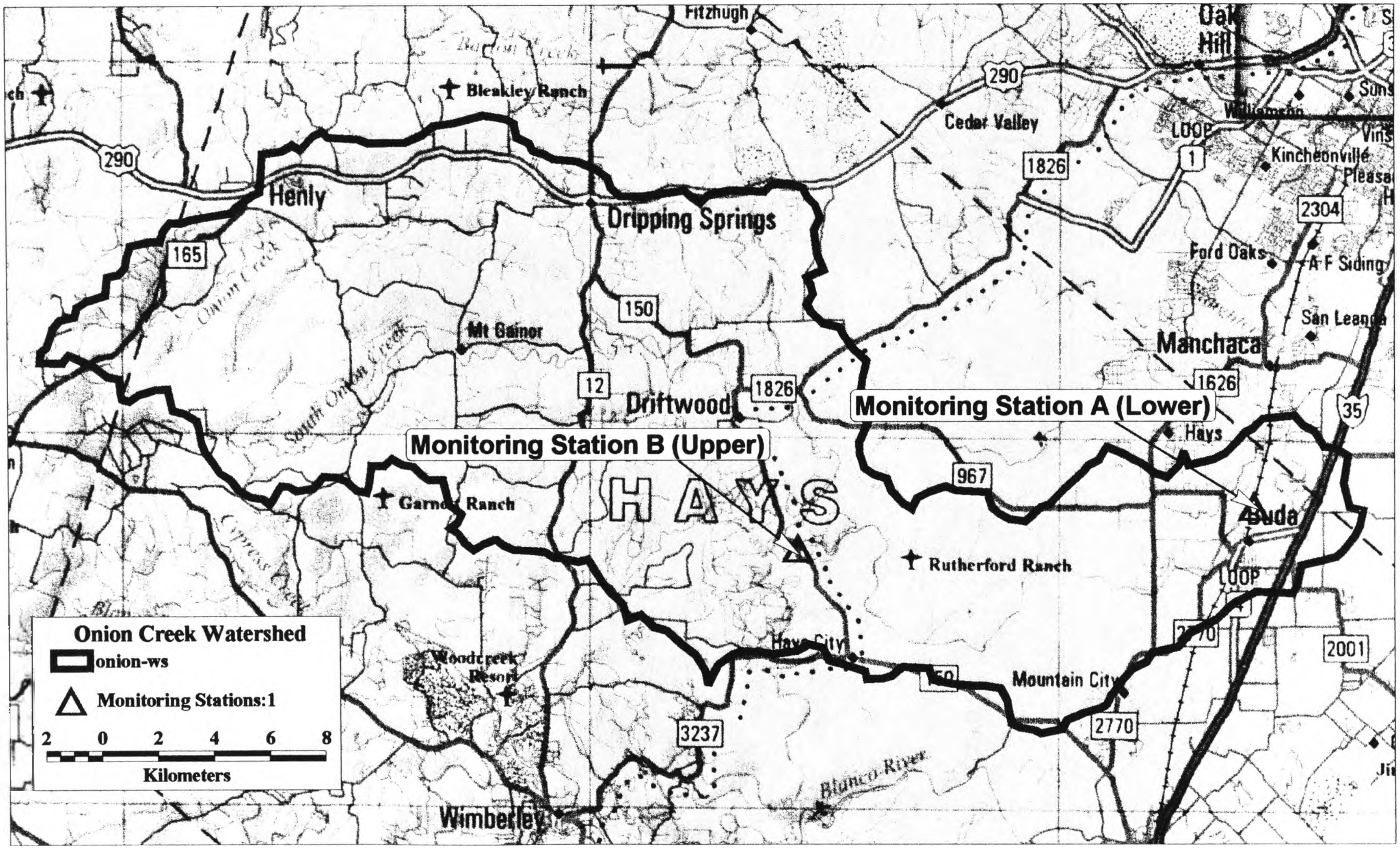
Onion Creek Watershed Description

Onion Creek flows from its source southwest of Dripping Springs, Texas, for 126.3 km (78.5 miles) in a northeasterly direction to the Colorado River southeast of Austin, Texas (figure 4.6). The Onion Creek drainage area is approximately 892 km^2 (344 mi^2). Onion Creek flows primarily through rural ranchland from its headwaters to IH-35. East of IH-35, suburban development of the watershed increases substantially. Widths of Onion Creek range from 5 to 40 m (16.4 to 131.2 ft) with depths varying from 0.3 to 1.5 m (1 to 5 ft). Banks in the upstream portion of the creek have gentle slopes that become more vertical toward the confluence with the Colorado River. Vegetation is moderately dense to dense throughout the Onion Creek Watershed.

The headwater flow of Onion Creek is mainly comprised of springwater and runoff from surrounding pasture that enter the creek directly or by way of several small tributaries. Major tributaries to Onion Creek include Mustang Branch, Gatlin Creek, Bear Creek, Slaughter Creek, and Williamson Creek. Most of these tributaries are seasonally intermittent with some large, permanent pools on either side of the Edwards Aquifer recharge zone. Flow reappears in the form of springs further downstream.

FIGURE 4.6

Onion Creek Watershed



The Williamson Creek Watershed is primarily suburban in its headwaters and heavily urbanized from south of US 290 to its confluence with Onion Creek. The Slaughter Creek Watershed has scattered subdivisions but is mostly rural. Swimming, fishing, and other recreational activities are common in some of the water bodies within the study area.

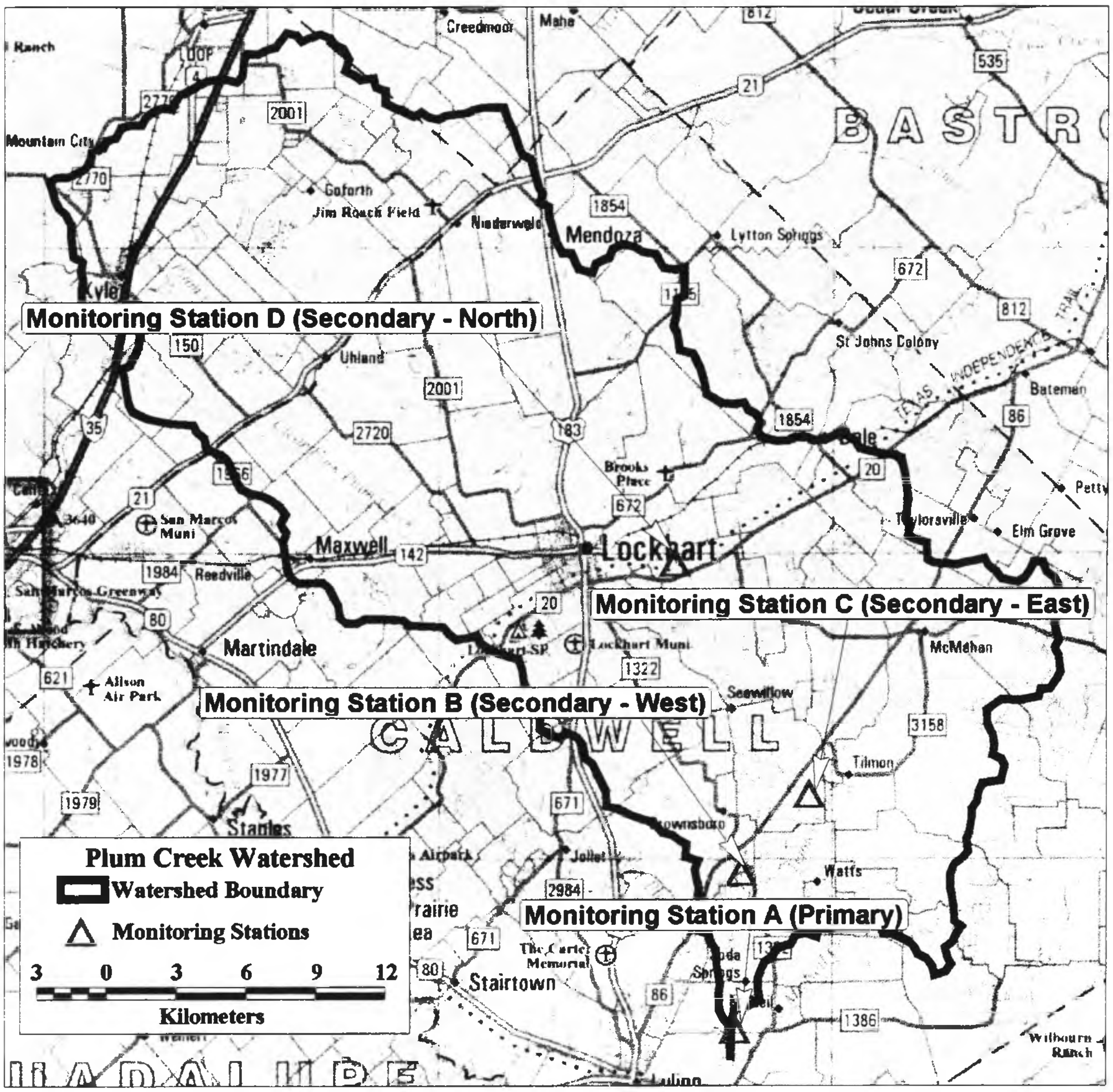
The Onion Creek Watershed extends from the Hill Country at the eastern edge of the Edwards Plateau across the Balcones Escarpment to the Blackland Prairie of Texas. Soils overlying the hard limestone in the western part of the study area are, in general, poorly developed, thin calcareous clays, clay loams, and strong clays. Bedrock is locally exposed. Soils on the soft limestones and shales of the Balcones Fault zone are generally dark brown calcareous clays, clay loams, or silty clay loams 15.2 cm (6 in) deep or more. Soils on the shaly formation in the eastern part of the study area are dark gray to olive calcareous clays and clay loams, 30.5 cm (12 in) or more thick (Gordon et al. 1985).

Plum Creek Watershed Description

Plum Creek is a fifth-order intermittent stream that drains portions of Hays, Travis, and Caldwell counties in south-central Texas (figure 4.7). Rainfall which averages around 838 mm (33 in) annual is the primary contributor to stream flow. Lowest mean monthly rainfall is in August (49 mm (1.9 in)), while the highest is in May (99 mm (3.9 in)). The main stream channel begins 9 km (5.6 mi) northwest of Lockhart, flows southeast for 51.6 km (31 mi), and empties into the San Marcos River 7.25 km (4.5 mi) southeast of Luling. Five oil fields are located within the watershed. Elevations of the watershed range from 274.3 m (900 ft) at the headwaters to 97.5 m (319 ft) at the mouth.

FIGURE 4.7

Plum Creek Watershed



The Plum Creek drainage basin covers 1011.13 km^2 (390.4 mi^2); 101.14 km^2 (39.1 mi^2) is flood plain. Over 85% of the watershed is cultivated or is pasture or rangeland. The topography is relatively level along the alluvial valley and gently rolling in the upland areas. Erosion in most areas is heavy, and a series of flood-control dams have been and are being constructed by the Soil Conservation Service at several sites in the drainage basin. Major flooding in the basin has occurred approximately once every 25 years.

The upper half of the drainage basin is underlain by Cretaceous limestone, shales, marls, and clays. Surface materials are predominantly clays and a few sandstones. The remaining portion is underlain by sandstones, sand, sandy shales, and clays of the Eocene age. Soils are yellowish-brown sandy and silty clays. A Pleistocene terrace, the Leona gravel, occurs within the bottomland area. Climax vegetation consists of little bluestem, Indian grass, and switchgrass. Live oak, pecan, hackberry, and American elm trees occur along many of the stream banks.

CHAPTER 5

QUANTITATIVE RESULTS

Based on the complexity of both the demographic and water quality data, it was expected that some parts of the quantitative analyses would not yield significant results. However, when all analytical results are examined together they yield meaningful insights about how changing human demographics resulting from migration, specifically, relate to changes in water quality.

This chapter reports the results of the quantitative analyses outlined in Chapter 3. The analyses are intended to address the first research hypothesis which asks whether migration driven demographic change is related to water quality change. In addition, the analyses provide a picture of the relationship that exists between changing water quality and demographic characteristics within watersheds in the Austin-San Antonio Corridor. In the first section of this chapter the key demographic variables are briefly discussed and important patterns and trends are highlighted. The second portion of the chapter will report the statistically significant relationships between demographic and water quality variables.

Overview of Demographic Data

The study region, consisting of the nine counties of the combined Austin-San Marcos and San Antonio MSAs, has grown quite rapidly in recent decades. During the main part of the study period (1980 to 1990) the whole region grew by 27%. This growth, however was not evenly distributed; some watersheds had population growth rates well in excess of 700% while a few actually witnessed declines.

Using population data from the 1980 and 1990 censuses, five variables were constructed to reflect traditional notions of population pressure. To control for varying watershed sizes, the variables were divided by the size of the watershed and measured per square mile where appropriate. The operational variables include: the population density in 1980, the population density in 1990, the change in density from 1980 to 1990, the number of out-of-state in-migrants from 1975 to 1980, and the number of out-of-state in-migrants from 1985 to 1990. After availability of water quality data was factored in, 29 potential watersheds remained. The data were then used to create three groups out of the 29 watersheds based on each of the five variables figures (5.1, 5.2, 5.3, 5.4, 5.5).

Results

Population Growth and Water Quality Change

This chapter examines the relationship between migration driven demographic change and several different measures of water quality. The most basic demographic change attributable to migration in the study area is population growth. Due to the vastly different sizes of the watersheds, which ranged from less than 5 to over 300 square miles, changes in density rather than changes in raw population counts were examined. The watersheds were grouped based on the percentage of change in population density between 1980 and 1990 using 0.5 standard deviations above and below the mean as the

FIGURE 5.1

Mean Population Density Change for Watersheds in Analysis between 1980 and 1990

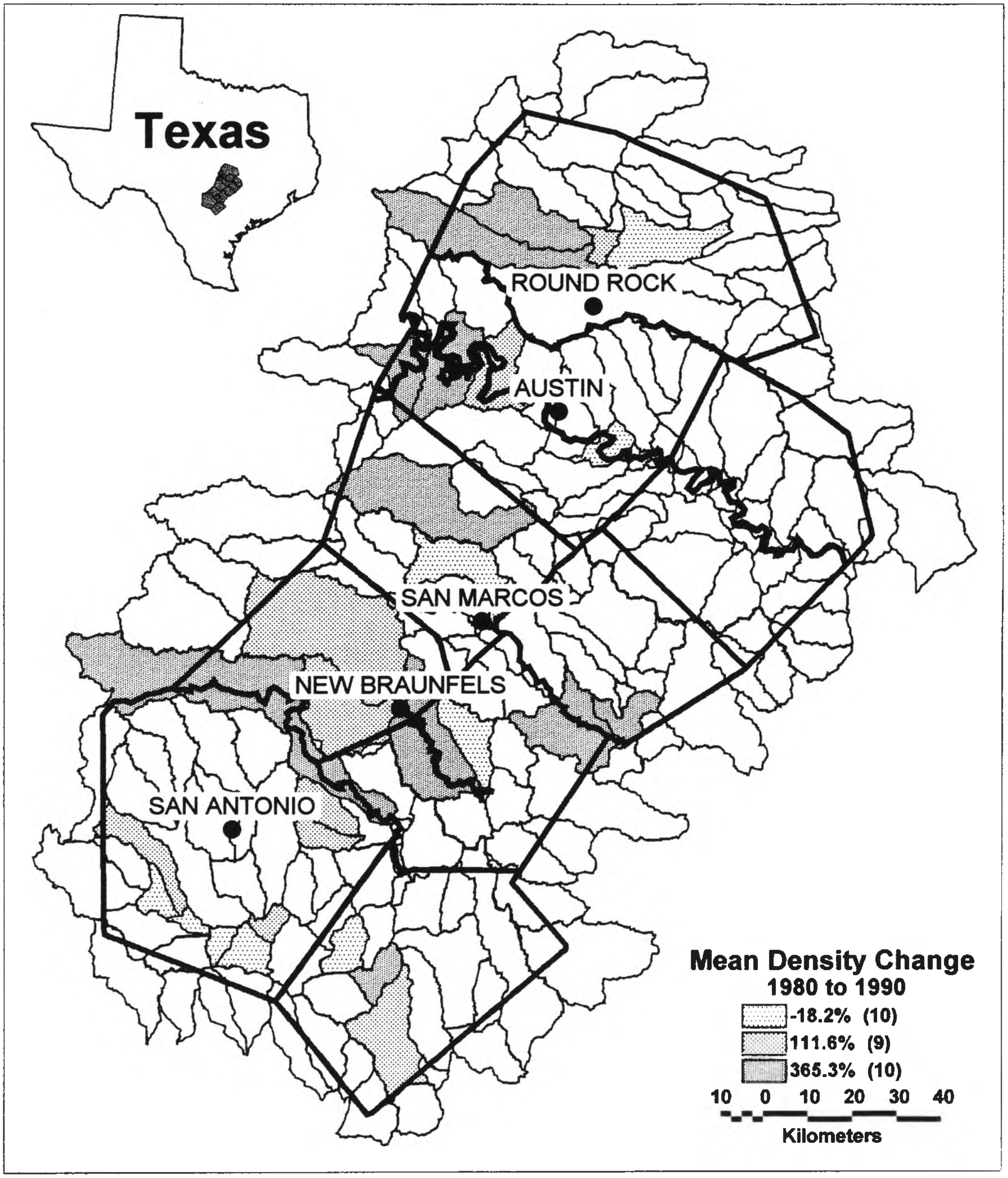


FIGURE 5.2

Population Density for Watersheds in Analysis in 1990

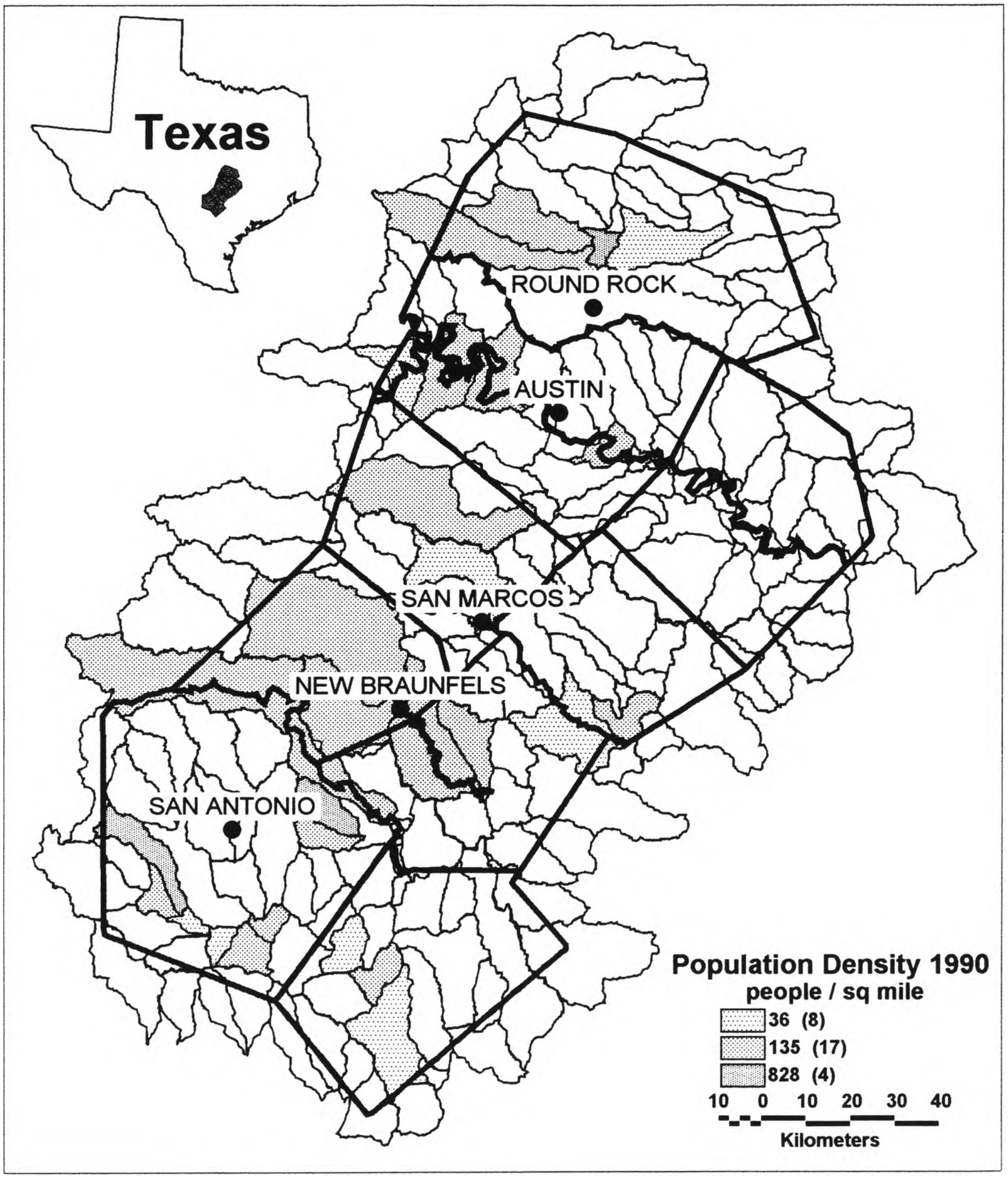


FIGURE 5.3

Population Density for Watersheds in Analysis in 1980

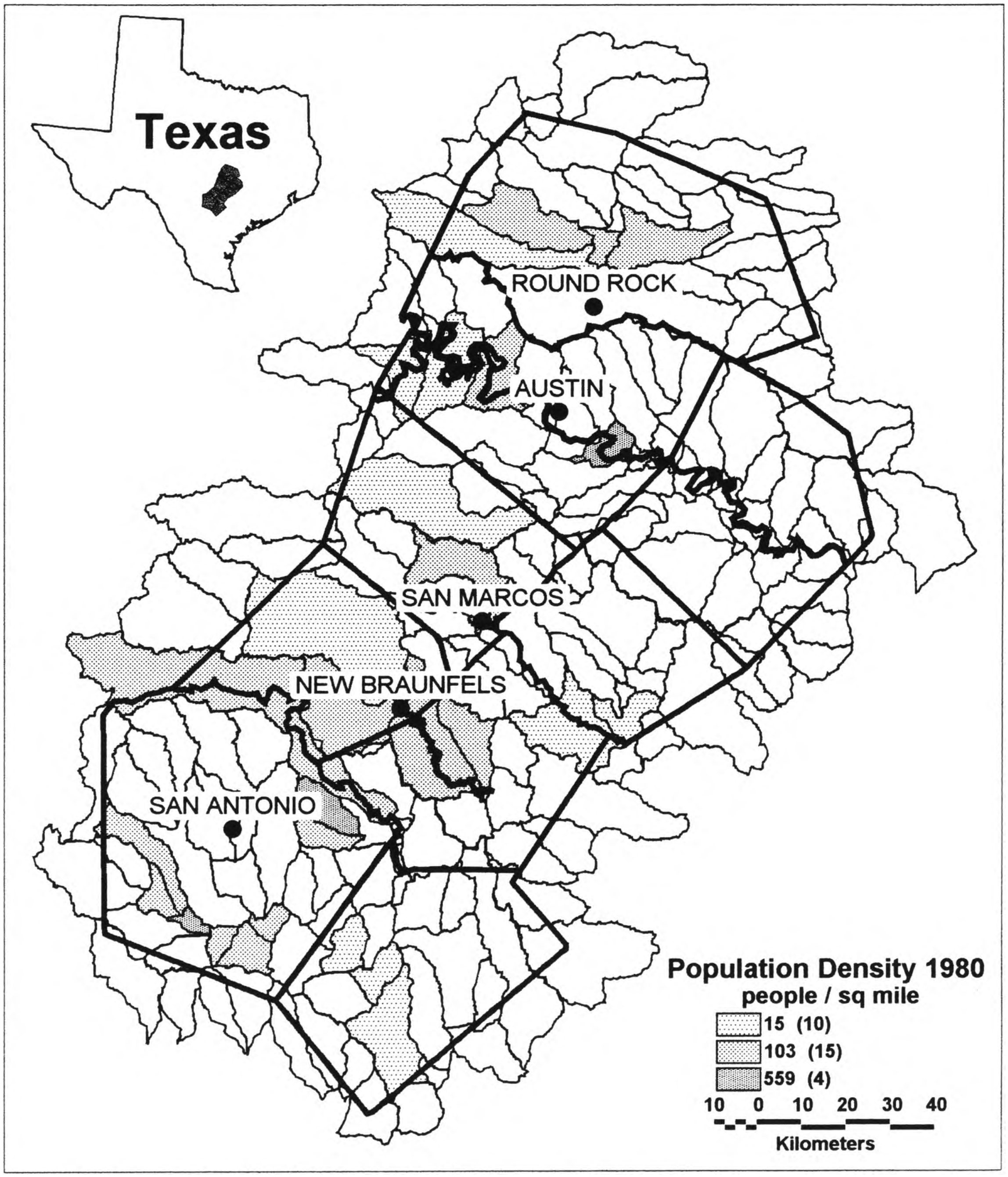


FIGURE 5.4

Number of In-migrants per Square Mile for Watersheds in Analysis between 1975 and 1980

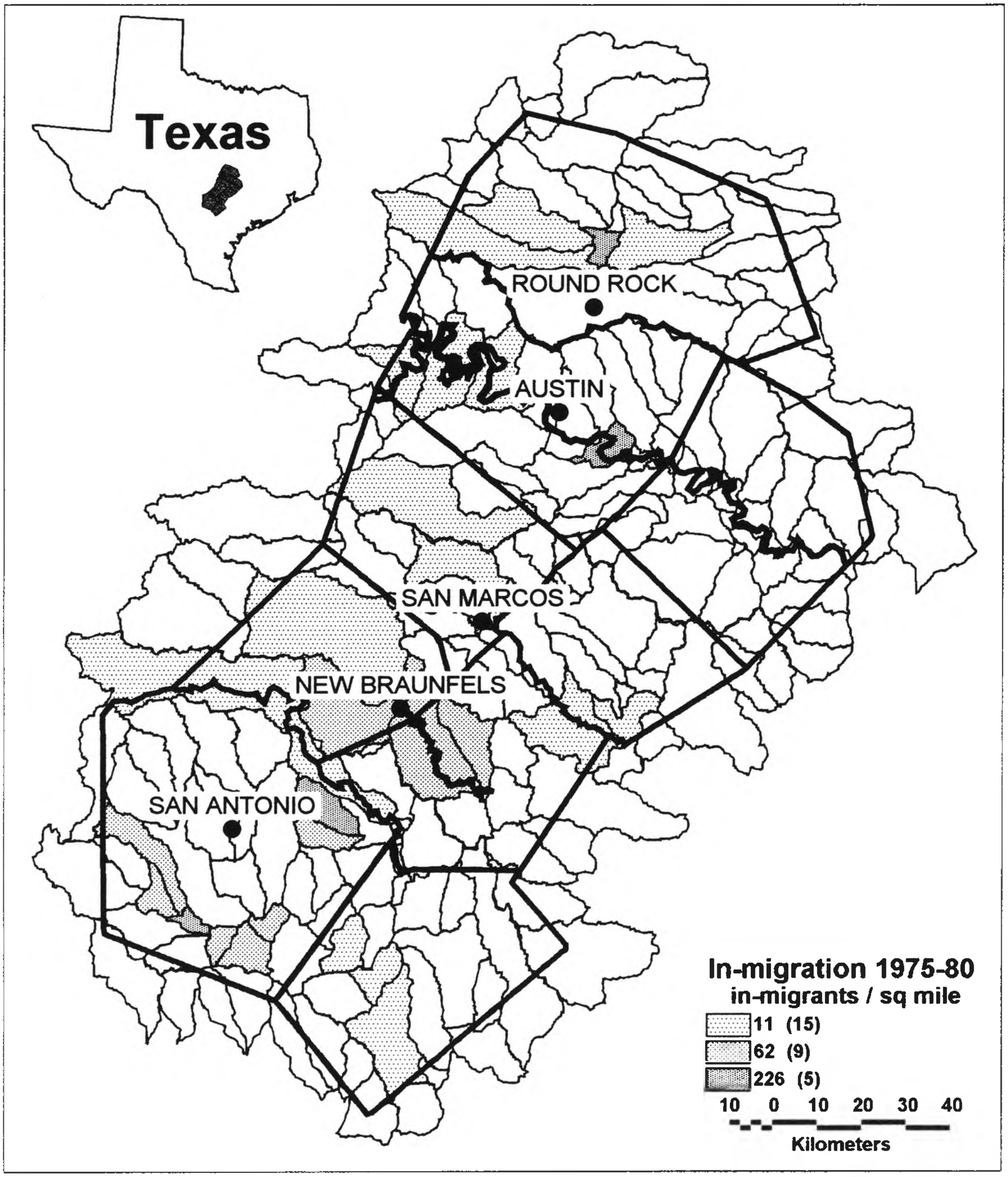
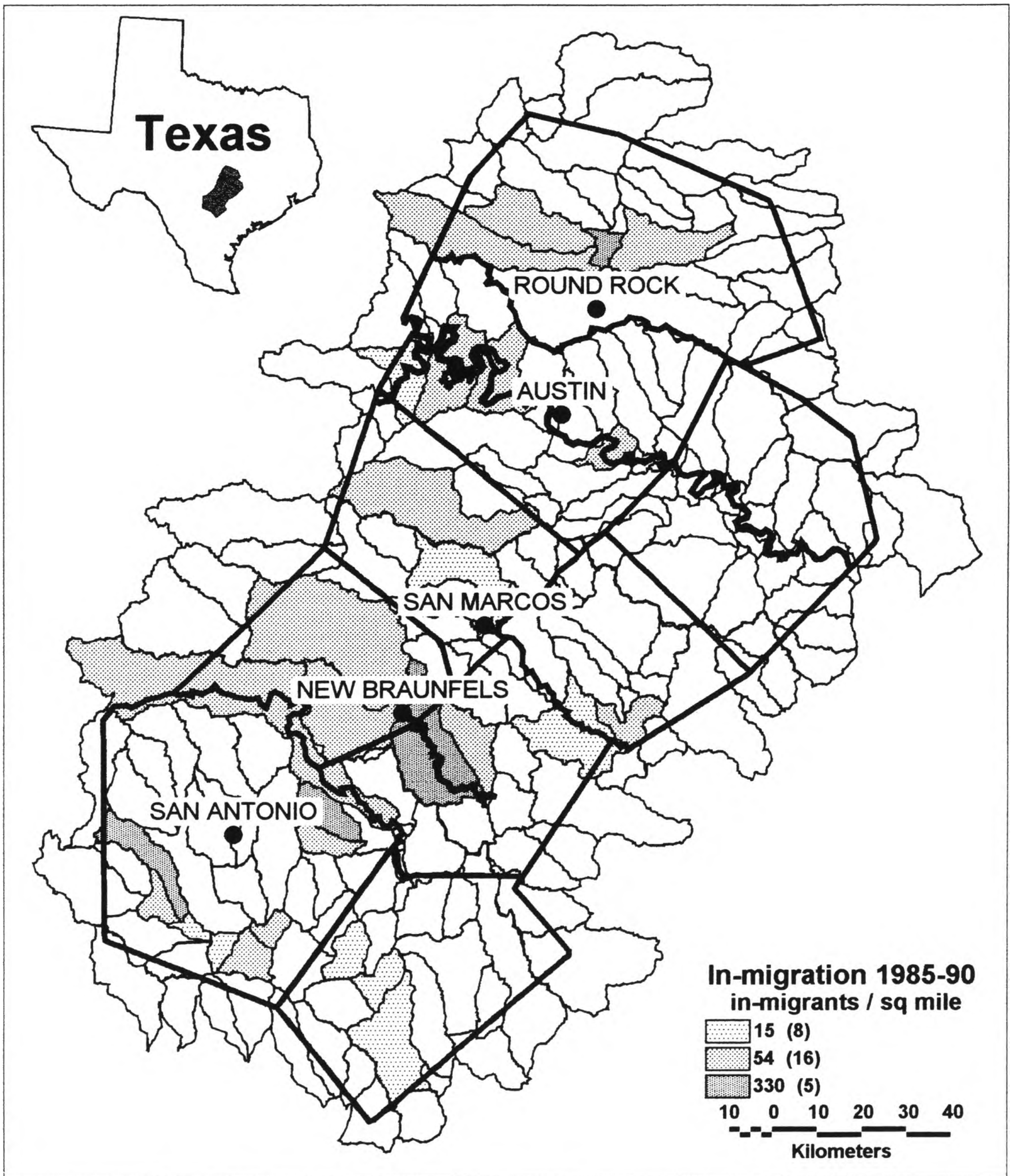


FIGURE 5.5

Number of In-migrants per Square Mile for Watersheds in Analysis between 1985 and 1990



breaks between the three groups. The mean density change in the three groups was -18, 112, and 365 percent (table 5.1). Between 16 and 28 watersheds had sufficient data for both water quality and demographics to be included in the nine separate analyses representing the various combinations of the three water quality variables (dissolved oxygen, nitrate, and fecal coliform) and the three periods (1980-90, 1975-90, and 1975-95).

Of the three water quality variables, only changes in dissolved oxygen varied significantly (at the 0.1 level) within the three groups of watersheds in more than one of the periods (table 5.1). Variation in the change in dissolved oxygen, significant at the 0.1 level, was evident during both the 1980-1990 and 1975-1990 periods. In addition, similar variation was observed for the longer 1975-1995 period, but this variation was only significant at the 0.25 level. During all three periods the group of watersheds with the greatest increase in population density had the smallest increase in dissolved oxygen. In fact, during the two longer periods those watersheds with the greatest increase in density showed evidence of decreasing dissolved oxygen and during the ten-year period only minor increases in dissolved oxygen.

Taken alone, the finding that the watersheds with the greatest increase in population density support the common notion that more people cause more degradation in water quality. This notion is further supported by the results for the other two groups of watersheds during the shortest period which show an inverse relationship between rates of population density increase and changes in dissolved oxygen. However, the two longer periods do not show this same relationship, with the middle group of watersheds showing the greatest increase in dissolved oxygen rather than those with the least increase in

TABLE 5.1

Demographic Characteristics and Percent Change in Mean Water Quality Indicators for Watersheds in the Austin-San Antonio Corridor, 1980 - 1990

	Dissolved Oxygen						Nitrate						Fecal Coliform					
	1980-90	(n)	1975-90	(n)	1975-95	(n)	1980-90	(n)	1975-90	(n)	1975-95	(n)	1980-90	(n)	1975-90	(n)	1975-95	(n)
Density Change 1980-90																		
1 (-18.2%)	***26.275***	(9)	***8.733***	(9)	*-0.368*	(9)	12.674	(6)	18.937	(7)	5.873	(6)	***-9.515***	(6)	-12.022	(5)	154.207	(7)
2 (111.6%)	***19.164***	(9)	***18.311***	(6)	*8.885*	(7)	45.991	(9)	98.752	(6)	47.222	(6)	***-49.866***	(8)	-37.524	(5)	-6.891	(5)
3 (365.3%)	***1.824***	(10)	***-8.433***	(8)	*-15.573*	(7)	56.759	(10)	100.243	(7)	-7.552	(7)	***288.857***	(10)	51.055	(6)	112.496	(6)
		(28)		(23)		(23)		(25)		(20)		(19)		(24)		(16)		(18)
Density 1990																		
1 (36 people/sq mile)	21.847	(8)	3.054	(8)	-8.352	(7)	***-5.740***	(7)	***-3.468***	(6)	-14.518	(5)	9.758	(7)	*28.048*	(5)	21.356	(5)
2 (135 people/sq mile)	11.714	(16)	4.446	(12)	-2.039	(13)	***81.129***	(14)	***130.565***	(11)	34.896	(11)	184.170	(14)	*17.306*	(8)	120.663	(10)
3 (828 people/sq mile)	16.251	(4)	14.403	(3)	11.617	(3)	***-9.519***	(4)	***3.789***	(3)	-15.187	(3)	-71.378	(3)	*-73.364*	(3)	135.520	(3)
		(28)		(23)		(23)		(25)		(20)		(19)		(24)		(16)		(18)
Density 1980																		
1 (15 people/sq mile)	11.630	(10)	*-0.647*	(10)	-10.487	(9)	62.728	(10)	*91.053*	(8)	-25.814	(8)	234.416	(10)	36.184	(7)	95.639	(7)
2 (103 people/sq mile)	14.414	(14)	*3.161*	(9)	-0.125	(11)	40.873	(12)	*80.143*	(9)	58.820	(9)	14.647	(11)	-9.128	(7)	30.912	(8)
3 (559 people/sq mile)	27.274	(4)	*24.756*	(4)	15.214	(3)	-20.068	(3)	*-7.647*	(3)	-28.578	(2)	-24.237	(3)	-65.398	(2)	267.735	(3)
		(28)		(23)		(23)		(25)		(20)		(19)		(24)		(16)		(18)
In-migrants 1985-90																		
1 (15 in-migrants/sq mile)	29.026	(8)	6.640	(8)	-5.670	(7)	***-6.122***	(7)	***4.727***	(6)	-1.303	(5)	384.411	(7)	*48.702*	(4)	36.698	(4)
2 (54 in-migrants/sq mile)	9.206	(15)	2.056	(12)	-3.484	(13)	***86.419***	(13)	***126.094***	(11)	28.889	(11)	-14.736	(13)	*9.321*	(9)	106.057	(11)
3 (330 in-migrants/sq mile)	11.381	(5)	14.403	(3)	11.617	(3)	***-4.608***	(5)	***3.789***	(3)	-15.187	(3)	-16.689	(4)	*-73.364*	(3)	135.520	(3)
		(28)		(23)		(23)		(25)		(20)		(19)		(24)		(16)		(18)
In-migrants 1975-80																		
1 (11 in-migrants/sq mile)	*8.872*	(15)	***-1.843***	(14)	*-9.472*	(13)	***40.350***	(15)	*64.459*	(12)	***-18.801***	(12)	156.947	(15)	12.458	(11)	57.739	(11)
2 (62 in-migrants/sq mile)	*23.752*	(8)	***9.555***	(5)	*3.909*	(7)	***92.254***	(6)	*135.240*	(5)	***109.696***	(5)	25.179	(6)	17.453	(3)	70.411	(4)
3 (226 in-migrants/sq mile)	*20.819*	(5)	***24.756***	(4)	*15.214*	(3)	***-25.307***	(4)	*-7.647*	(3)	***-28.578***	(2)	-24.237	(3)	-65.398	(2)	267.735	(3)
		(28)		(23)		(23)		(25)		(20)		(19)		(24)		(16)		(18)

Note: Bold numbers indicate statistical significance at the 0.1 level, while numbers in italics indicate significance at the 0.25 level.

population density as would be expected. Thus some increase in population density, at least to a point, can coincide with improvements in water quality.

Dissolved oxygen was the only water quality variable with significant results for multiple periods. Differences significant at the 0.1 level, however, were identified for changes in fecal coliform for the period 1980-90. During this decade fecal coliform concentrations declined substantially in watersheds with the most rapid population growth. The results for the two longer periods were not statistically significant, but do, in general, support the pattern observed in the shorter period. This pattern is similar to that observed for the longer periods with respect to dissolved oxygen. The most pronounced decrease in water quality is associated with those watersheds growing most rapidly. The inverse does not hold, however, with the greatest improvements in water quality found not with the slowest rates of density increase, but rather with the moderate-growth watersheds. This supports the notion that increasing numbers of people cause greater degradation to water quality, however, there is evidence to suggest that at some point increased density is having a positive rather than negative impact on water quality. Indeed, a U-shaped relationship seems to exist between population density increase and changes in fecal coliform content. This is clearly shown by the biggest increases in fecal coliform being associated with neither the fastest- nor the slowest-growing watersheds, but rather the moderate growth watersheds.

Population Density and Water Quality Change

The previous section concerned itself primarily with rates of population growth in terms of changes in population density over time. Rates of density change are not, however, tantamount to actual population density. We know from gravity models of migration that places with greater population (i.e., greater density) tend to attract more migrants, all other things being equal (for a review of gravity models see, Hua and Porell 1979). We also know, however, that population growth within a defined geographic space will begin to slow as it reaches some maximum density. Thus rates of density increase and actual population density may not have the same relationship with changes in water quality.

In the second series of analyses the watersheds were again divided into three groups, this time based on actual population density in 1990. The breaks between the three groups were defined as 0.5 standard deviation above and below the mean. Between 16 and 28 watersheds were included in the analysis depending on the data availability for the various combinations of the three periods and water quality variables.

Similar to the previous analyses on change in population density, significant differences in change in water quality were observed with both dissolved oxygen and fecal coliform. The results of this analysis of actual population density have some distinct differences. The first and most obvious is that neither dissolved oxygen nor fecal coliform varied significantly between the three groups of watersheds significant at the 0.1 level. However, significant variation in nitrates were observed between the groups for both the 1980-90 and 1975-90 periods. During both of these periods declining or minor increases in nitrate levels were noted for both the least and most densely populated watersheds (which averaged 36 and 828 people per square mile respectively). In contrast major increases in nitrate levels were observed for the middle group of watersheds with population densities averaging 135 people per square mile. This suggests that it is the transition of areas from less to more densely populated that should be of principle concern.

Migration and Water Quality Change

Conventional wisdom tells us that there should be some relationship between the population that inhabits an area and the condition of the natural environment. However, the results from the two previous analyses do not support the conventional notion that this is a direct relationship (i.e., increasing densities result in degrading water quality). One of the hypotheses behind this research is that migration may play a role in modifying what might otherwise be a simple linear relationship. To examine this idea, similar analyses to those already reported were conducted, with the watershed this time divided into three groups based on the number of out-of-state migrants per square mile coming to a given watershed. As with the earlier analyses, the watersheds were divided into three groups using 0.5 standard deviation above and below the mean as the breakpoints. Census data pertaining to migration was available from both the 1980 and 1990 census. Thus the analysis was repeated for each water quality variable for both sets of migration data.

Dissolved oxygen had no significant variation between the three groups of watersheds based on 1990 migration data; however, there were significant variations in dissolved oxygen change at the 0.25 level for all three periods, with the fifteen-year period (1975-90) significant above the 0.1 level. The trend was for dissolved oxygen content to increase with increasing numbers of out-of-state migrants arriving in the area. Watersheds with the fewest number of migrants arriving from out of state witnessed declining or only modest improvements in dissolved oxygen content. This implies higher rates of in-migration were associated with improving water quality.

Of the six possible combinations of the two migration variables and three periods, four varied significantly at the 0.1 level with one of the two remaining combinations significant above the 0.25 level. The U-shaped relationship between demographic factors and water quality levels continued with this analysis with the middle group of watersheds consistently showing greater increases of nitrates over the relevant periods than either the group with the least or most migrants. In all but one instance the group of watersheds with the highest rates of interstate in-migration indicated decreasing nitrate levels. The only instance where this was not true was for the grouping based on migration from 1985 to 1990 with water quality change from 1975 to 1990, in which there was a very slight increase in the mean nitrate level. Those watersheds with the least in-migration also had less increase in nitrates with three of the six combinations indicating decreasing nitrate levels and the remaining three having increasing nitrate levels, but at much less that seen for the middle group of watersheds.

Fecal coliform levels did not show variation significant at the 0.1 level with migration. One combination of migration data (1985-90) and water quality data (1980-90) was significant at the 0.25 level. In this one case there was a strong inverse correlation between increased in-migration and fecal coliform levels. The remaining five non-significant combinations provide little to support the pattern, with several combinations seeming to indicate a direct correlation. With the statistical significance this weak it is difficult to draw any meaningful conclusion about the relationship between in-migration and fecal coliform levels.

Summary

This chapter of the study was intended to test the common assumption that there is a direct linear relationship between increasing population pressure and degrading water quality. The results of the analyses do largely reject the notion of a direct linear relationship between demographic and water quality change. Quite interestingly, however, strong evidence was found for another unexpected relationship where water quality showed very slow degradation or improvement under conditions of both minimal and maximal population pressure. The worst degradation of water quality seemed to be occurring in those places with moderate population pressure. This relationship would seem to have two plausible explanations. Perhaps places of moderate population growth are going through a transition where the mechanism for water quality control are not keeping pace with increased population pressure. Alternatively, the places with moderate levels of population pressure and more rapid rates of water quality change could be interpreted as places of stagnant growth. In these places population pressure can be significant with a population large enough to exert pressure on the environment, but perhaps too small to have the critical mass to notice or care about the damage they are causing. This portion of the research does not provide sufficient evidence to speculate on which or what combination of these two scenarios may explain the results. This will be one of the tasks of the more qualitative analysis that follows.

CHAPTER 6

CASE STUDIES: POPULATION AND CHANGE

In this chapter the changing demographic character of Onion and Plum Creek Watersheds is examined. Each of the watersheds has been divided into smaller areas ("sub-sheds") determined by available water quality data. Using census block group data, sub-sheds were created around the available monitoring stations. Much of the discussion of the demographic character of the area is based on these sub-shed units. Even greater resolution is possible, however, since most of these sub-shed units are based on several block groups.

I first elaborate on the population characteristics in 1990 (the end of the study period) for each watershed. This is followed by an evaluation of the population changes that occurred during the 1970s and 1980s that produced the population characteristics observed in 1990.

Onion Creek

The Onion Creek Watershed represents what might be called a frontier zone of the Austin metropolitan area. The watershed has experienced relatively high rates of population growth through 1970s and 1980s, the focus of this study, as well as through the 1990s. Despite this extended population growth period, the watershed maintains a largely rural appearance. This rural atmosphere is mainly due to the existence of several large ranches. In the 1990s several of these ranches have been subdivided or limited their operations and are now being converted to other land uses, most notably residential developments. This conversion of the large ranches within the Onion Creek watershed has only recently begun and was not a factor during the 1970s and 1980s, the period which is the focus of this research. Most of the residential development has tended to be in smaller subdivisions of fewer than a couple of hundred acres (table 6.1). The few large subdivisions (over one thousand acres) that existed at the end of the study period in 1990 were platted almost exclusively in the early to mid-1970s.

The Population of Onion Creek in 1990

In 1990 the population of the Onion Creek watershed was approximately 10,000. This population is concentrated in the upper (western) reaches of the watershed around Dripping Springs and in the downstream (eastern) portions of the watershed around Buda (figure 4.6). These two concentrations have markedly different populations.

Seven census block groups approximate the geographic extent of the Onion Creek watershed. The two westernmost block groups (one and two) encompass the Dripping Springs end of the watershed. The other five block groups (three through seven) represent the downstream portions of the watershed focused on Buda (figure 6.1). These two divisions roughly divide the watershed in half. The upstream section is slightly larger in terms of land area at 267 km^2 (103 mi^2) compared to the 199 km^2 (77 mi^2) in the lower portion. The population of the lower portion is larger with 6067 people and a density of

TABLE 6.1

Platted Subdivisions in the Onion Creek Watershed
by Size and Year Platted

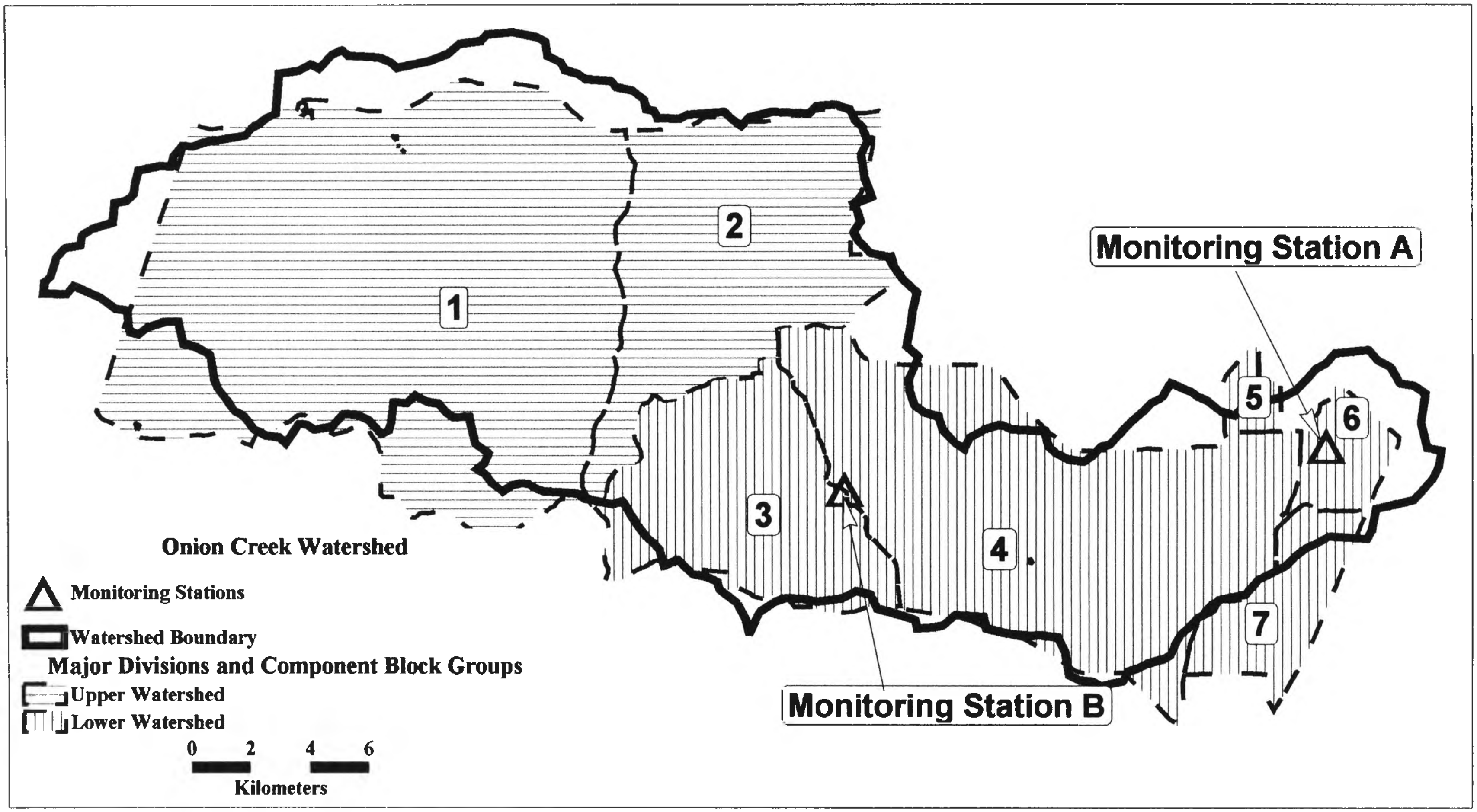
Subdivision Name	Year Platted	Area (acres)
Hill Country Ranches	1972	2512.232
Rolling Oaks	1973	1857.793
Hays Country Oaks	1977	1410.123
Sunset Canyon	1982	1355.280
Kirby Springs	1989	899.196
Springlake	1953	695.576
Harmon Hills	1974	407.881
Sunset Canyon	1982	389.742
Los Ranchos	1978	371.524
Leisurewoods	1977	349.897
Meadow Creek Ranch	1990	248.871
Crosshouse	1985	226.259
Hays Country Acres	1978	203.347
Mountain City Oaks	1978	199.035
Coves of Cimmaron	1984	197.317
B.M. Needham Estates	1979	188.010
Forest Woods	1985	180.935
Fieldstone	1981	180.264
Oxbow Trails	1975	174.522
Blue Creek Ranch	1989	170.366
Green Hills	1980	157.711
Springwood	1977	151.835
Oak Springs	1978	151.814
Rainbow's End	1985	143.846
Lifchutz Subdivision	1948	134.907
Hunnington Estates	1985	115.988
Meadow Oaks	1985	83.500
Sequoyah	1976	80.402
Creek at Driftwood	1986	75.747
Blue Ridge	1978	74.728
Driftwood Falls Estates	1986	66.245
Bonita Vista	1982	65.050
Hollowrock	1988	63.125
Sundbeck/La Truffierfa	1988	60.258
Dripping Springs Heights	1973	49.388
Allen Subdivision	1990	49.334

Table 6-1--continued

Subdivision Name	Year Platted	Area (acres)
Onion Creek Drive Estates	1982	38.748
Olliewood	1989	37.713
Dobie Lane Acres	1985	33.915
Hays Co. Ind. Park	1985	28.486
Double R Ranch	1973	25.085
Pier Branch	1986	20.048
St. Martin's Subdivision	1989	19.079
Creeks Bend	1985	15.022
Bill's Hill	1989	14.453
Ryan Hills	1984	14.350
Shelton Subdivision	1989	10.953
Rustic Oaks Estates	1986	10.157
Leif Johnson Ford Comm.	1989	9.691
Davenport Addition	1982	9.613
Candledancer	1988	8.359
Cole Springs Subdivision	1985	6.044
Lowden Subdivision	1986	5.441
Teichelmanns Subdivision	1989	4.892
Grape Creek Subdivision	1983	4.478
Possum Trot Park	1978	4.263
H. Cummings Ind. Park	1988	3.055
The Village at Buda	1986	2.462
Loop 4 Business Center	1986	1.966
Goforth Road	1987	1.611
Tarra Subdivision	1988	1.580
Penn Addition	1990	0.000
Shoemaker Ranch	1989	0.000

FIGURE 6.1

Census Divisions in the Onion Creek Watershed



30 people/km^2 (78 people/mi^2). In contrast, the upper portion had a population of 4526 and a density of 17 people/km^2 (44 people/mi^2).

Household Income

The upper and lower portions of the watershed differ demographically in a number of ways. One of the more obvious differences is income. In the upper part of the watershed over 50% of the households had income over $40,000 per year in 1990, and almost half of those had household incomes over $75,000 per year (table 6.2). At first glance these values seem similar to the 48% of household with incomes over $40,000 found in the lower watershed. This value, however, is heavily biased by Block Group Five in the lower watershed (figure 6.1). This area represents only 2% of the land area in the lower portion of the watershed and over half of that is technically outside the watershed. This small area represents 37% of the population and is demographically more like the upper portions of the watershed. By dropping Block Group Five the percentage of households with incomes over $40,000 drop from 48 to 27%.

Education Attainment

Educational attainment shows substantial variation between the upper and lower portions of the watershed. Residents of the upper parts of the watershed appear to be more highly educated with 29% of the population over age 25 having a college degree (table 6.3). By comparison, only 21% of the adult population in the lower part of the watershed have a college education. At the other end of the education spectrum, 8% of the population in the lower watershed over 25 did not graduate from high school. Six

TABLE 6.2

Household Income in the Onion Creek Watershed, 1990

Household Income	Upper Watershed Block Groups			Lower Watershed Block Groups					
	ALL	1	2	ALL	3	4	5	6	7
Less than $5,000	2.1%	0.9%	4.9%	5.6%	9.3%	10.4%	1.1%	0.0%	13.4%
$5,000 to $9,999	6.8%	2.7%	16.6%	6.7%	11.1%	14.0%	0.8%	7.1%	7.3%
$10,000 to $12,499	1.8%	1.3%	3.1%	5.3%	1.6%	12.4%	2.4%	8.3%	13.4%
$12,000 to $14,999	2.8%	2.7%	3.1%	3.3%	0.0%	9.9%	1.3%	8.3%	0.0%
$15,000 to $17,499	4.1%	2.1%	9.0%	4.5%	4.8%	8.6%	1.0%	11.9%	9.8%
$17,500 to $19,999	2.7%	1.0%	6.6%	2.6%	6.6%	0.0%	2.4%	0.0%	0.0%
$20,000 to $22,499	5.9%	5.7%	6.4%	4.4%	1.9%	10.4%	2.8%	7.1%	0.0%
$22,500 to $24,999	3.6%	3.9%	2.9%	2.7%	7.2%	1.3%	0.9%	8.3%	0.0%
$25,000 to $27,499	5.1%	6.3%	2.3%	4.8%	5.3%	1.8%	7.2%	0.0%	0.0%
$27,500 to $29,999	2.5%	3.0%	1.4%	6.4%	3.7%	5.8%	5.6%	17.9%	17.1%
$30,000 to $34,999	9.0%	8.9%	9.2%	6.1%	13.0%	4.1%	2.2%	11.9%	15.9%
$35,000 to $39,999	8.2%	8.1%	8.2%	10.8%	8.8%	9.6%	11.1%	9.5%	23.2%
$40,000 to $49,999	20.7%	23.7%	13.5%	14.8%	8.5%	8.1%	24.4%	0.0%	0.0%
$50,000 to $74,999	21.2%	25.2%	11.5%	14.9%	13.5%	1.5%	24.5%	9.5%	0.0%
$75,000 or more	3.7%	4.6%	1.4%	7.1%	4.8%	2.0%	12.3%	0.0%	0.0%
Median	N/A	$40,907	$22,857	N/A	$29,018	$15,956	$44,129	$24,643	$28,393

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

TABLE 6.3

Educational Attainment in the Onion Creek Watershed, 1990

Educational Attainment	Upper Watershed Block Groups			Lower Watershed Block Groups					
	ALL	1	2	ALL	3	4	5	6	7
Less than 9th grade	6.1%	3.6%	12.8%	8.2%	11.1%	8.3%	3.5%	29.9%	19.9%
	(182)	(80)	(102)	(256)	(79)	(48)	(54)	(44)	(31)
High School Graduate	19.6%	18.3%	23.2%	30.1%	27.5%	35.6%	29.3%	21.1%	37.8%
	(589)	(404)	(185)	(938)	(195)	(205)	(448)	(31)	(59)
College Degree	29.2%	30.1%	26.6%	20.7%	18.9%	18.8%	24.6%	19.0%	0.0%
	(877)	(665)	(212)	(645)	(134)	(108)	(375)	(28)	(0)

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

percent of the population in the upper watershed failed to complete high school. This is only a slight, and probably statistically insignificant difference in the less educated.

While residents of the lower parts of the Onion Creek Watershed tended to have lower educational attainment, there was considerable variation among the five block groups ranging from no college educated people living in Block Group Seven to 25% of the adult population in Block Group Five having received college degrees. The three remaining block groups of the lower watershed (3, 4, and 6) each had about 19% of the population with college education. The percentage of adults with a college degree in the two block groups of the upper watershed were quite similar, with Block Group One at 30% and Block Group Two at 27%.

There appears to be more variation within the lower portion of the Onion Creek watershed than in the upper portion. For example, median household incomes ranged from as low as $16,000 to over $44,000 in the lower watershed and educational attainments ranging from 0% to 24% with college education. This diversity is not limited to education and household income. Other demographic variables such as age and race show considerably more variation in the lower portion than in the upper portion of the Onion Creek watershed.

Race/Ethnicity

In the upper watershed, the population is overwhelmingly Anglo (white nonhispanic) with 62% and 81% of the resident population Anglo in Block Groups 1 and 2 respectively (table 6.4). For the entire upper portion of the watershed the population is 67% Anglo, 29% Hispanic, and 3% Black. The cumulative percentages of the entire

TABLE 6.4

Race and Hispanic Origin in the Onion Creek Watershed, 1990

Race/Ethnicity	Upper Watershed Block Groups			Lower Watershed Block Groups					
	ALL	1	2	ALL	3	4	5	6	7
Anglo	66.7%	62.1%	81.3%	67.1%	88.8%	35.9%	92.1%	49.6%	37.1%
	(3021)	(2130)	(891)	(4071)	(992)	(807)	(2074)	(122)	(76)
Black	2.7%	3.4%	0.6%	13.0%	0.0%	35.1%	0.0%	0.0%	0.0%
	(122)	(115)	(7)	(788)	(0)	(788)	(0)	(0)	(0)
Hispanic	29.0%	32.7%	17.6%	18.6%	11.2%	25.5%	7.9%	50.4%	62.9%
	(1314)	(1121)	(193)	(1129)	(125)	(572)	(179)	(124)	(129)
Other	1.5%	1.9%	0.5%	1.3%	0.0%	3.5%	0.0%	0.0%	0.0%
	(69)	(64)	(5)	(79)	(0)	(79)	(0)	(0)	(0)

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

lower watershed for racial composition does not seem vastly different with 67% Anglo, 17% Hispanic, and 13% Black. The diversity within the lower part of the watershed, however, becomes evident when we examine the five individual block groups of the lower watershed. The percentage of population that is Anglo ranges from 36% in Block Group Four to 92% in the very affluent Block Group Five. The percentage of population that is Hispanic varies from 8% to 63%, and with the exception of Block Group Four (with 35% Black) no other area has any Black population. Block Groups Three and Five are each about 90% Anglo. Block Group Seven is predominately Hispanic (63%) and the remaining is Anglo. Block Group Four is uniquely diverse with 36%, 26%, and 35% respectively for Anglo, Hispanic and Black.

Age

Age structure, the last of the major demographic variables discussed here, also varies considerably not only between the upper and lower portions of the watershed, but also within these two divisions of the watershed. There are clearly greater proportions of people between 25 and 44 years in the upper watershed compared to the lower portion of the watershed (table 6.5). There is also a somewhat larger population in the youngest age category in the upper watershed (age 5 to 14). Also we have seen that people in the upper watershed have higher incomes, more education and a preference for the better schools of the Dripping Springs Independent School District. It is logical to conclude that the population of this area is predominantly working people with children. In contrast, the older population (after the mid to late 40s) make up a markedly smaller percentage of the population. Differences between the two block groups forming the upper watershed are

TABLE 6.5

Population Age Structure by Subunits in the Onion Creek Watershed, 1990

Age	Upper Watershed Block Groups			Lower Watershed Block Groups					
	ALL	1	2	ALL	3	4	5	6	7
5 to 14	13.5%	14.5%	10.3%	12.4%	15.8%	7.4%	14.3%	16.7%	23.9%
15 to 24	11.3%	11.0%	12.4%	30.7%	14.1%	63.0%	11.5%	13.8%	0.0%
25 to 34	27.6%	29.5%	21.9%	13.2%	12.6%	9.5%	15.0%	23.6%	25.4%
35 to 44	16.1%	16.6%	14.2%	12.8%	12.4%	7.8%	17.9%	16.3%	7.8%
45 to 54	7.6%	7.4%	8.3%	9.6%	10.7%	3.0%	15.9%	3.7%	13.2%
55 to 64	7.4%	6.3%	10.7%	7.1%	5.8%	2.2%	12.7%	6.5%	5.4%
65 to 74	4.2%	2.7%	8.8%	4.6%	7.7%	1.6%	4.7%	7.3%	15.1%
75 to 84	2.8%	1.3%	7.6%	3.4%	10.7%	1.5%	1.2%	2.4%	9.3%
85 plus	0.8%	0.6%	1.4%	0.7%	3.5%	0.0%	0.3%	0.0%	0.0%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992 relatively minor. Block Group Two has a slightly older population than Block Group One.

The age structure of people in the lower watershed is not too dissimilar to the distribution of the upper watershed. The only exception to this is the disproportional 31% of the population between 15 and 24 years old. The lower watershed, as has been the trend thus far, shows much greater variation among the block groups that form it. A closer examination of the age structure within each of the five block groups reveals notable differences. In terms of age structure the most unique block groups are Four and Seven. Block Group Four has the most unusual age distribution with a remarkable 63% of it entire population between 15 and 24 years old. While the age distribution of the population in Block Group Seven is not as unusual as that Block Group Four it still is worthy of note. Block Group Seven has a series of small bulges in the age distribution as you move from younger to older age groups.

The three remaining block groups have more typical age distributions. Block Group Six is very similar in age structure to the upper watershed, with a bias towards children and adults in the child-rearing ages. The population of Block Groups Three and Five are somewhat older than might be expected. Block Groups Three and Five are not the same however. The most notable difference is in the older age groups. The population in Block Group Five is younger on average with fewer older people. The population of Block Group Three is considerable older on average with a large retirement aged population. The population of Block Group Five shares a fairly typical age distribution with the upper portion of the Onion Creek Watershed with the exception that Block Group Five's population is slightly older on average. This is in part substantiated by plat dates of the primary subdivisions there which tend to be earlier than those in the upper watershed. In addition, the slightly higher median household incomes might be indicative of older working people who have simply had more time for more raises and promotions than their younger colleagues now living in the upper watershed.

Population Change in Onion Creek 1970 to 1990

An understanding of the demographic character of the Onion Creek watershed in 1990 is important in and of itself. However, what is of even greater importance is a more complete understanding of the demographic changes that were occurring in the watershed during the 1970s and 1980s, which eventually resulted in the 1990 patterns described above. The problem is that, prior to 1990, census data were not reported for non-urban areas at the block group level of detail. As a result only rather crude estimates of the demographic characteristics of the Onion Creek watershed are possible prior to 1990. To counter this weakness, multiple sources of evidence were examined to attempt to construct a reasonably accurate portrait of the demographic changes that were occurring in the Onion Creek watershed between 1970 and 1990. Data sources that are examined include: coarse resolution census data, mobility data from the 1990 census, timing of new developments based on county plat maps, and interviews.

Changes in the Upper Onion Creek Watershed

Development in the upper portion of the Onion Creek watershed has been quite rapid. This has been perhaps most evident in the 1990s, but it certainly began prior to 1990. A look at the subdivisions platted in the upper part of the Onion Creek watershed clearly illustrates two points about population growth in the area. First, within the upper watershed most of the growth has been in the area of Dripping Springs [school district]. Second, by using the dates that subdivisions were platted as a surrogate for timing of population growth, we clearly see an explosion of growth in the late 1980s with 17 of the 33 existing subdivisions platted between 1985 and 1990 (table 6.1). The dates of platting show an acceleration in the development of new subdivisions in the area with only three platted between 1970 and 1975, five during the following five years, six more between 1980 and 1985, and finally 17 new subdivisions between 1985 and the end of the study period in 1990.

The explosion of new subdivisions at the end of the 1980s fits nicely with the mobility data from the 1990 census, which accounts for place of residence five years earlier. Only 21% of the population within the upper watershed lived in the same house in 1990 as in 1985 (table 6.6). There is, however, considerable difference between the two block groups forming the upper watershed. Eighty-nine percent of the population living in Block Group One in 1990 moved at least once in the preceding five years, compared to 50% for Block Group Two. Fifty percent of the moves in Block Group One occurred within Hays County. Ten percent of the population moved from another county in Texas and 28% moved from outside the state. In marked contrast, only 5% of Block Group Two's population lived outside of Texas in 1985. Forty-five percent of Block Group Two's population lived within Texas five years earlier, with half of those living in the same county (Hays). Mobility tended to be higher in Block Group One than Two. A much higher percentage moved into these two block groups from outside of Texas. The increased mobility and prevalence of out-of-state migrants might indicate a more diverse

TABLE 6.6

Place of Residence in 1985 in the
Upper Onion Creek Watershed, 1990

	Block Groups		
	ALL	1	2
Same House	21.4%	11.5%	50.4%
Same County	42.8%	50.0%	21.6%
Same State	13.6%	10.4%	22.9%
North East	0.9%	1.0%	0.4%
North Central	7.1%	9.1%	1.1%
South	2.8%	3.0%	2.2%
West	6.4%	8.6%	0.0%
Abroad	5.0%	6.3%	1.3%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

population as ideas and lifestyles are brought into the area from other parts of the country and world (see discussion in Chapter 2).

Undoubtedly some of the people moving into the upper portion of the Onion Creek Watershed were returning to the area after the economic bust that rocked Texas during the late 1970s and early 1980s. However, the economic boom that followed, beginning in the mid-1980s, attracted large numbers of non-native Texans to the area as well. Census data describing places of birth supports this idea as well and lends support to the idea of a more ideologically diverse population being created by the breadth of places contributing to the population growth. Thirty-nine percent of the population in the upper part of the Onion Creek Watershed was born outside of the state of Texas (table 6.7). However, as with the mobility data discussed above, place of birth varies considerably between the two block groups in the upper watershed as well. While 71% of the population in Block Group Two were born in Texas, only 58% were born in Texas in Block Group One. Interestingly, much of the difference between the percentage of population born outside Texas is accounted for by people born not only outside of Texas, but outside the United States. Over 9% of Block Group One's population was foreign born (4% in US territories and possessions and 5% in foreign countries).

Changes in the Lower Onion Creek Watershed

As in the upper portion of the watershed, lower Onion Creek has experienced rapid development and population growth. The increase in the number of subdivisions being platted over the study period is very similar to the exponential increase observed in the upper watershed. In the lower watershed three platted subdivisions existed prior to

TABLE 6.7

Birth Place of Residents in the
Upper Onion Creek Watershed, 1990

	Block Groups		
	ALL	1	2
Same State	61.0%	57.8%	70.8%
Different State	31.7%	33.0%	27.9%
Abroad	3.2%	4.2%	0.0%
Foreign	4.1%	5.0%	1.3%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

1975. Between 1975 and 1980 seven new subdivisions were platted. The early 1980s witnessed a slight slowdown in the establishment of new subdivisions, and in the final five years of the decade there was an explosion in subdivision development with 17 new subdivisions platted.

At first glance the population of the lower watershed would appear to be less mobile than the population of the upper watershed with 41% of the population living in the same place in 1990 as they did in 1985 (table 6.8). However, as observed previously with many demographic characteristics there is considerable variation among the block groups in the lower watershed. A close look reveals that percentages of the population who have not moved in the previous five years range from 20% in Block Group Four to 83% in Block Group Seven. Each of the five block groups in the lower watershed is unique and warrants individual attention.

Block Group Three's most notable characteristic with respect to mobility is the rather high percentage of the population (41%) who lived in a different home in the same county in 1985. This high proportion of short distance moves in addition to the 36% of the population who did not move during the previous five years seems to indicate that the population is primarily composed of long-term residents with little long-distance mobility. Block Group Seven, however, is the most extreme example of a stable population with very low mobility. In Block Group Seven 83% of the population lived in the same house from 1985 to 1990. The remaining 17% of the population lived in the Hays County five years earlier. This unusually stable population, however, is based on a block group with a population of only 205. The block group with the greatest mobility in the lower watershed was Block Group Four. In Block Group Four only 20% of the population lived

TABLE 6.8

Place of Residence in 1985 in the Lower Onion Creek Watershed, 1990

	Block Groups					
	ALL	3	4	5	6	7
Same House	40.7%	36.2%	19.8%	59.3%	48.2%	83.4%
Same County	11.5%	40.7%	0.9%	6.6%	18.5%	16.6%
Same State	32.2%	13.6%	52.1%	24.7%	26.1%	0.0%
North East	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
North Central	1.2%	0.0%	1.1%	1.5%	7.2%	0.0%
South	9.8%	2.5%	18.4%	6.7%	0.0%	0.0%
West	2.5%	4.9%	4.3%	0.0%	0.0%	0.0%
Abroad	2.1%	2.1%	3.4%	1.3%	0.0%	0.0%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

in the same house five years earlier while 27% lived outside Texas (including some from outside the United States). Nearly the entire remaining population lived somewhere else within Texas in 1985. In Block Group Four, two-thirds of the population that lived outside of Texas in 1985 originated from the South. This may help explain the larger Black population in Block Group Four.

Plum Creek

The Plum Creek Watershed like the Onion Creek Watershed is primarily rural. The primary exceptions to this rural atmosphere are the city of Lockhart (located in the heart of the watershed), most of the community of Kyle, and outlying parts of both Buda and Luling (figure 4.7). Several forces have played roles in the population growth of the Plum Creek Watershed over the years. One of the earliest forces driving population growth, particularly in the Blackland Prairie area of the northern parts of the watershed, was agriculture and cotton. In the 1920s, oil was discovered in the southern part of the watershed near Luling. Most recently, Austin (to the north and west) has expanded to the point that much of the northern part of the watershed is within commuting distance.

The Population of Plum Creek in 1990

In 1990 the Plum Creek Watershed population was approximately 25,000. The population was focused on the city of Lockhart with nearly 10,000 people. Another 9000 people were located in the area north of State Highway 21 in the vicinity of IH-35 and the cities of Kyle and Buda.

Twenty-six 1990 census block groups approximate the geographic extent of the Plum Creek Watershed (figure 6.2). In the less densely populated areas, the block groups are quite large and therefore poorly fit within the watershed boundaries. Few settlements however, exist in areas outside the watershed and the small population that lives in the area is relatively evenly distributed. Patterns observed for the entire block group will likely hold for the smaller portions that are within the watershed. These purposes of this analysis the twenty-six block groups were merged into four divisions within the watershed. The divisions were based on the hydrology of the watershed and the location of water quality monitoring stations with usable data. The demographic character of the region in 1990 and the population changes culminating in the 1990 pattern are examined in the context of these four divisions of the watershed as well as for the watershed as a whole.

Household Income

As a whole, people in the Plum Creek Watershed have, on average, lower incomes than people living in the Onion Creek Watershed. In 1990 over 40% of households in Onion Creek had incomes of over $50,000 per year compared to 22% in Plum Creek (table 6.9). There is variation within the Plum Creek watershed however, with the South/Central Division having the highest incomes, on average, with the most higher income households (18.4%) and the fewest low income households (24.8%). In contrast, the Eastern Division had the least households with over $50,000 annual income (13.5%) and the most households earning less than $15,000 annually (36.5%). This makes the Eastern Division the poorest in the watershed. The Northern Division had the most bi-modal income distribution, ranking second of the four at both ends of the income

FIGURE 6.2

Census Divisons in the Plum Creek Watershed

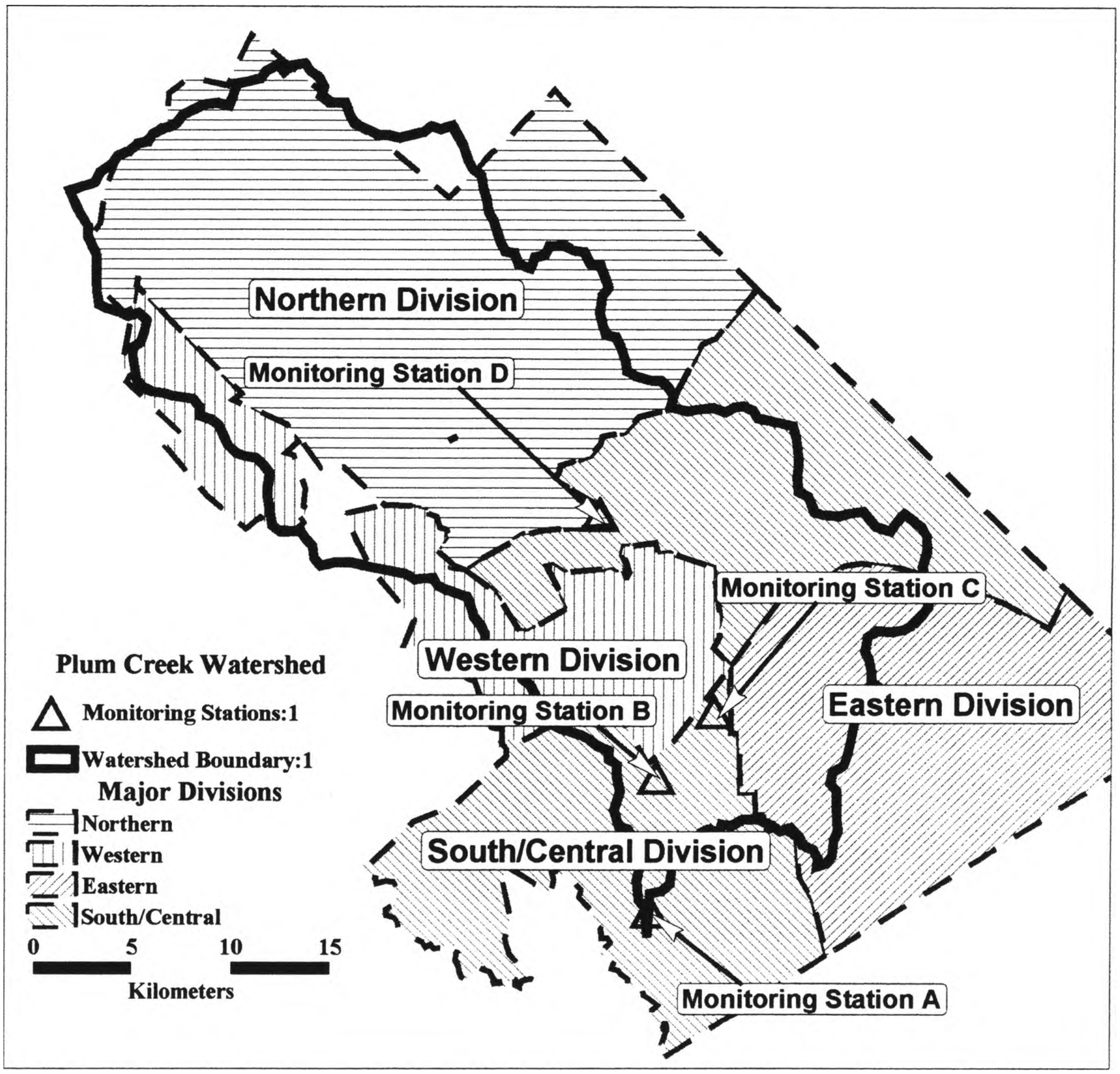


TABLE 6.9

Household Income in the Plum Creek Watershed, 1990

Household Income	Division				
	All	Northern	Western	Eastern	South/Central
Less than $5,000	10.0%	11.4%	3.3%	3.2%	6.6%
$5,000 to $9,999	10.7%	10.5%	8.9%	13.5%	12.3%
$10,000 to $12,499	5.4%	6.0%	3.5%	3.6%	3.7%
$12,000 to $14,999	6.1%	6.1%	9.7%	16.2%	2.2%
$15,000 to $17,499	5.2%	4.8%	4.3%	12.6%	6.4%
$17,500 to $19,999	5.6%	5.5%	6.2%	7.2%	6.0%
$20,000 to $22,499	6.3%	6.0%	7.5%	3.6%	8.1%
$22,500 to $24,999	4.7%	5.0%	2.3%	0.0%	5.6%
$25,000 to $27,499	3.6%	3.7%	3.7%	4.1%	2.7%
$27,500 to $29,999	5.0%	5.2%	10.0%	0.0%	1.6%
$30,000 to $34,999	9.1%	8.3%	12.7%	22.5%	8.6%
$35,000 to $39,999	6.5%	6.0%	7.2%	0.0%	10.6%
$40,000 to $49,999	9.7%	10.4%	9.5%	0.0%	7.2%
$50,000 to $74,999	9.2%	9.1%	11.0%	3.6%	10.1%
$75,000 or more	2.9%	2.0%	0.0%	9.9%	8.3%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

distribution with 22% of household making over $50,000 and 34% making less than $15,000. The Western Division follows ranking third at both ends with 21% over $50,000 and 25% under $15,000. With over three-quarters of the households of the entire watershed it is no surprise that the Northern Division's income distribution is most similar to the overall income distribution.

Age

Age distribution for the entire watershed is reasonably typical (table 6.10). This is true also for the more populated Northern Division, which includes all of Lockhart and parts of the small towns of Buda and Kyle. Both the increased population and the inherent diversity of the inclusion of an entire community makes this observation expected. The South/Central Division, with a population of three thousand and areas adjacent to both Lockhart and Luling, has a population age distribution that varies only slightly from that of the Northern Division and the watershed as a whole.

While the Plum Creek Watershed as a whole and both the South/Central and the Northern Divisions have typical population age distributions, the other two have more unusual age distributions. The Eastern Division with only about five hundred people has an age distribution biased heavily towards older people. In fact 45% of the population in the Eastern Division was fifty-five or older in 1990. This might point toward a region with retirement amenities. While these people may be retired or approaching retirement, the absence of growth in population indicates that these are not in-migrant retires, but rather are residents aging in place.

TABLE 6.10

Population Age Structure by Subunits
in the Plum Creek Watershed, 1990

Age	Division				
	All	Northern	Western	Eastern	South/Central
5 to 14	18.0%	19.0%	14.2%	8.6%	16.5%
15 to 24	14.0%	13.9%	16.8%	7.4%	13.2%
25 to 34	17.2%	16.9%	24.2%	14.7%	13.6%
35 to 44	15.5%	14.9%	19.0%	4.5%	18.3%
45 to 54	9.2%	9.4%	6.2%	12.5%	9.2%
55 to 64	7.7%	7.2%	6.2%	19.2%	10.2%
65 to 74	5.5%	5.4%	3.8%	12.3%	6.8%
75 to 84	3.5%	3.3%	1.9%	10.6%	4.4%
85 plus	1.2%	1.0%	0.9%	2.7%	2.2%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

The Western Division's population age distribution also tells us some interesting things. The most notable observation is that 43% of the population is between the ages of 25 and 44. We also note that the percentage of the population in the younger age groups is consistent with all the other divisions except that of the Eastern Division. This means that a larger than expected child bearing and raising adult population is having far fewer children than in other areas of the watershed. Families living in this part of Plum Creek are having fewer children or some segment of the adult population in the area is having virtually no children.

Race/Ethnicity

Within Plum Creek 51% of the population was Anglo in 1990, 42% of the population was Hispanic, and 7% was Black. These racial/ethnic proportions are mirrored in the Northern and Western Divisions with very similar ratios of Anglo, Hispanic, and Black populations (table 6.11). The Eastern Division's the small population is 94% Anglo. The remaining 6% of the population is Hispanic. The South/Central Division is also predominately Anglo, but at 71% not quite as overwhelmingly as in the Eastern Division. The remainder of the population is almost evenly split between Blacks and Hispanics representing 13% and 14% respectively. The 13% of the population that is Black in the South/Central Division is nearly twice the percentage Black in any of the other three divisions.

TABLE 6.11

Race and Hispanic Origin in the Plum Creek Watershed, 1990

Race/Ethnicity	Division				
	All	Northern	Western	Eastern	South/Central
Anglo	50.5%	46.1%	51.8%	93.9%	70.9%
	(12718)	(8882)	(1261)	(459)	(2116)
Black	7.1%	6.3%	7.2%	0.0%	13.4%
	(1792)	(1216)	(176)	(0)	(400)
Hispanic	41.9%	47.3%	40.7%	6.1%	14.1%
	(10551)	(9109)	(991)	(30)	(421)
Other	0.4%	0.3%	0.3%	0.0%	1.5%
	(109)	(56)	(7)	(0)	(46)

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

Educational Attainment

As with the other demographic variables education varies among the four divisions of the Plum Creek Watershed. Twenty-one percent of the population over the age of 25 years old in the Plum Creek Watershed completed fewer than nine years of education (table 6.12). Twenty-nine percent of the population earned a high school diploma either by graduation or GED. Fourteen percent of the population received a college degree. Both the Northern and Western divisions have educational attainment rates similar to the whole watershed. A major reason for this similarity is that three-quarters of the population lives in the Northern Division, almost ensuring that the numbers for the watershed as a whole will follow suit.

Educational attainment rates in the Eastern and South/Central Divisions of Plum Creek are higher. Of these two divisions the sparsely populated Eastern Division seems to have the highest level of educational attainment. Twenty-three percent of the population 25 or older in this division earned a college degree. Thirty-eight percent earned a high school diploma. Only 12% of the population had completed fewer than nine years of school. Compared to the Eastern Division, the South/Central Division's population has achieved only a slightly higher level of education attainment than the population of the watershed as a whole. In the South/Central Division 19% have college degrees, 33% high school diplomas, and 15% did not attend school after the eighth grade.

Population Change in Plum Creek 1970 to 1990

As was the case in Onion Creek, only crude estimates of population change in Plum Creek are possible since a finer level of resolution is not available for years form

TABLE 6.12

Educational Attainment in the Plum Creek Watershed, 1990

Educational Attainment	Division				
	All	Northern	Western	Eastern	South/Central
Less than 9th grade	20.9%	22.5%	19.2%	11.5%	14.7%
	(3140)	(2524)	(290)	(43)	(283)
High School Graduate	29.0%	28.4%	26.3%	38.0%	33.0%
	(4358)	(3180)	(398)	(142)	(638)
College Degree	14.1%	13.1%	12.8%	23.3%	19.1%
	(2118)	(1469)	(194)	(87)	(368)

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

prior to 1990. Clipping larger census units to the limits of the watershed is not practical since significant errors can be introduced in this process. This is particularly true when dealing with rural areas with clustered populations (i.e., a small town). To deal with this problem, emphasis is placed on data that are already tied to the appropriate geographic areas or those that can be assigned to an appropriate spatial unit with minimal error.

Considerable amounts of longitudinal data are available for Caldwell County, within which most of the Plum Creek Watershed is located. The watershed covers over half of the county's land area. Important are concentrations of population in Caldwell County outside of the Plum Creek Watershed are along the San Marcos River and Luling. In addition, some important clusters in the Plum Creek watershed in the vicinity of Kyle and Buda are not in Caldwell County. Despite these problems, the county provides a spatial unit for which demographic data have been consistently gathered over many years. Given that the Plum Creek Watershed accounts for approximately half of Caldwell County's land area and population, it is still useful to examine the county level data for trends of change in the area.

In the following pages the population changes that have occurred in Caldwell County will first be examined to assess demographic trends that are likely to reflect those of the Plum Creek Watershed. After this area-wide examination of demographic and population growth trends, a larger-scale analysis of the Plum Creek Watershed itself and its divisions is presented to compare the county trends to the smaller units.

Changes in Caldwell County

Between 1980 and 1990 the population of Caldwell County grew by 12% from 23,637 to 26,392 (table 6.13). While a population growth rate over ten years of 12% is certainly strong, it is not extraordinary compared to other counties in the very rapidly growing Central Texas region. All racial/ethnic groups in Caldwell have not grown at the same rate. The Anglo population grew by 12%, a rate consistent with the total population. The Black population, however, declined from 3,867 to 2,822 between 1980 and 1990, a drop of 27%. The percentage of Hispanics increased, however, and easily offset the declines in the Black population. The Hispanic population grew by 27% over the ten-year period. In 1990 Hispanics represented 37% of the total population, up from 31% in 1980.

Another set of data available for multiple time periods at the county level is "place of residence five years before the census." These data clearly show that in the 1970s, the movement of people from outside of Texas was much more important than in the 1980s when shorter distance moves within the county and region predominated (table 6.13). These observations are consistent with the prevailing economic conditions of the time in which the Texas economy was booming in the late 70s and early 80s while much of the rest of the country was experiencing a marked economic slowdown. The mid- and late-1980s saw a reversal of fortune as the national economy began to recover and Texas's faltered only to begin to recover at the very end of the decade.

While the place of origin in changes of residence differed between the two time periods (1975-80 and 1985-90), the overall rate of mobility was almost identical: 52% in the former and 51% in the later having changed residences in the five prior years. This is

TABLE 6.13

Summary of Demographic Change in Caldwell County between 1980 and 1990

	1980		1990		Change
	Number	Percent of Total	Number	Percent of Total	
Total Population	23,637	100.0%	26,392	100.0%	11.7%
Race/Ethnicity					
Anglo	16,847	71.3%	18,913	71.7%	12.3%
Black	3,867	16.4%	2,822	10.7%	-27.0%
Hispanic	7,754	32.8%	9,852	37.3%	27.1%
Residence Five Years Earlier (Population Five and Over)					
Same House	11,410	51.9%	12,846	52.6%	12.6%
Different House Same County	4,086	18.6%	5,253	21.5%	28.6%
Different County Same State	4,093	18.6%	4,889	20.0%	19.4%
Different State Northeast	401	1.8%	6	0.0%	-98.5%
Different State North Central	329	1.5%	185	0.8%	-43.8%
Different State South	955	4.3%	584	2.4%	-38.8%
Different State West	329	1.5%	307	1.3%	-6.7%
Abroad	379	1.7%	360	1.5%	-5.0%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

of particular interest when we consider that the population of Caldwell County grew by 7% from 1975-80, but declined slightly (-.7%) from 1985-90.

Changes within the Plum Creek Watershed

Northern Division of Plum Creek

The Northern Division of Plum Creek with about three-quarters of both the watershed and county's population has, as would have been expected, experienced changes in population and demographic character similar to that observed for Caldwell County. The only exception might be in the Black population that in percentage terms is more focused in the Luling area, to the south. This slight bias might contribute to a higher relative rate of population growth in the Lockhart area since the Black population countywide declined so rapidly between 1980 and 1990. Another factor which might contribute to a more rapid relative rate of population growth is the larger Hispanic population which can be both a result of and a contributing factor to the very rapid county-wide increase in the Hispanic population. Taken together, it is likely that the Northern Division has grown slightly more rapidly than the county as a whole.

Western Division of Plum Creek

The Western Division of the Plum Creek had some particularly interesting patterns of population and demographic change. The data shows the 5% of the population in 1990 lived outside the United States in 1985 (table 6.14). Alone 5% does not sound very high, but this is in contrast to nothing higher than 1% for any of the other three divisions or the

TABLE 6.14

Place of Residence in 1985 in the Plum Creek Watershed, 1990

		Division			
	All	Northern	Western	Eastern	South/Central
Same House	54.3%	55.0%	47.0%	57.7%	55.3%
Same County	20.5%	20.8%	11.9%	22.3%	24.9%
Same State	21.4%	20.7%	33.3%	17.7%	17.2%
North East	0.1%	0.1%	0.0%	0.0%	0.0%
North Central	0.7%	0.8%	0.9%	0.0%	0.2%
South	1.0%	0.9%	1.3%	0.0%	1.2%
West	0.8%	0.9%	0.8%	2.2%	0.4%
Abroad	1.2%	0.8%	4.8%	0.0%	0.7%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readable data files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

county of Caldwell as a whole. We also find that of the mobile population between 1985 and 1990, 33% lived elsewhere in Texas in 1985. This also represents a considerably higher than expected percentage of the population considering that the next highest was the Northern Division with only 21% and the Eastern and Southern Divisions were 18% and 17% respectively. While it is not possible based entirely on the census data to prove, it is likely that these unusual percentages reflect substantial growth in the Hispanic population and that the Western Division may be an important contributing area to the overall increase in the Hispanic population observed in Caldwell County (Bell 2001).

Eastern Division of Plum Creek

Over the period 1985-90 the Eastern Division had the lowest overall mobility with 58% of the population not changing residency during the period. The Eastern Division also had the highest percentage of vacant homes in 1990 with 36% of all housing units standing vacant (table 6.15). This suggests that the Eastern Division may have been particularly hard hit by the economic slowdown of the mid-80s. The older retirement-aged population was staying where they were and the younger population was leaving to look for places with better opportunities. What is interesting, however, is that despite the very high vacancy rates in 1990, 16% of the housing units were built after 1984 (a value very similar to other parts of Plum Creek). Even more interesting is that 5% were built in 1989 or 90, which is much higher than the other parts of the watershed which tended to have 1% or less of their housing stock newer that 1988 (table 6.16). One scenario for this unusually high percentage of new homes may be older retirees building retirement homes in the area.

TABLE 6.15

Occupied and Vacant Housing Units in the Plum Creek Watershed, 1990

	All		Northern		Western		Eastern		South/Central	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Total Housing Units	9,398		7,088		699		334		1,277	
Occupied Housing Units	8,121	86.4%	6,211	87.6%	604	86.4%	214	64.1%	1,092	85.5%
Vacant Housing Units	1,277	13.6%	877	12.4%	95	13.6%	120	35.9%	185	14.5%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readabledata files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

TABLE 6.16

Housing Units in the Plum Creek Watershed by Year Structure Built, 1990

	All		Northern		Western		Eastern		South/Central	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Total Housing Units	9,398		7,088		699		334		1,277	
Year Structure Built										
1989 to March 1990	69	0.7%	34	0.5%	7	1.0%	17	5.1%	11	0.9%
1985 to 1988	1,475	15.7%	1,132	16.0%	91	13.0%	33	9.9%	219	17.1%
1980 to 1984	2,070	22.0%	1,585	22.4%	160	22.9%	70	21.0%	255	20.0%
1970 to 1979	2,311	24.6%	1,662	23.4%	197	28.2%	101	30.2%	351	27.5%
1960 to 1969	830	8.8%	604	8.5%	75	10.7%	26	7.8%	125	9.8%
1950 to 1959	755	8.0%	601	8.5%	32	4.6%	11	3.3%	111	8.7%
1940 to 1949	699	7.4%	534	7.5%	61	8.7%	8	2.4%	96	7.5%
1939 or earlier	1,189	12.7%	936	13.2%	76	10.9%	68	20.4%	109	8.5%

Source: Census of Population and Housing, 1990: Summary Tape File 3 on CD-ROM [machine-readabledata files] / prepared by the Bureau of the Census. -Washington: The Bureau [producer and distributor], 1992.

Southern Division of Plum Creek

The Southern Division was a close second for the lowest level of mobility to the Eastern Division. Eighty-four percent of the population was born in Texas and 55% had not changed residence between 1985 and 1990. Rates of new housing construction were similar to the watershed as a whole. The only demographic characteristic that seems to have changed is the percentage of population that is Black. Given the 27% decline in the overall Black population of Caldwell County and that the Southern Division has the highest percentage Black it seems logical to assume that some of that decline must be attributed to that area. Given the small Hispanic population of the Southern Division it seems unlikely that strong migration streams would have developed to the area. Lack of Hispanic migration streams would mean that the Southern Division could only have been a minor contributor to the 27% increase in the Hispanic population countywide.

Population and Demographic Change in Review

Despite being spatially adjacent, even sharing a common border, the Plum and Onion Creek Watershed clearly differ in their demographic composition and the rates at which their populations have grown and changed. Onion Creek's population has consistently grown more rapidly than Plum Creek's population. Onion Creek is more Anglo than Plum Creek which has a very large Hispanic minority almost equaling the Anglo population. Onion Creek's minority population, however, is more evenly split, with smaller but significant Hispanic and Black populations. The population of the Onion Creek is also wealthier and more highly educated than the population of Plum Creek.

The broad brush generalization for Onion Creek is a well educated Anglo population with a higher than average income. With a combination of both high population growth rates and mobility much of the population is relatively new to the area. While accurate as a generalization for the entire watershed some parts of the Onion Creek Watershed do differ considerably. The most striking variations are found in the Lower Watershed in the vicinity of Buda. The lower half of the Onion Creek Watershed in fact has considerable demographic diversity. Some areas fit the generalization well, while other areas are better characterized as predominately minority (both Black and Hispanic), considerably lower incomes and levels of educational attainment. In fact, one of the notable characteristics of the lower Onion Creek Watershed is its patchwork of demographically distinct areas.

The population of the Plum Creek Watershed is still predominately Anglo, but not to the same degree as Onion Creek. The population also tends to have a slightly lower level of educational attainment and lower incomes than their counterparts in Onion Creek. Plum Creek does share the spatial patchwork of demographically distinct areas seen in the lower part of the Onion Creek Watershed. The more rapidly growing Northern and Western Divisions of the watershed are most characteristic of the watershed as a whole with large Anglo and Hispanic populations. The Eastern Division of the watershed is the least characteristic of the watershed. The population of the Eastern Division is primarily older Anglos with a significant percentage of the population toward the lower end of the income scale.

These generalizations of the demographic characteristics of the Plum and Onion Creek Watersheds along with the more detailed demographic information provided earlier in this chapter serve as the back drop for the discussion of water quality change in the next chapter.

CHAPTER 7

CASE STUDIES: WATER QUALITY AND RELATIONSHIP TO POPULATION CHANGE

In the quantitative portion of this research (Chapter 5), I examined the relationship of changes in population to water-quality-change within watersheds in Central Texas. In this part of the research the Onion Creek and Plum Creek Watersheds are examined in greater detail to determine the relationship between population change and water quality in greater spatial detail and with less restrictive definitions of both variables. In the previous chapter the 1990 demographic characteristics of the two watersheds were discussed. In addition, the changes leading to the demographic patterns observed in 1990 were examined.

In this chapter, water quality trends are examined. In the earlier analysis a single monitoring station within the watershed and a limited set of water quality variables were used. All monitoring stations with longer periods of regular data collection are used to provide finer detail by breaking each of the watersheds into smaller units (when possible) to match the available demographic data. In addition, some monitoring stations with only a limited number of monitoring events are included in the discussion of water quality change as additional evidence when appropriate. In the process of presenting the water quality data, the demographic characteristics discussed in the previous chapter are reintroduced as the backdrop on which changes and patterns in the water quality data will be interpreted.

Onion Creek

The Onion Creek Watershed contains two monitoring stations which have been monitored regularly over an extended period of time. These two monitoring stations roughly divide the watershed in half and correspond well to the division of the Onion Creek Watershed used in the previous chapter. The monitoring station for the lower portion of the watershed (TNRCC Station 12448) is located 1.13 km (0.7 miles) north of Buda next to the Mopac railroad track. The monitoring for the upper part of the watershed station (TNRCC Station 12451 / USGS Gage 08158700) is located at FM 150, 0.61 km (0.38 miles) downstream of the Flat Creek confluence (figure 4.6). Monitoring data is available from the lower monitoring station from June 1975 and to June of 1994. Water quality monitoring began at the upper station in May 1981 and continued to June of 1998.

A 1981 survey of water quality in Onion Creek concluded that the water quality of Onion Creek was excellent, particularly from IH-35 to its headwaters (the area being examined in this research). This survey pointed out that the rate at which water flows in Onion Creek is unusually slow with an average velocity of 0.00399 m/s (0.013 ft/s) in the upper portion of the creek above the Edwards Aquifer recharge zone. The velocity was even slower below the recharge zone in the vicinity of Buda averaging only 0.00136 m/s (0.004 ft/s) at normal flow. How fast the water moves is a major factor in how quickly dissolved oxygen can be replaced in the system. Despite generally high water quality the slow flow means that even relatively small quantities of waste material can produce marked declines in water quality given the low reaeration capacity (Respess 1982).

Incorporating the assessment of generally good water quality in the 1981 intensive study of the watershed we now examine the trends in water quality both prior to and following the 1981 study. Trends in the water quality data are examined in the light of population growth and the changing characteristics of that growth within the watershed.

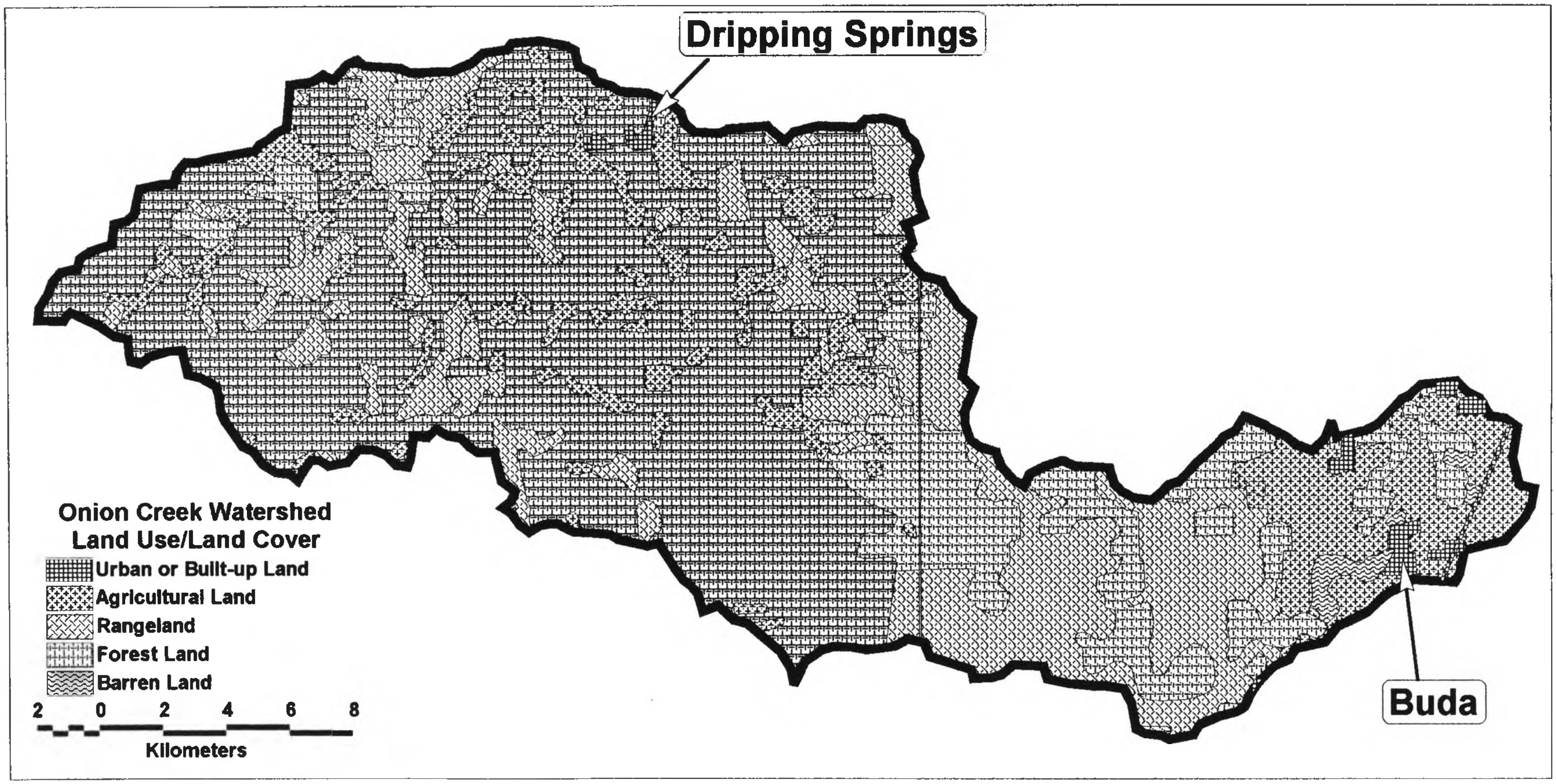
The unique geology of Onion Creek flowing over the Edwards Aquifer recharge zone makes Onion Creek go completely dry over this area during periods of lower precipitation and less stream flow. This creates essentially two different watersheds for the same streambed. The upper and lower portions of the Onion Creek watershed also differ in their basic topography with the lower portion of the watershed being a transition zone between the Texas Hill Country and the Blackland Prairie to the east. This means that the lower watershed has considerably more agricultural use. Indeed figure 7.1 shows that large portions of the lower Onion Creek Watershed were classified as either agricultural or rangeland in 1987. In the upper portion of the watershed these land uses were also evident but tended to be much smaller in scale and spread out along the stream floodplain rather than the large expanses as in the lower watershed.

Water Quality in the Lower Onion Creek Watershed

Water quality data for the Lower Onion Creek Watershed was collected 0.7miles north of Buda next to the Mopac railroad track bridge over the creek. Water quality sampling at this location began in 1975 and continued through 1994. This nineteen-year record of continuous monitoring represents one of the longer continuously monitored

FIGURE 7.1

Land Use and Cover in the Onion Creek Watershed



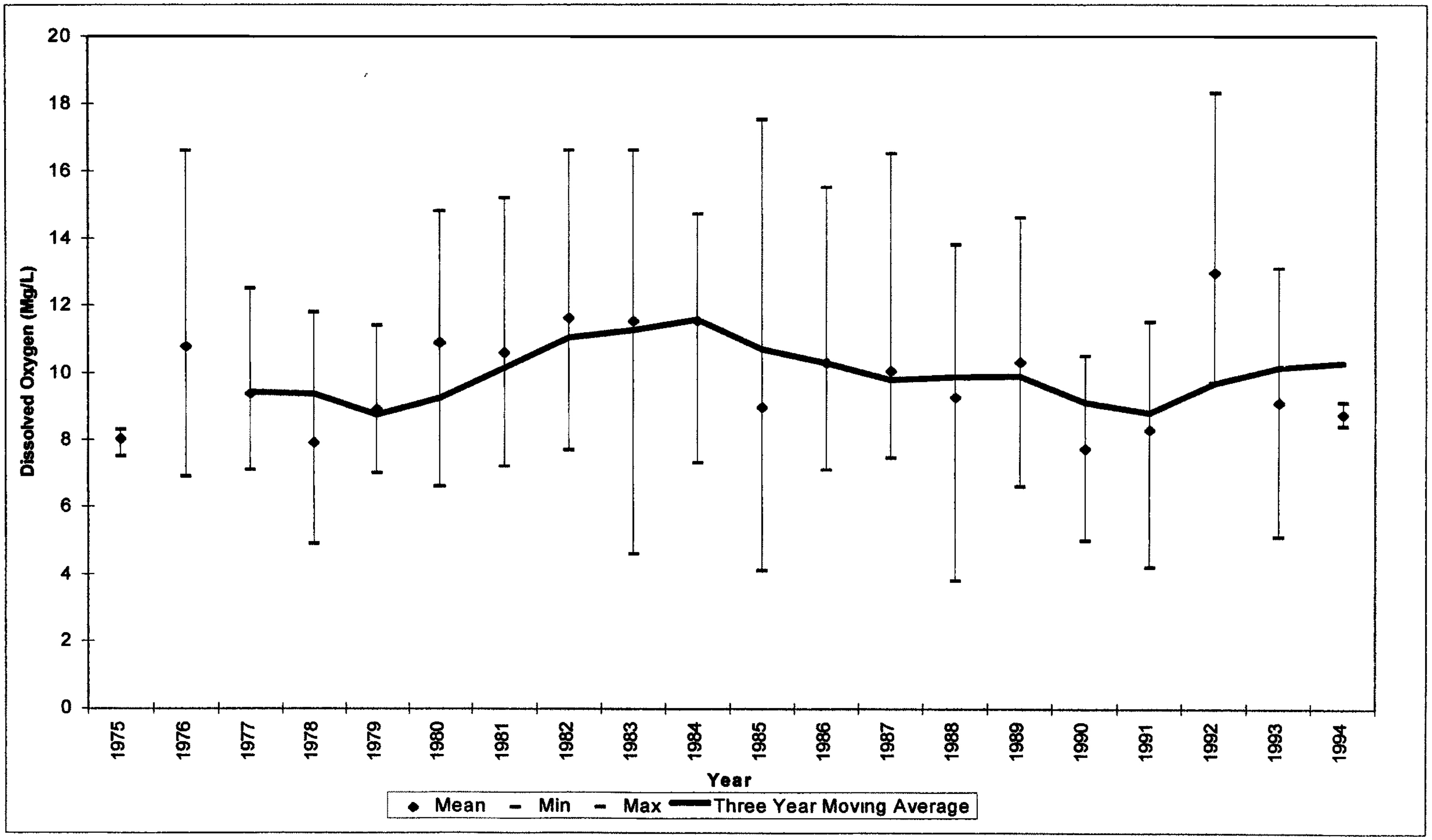
locations encountered in this study. No obvious trends are evident in the dissolved oxygen data with the yearly mean tending between 8 and 10 mg/l over the entire period (figure 7.2). Other water quality variables including fecal coliform and nitrogen did, however, seem to have non-random trends in their data.

At the beginning of the study period (in 1975) nitrogen in the form of ammonia nitrate had a concentration of 0.1 mg/l of water in Lower Onion Creek. Nitrogen levels in this portion of Onion Creek declined during the late 1970s before reaching a low of about 0.02 mg/l in the early 1980s (figure 7.3). Low nitrogen levels were the rule throughout most of the 1980s, however, in 1988 a three-year period of elevated nitrogen levels began. Nitrogen concentration during this periods reached levels similar to those of the mid-1970s. By 1991 nitrogen levels once again returned to and stayed at lower levels.

This pattern of lower and higher nitrogen concentrations in Lower Onion Creek seems to mirror periods of faster and slower rates of population growth, which are, in turn, tied to prevailing economic conditions (figure 7.4). The period of declining nitrogen levels in the late 1970s followed by several years of low nitrogen concentration seems to closely match the economic boom and subsequent population growth in Texas during the same period. This inverse relationship between nitrogen pollution and population growth continued through the remainder of the study period. In the later half of the 1980s the economy turned downward in Texas and population growth slowed dramatically, matching closely the three-year period of elevated nitrogen levels noted earlier. As the Texas economy began to improve in the 1990s and population growth rates once again began to increase, nitrogen levels fell.

FIGURE 7.2

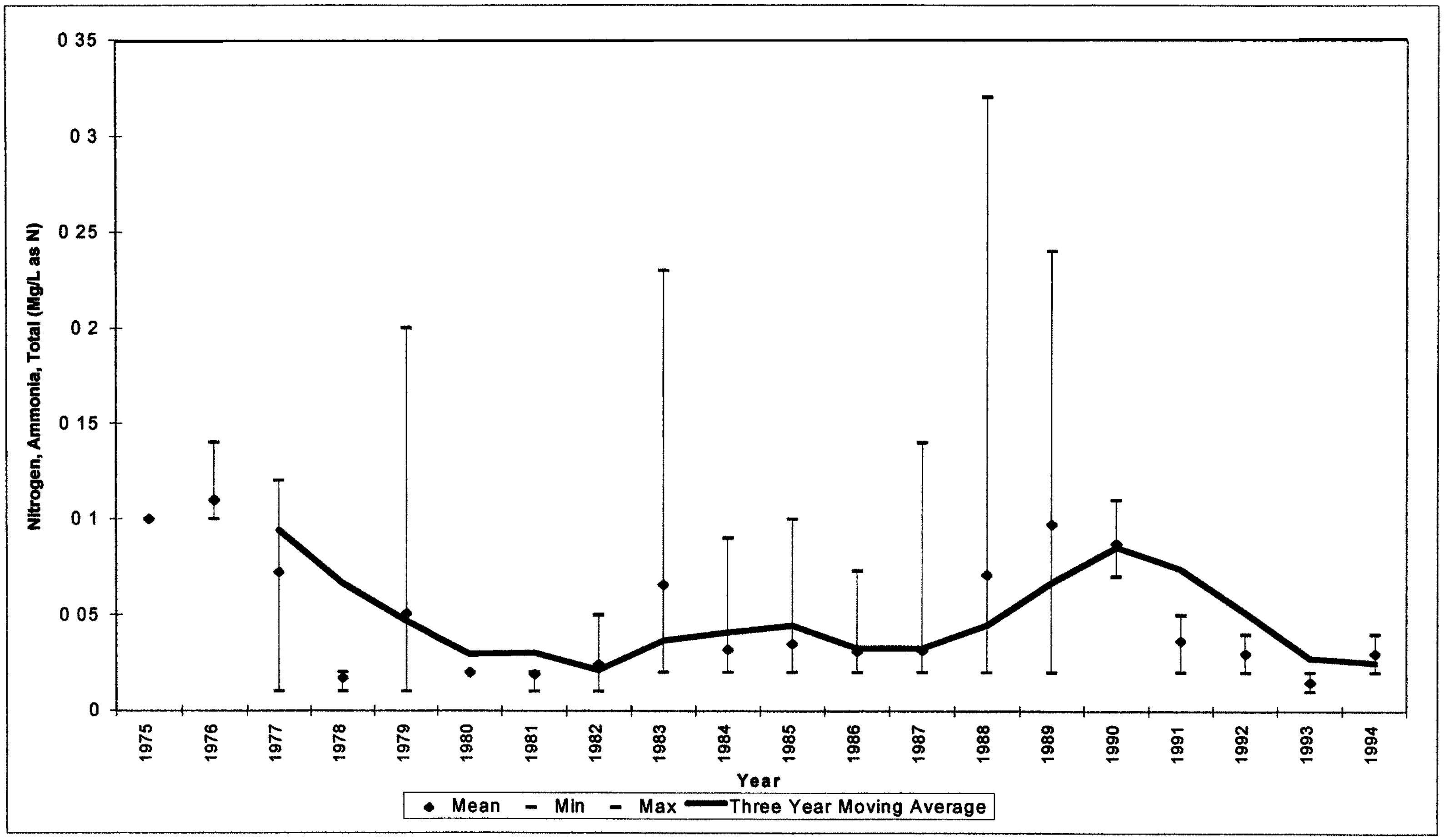
Annual Mean Dissolved Oxygen Concentrations in the Lower Onion Creek Watershed



Source: Surface Water Quality Monitoring (SWQM) Database. Texas Natural Resource Conservation Commission (TNRCC), 1999.

FIGURE 7.3

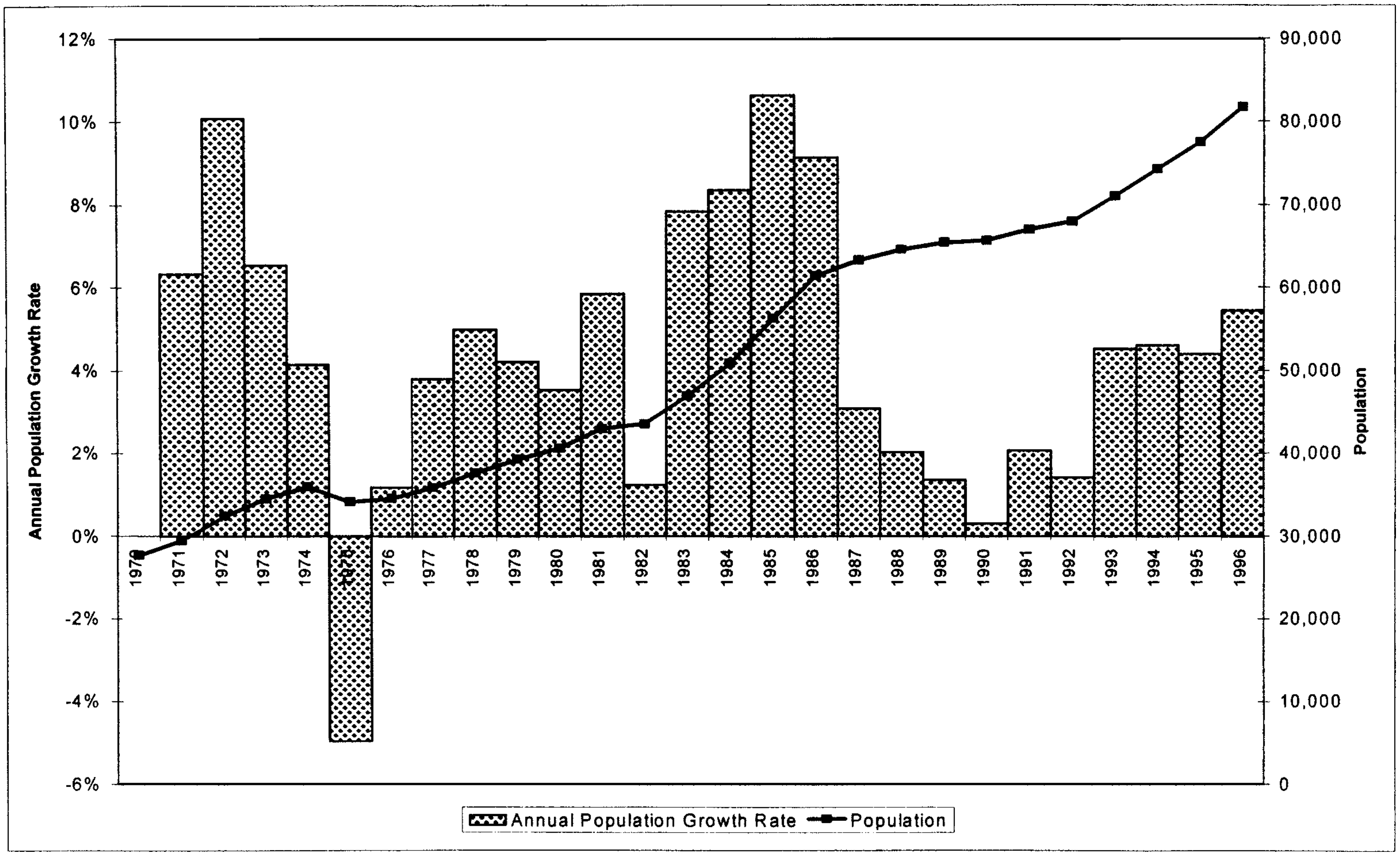
Annual Mean Concentrations of Nitrogen as Ammonia Nitrate in the Lower Onion Creek Watershed



Source: Surface Water Quality Monitoring (SWQM) Database. Texas Natural Resource Conservation Commission (TNRCC), 1999.

FIGURE 7.4

Population Growth and Annual Rate of Change for Hays County, 1970 to 1996.



Although rapid population growth and improving environmental quality are not normally associated, it seems to have been the case with respect to nitrogen pollution in the Lower Onion Creek Watershed. The most probable reason for this relationship lies in the leading source of nitrogen, agricultural runoff (USEPA 2000a; USGS 1999a). It follows that an increasing population will require more housing and will encourage urban expansion. Urban development will necessitate the conversion of agricultural lands to urban land uses. Finally, if there is less agricultural land, which is the leading source of nitrogen pollution, then lower levels of nitrogen in the water should follow. This chain of events linking population growth to changing amounts of nitrogen pollution seems to make sense, however, it turns out to be only a partial explanation.

A couple of inconsistencies seem to exist between the actual pollution and population growth data, and what would be expected based strictly on land use change brought on by population growth. The first question that does not seem to be adequately addressed is how nitrogen concentration rates can fall so rapidly if land use alone is driving the conversion. The second question is why during a period of slowed population growth nitrogen concentrations would increase as they did at the end of the 1980s, a feat that would seem to require the conversion of land from urban back to agricultural uses.

Addressing these two concerns does not require abandonment of the original notion of the role of land conversion from agricultural to urban use in explaining changes in nitrogen pollution. In reality, crops in agricultural areas are rarely tilled under by construction equipment building roads and pouring foundations. Instead land is typically taken out of agricultural use prior to being developed. In areas of rapid economic and population growth agricultural land may be taken out of agricultural use well in advance of the actual expansion of the urban area as land speculators gamble on the direction and duration of urban growth. By factoring land speculation into the original notion of population-growth-driven land conversion from agricultural to urban use, the inconsistencies between actual observation and what might at first be expected disappear.

Land speculation provides an elastic phase of transition from agricultural to urban uses. Speculators in periods of rapid economic and population growth will purchase undeveloped land in anticipation of growth into that area. The speculators may buy large amounts of land, far in excess of what could ever be developed in the foreseeable future. Little of the land will be used for raising crops once bought on a speculative basis since planting and caring for a crop represents an investment that would not be recovered if the property were resold. Thus in times of rapid economic growth land speculation can potentially result in large decreases in nitrogen pollution as formerly productive cropland is left idle waiting for conversion to urban use. That may never come, as was the case in the later 1970s in the Lower Onion Creek Watershed. When the economy and population growth does slow, idle cropland may be returned to production and nitrogen may begin to increase as happened in the late 1980s in the Lower Onion Creek Watershed.

Evidence supporting this transition of cropland in and out of production is found in the United States Agricultural Census. The county is the smallest geographic unit used in the Agricultural Census, however, there is good reason to expect the trends in data to be similar for Hays County and the Onion Creek Watershed which occupies a large percentage of the county. According to the Agricultural Census of 1978, taken at the beginning of the economic boom that continued well into the 1980s, 27,638 ha (68,267 acres) of land in Hays County was used as cropland (table 7.1). By the next agricultural

TABLE 7.1

Agricultural Land Use in Hays County

	Hays					
	1974	1978	1982	1987	1992	1997
Farms (number)	503	530	643	701	704	816
Land in farms (acres)	293,508	302,020	210,668	297,443	463,450	298,493
Land in farms, average size of farm (acres)	584	570	328	424	658	366
Total cropland (acres)	61,645	68,267	51,050	47,572	48,976	73,856
Total cropland, harvested cropland (acres)	21,933	27,262	24,888	17,127	19,681	25,758
Total cropland, cropland used only for pasture or grazing (acres)	35,496	38,128	24,479	23,641	26,895	45,833
Total cropland, other cropland (acres)	--	2,877	1,683	6,804	2,400	2,265
Other cropland, cropland in cover crops (acres)	--	724	178	450	516	1,138
Other cropland, cropland on which all crops failed (acres)	--	1,081	315	788	530	614
Other cropland, cropland in cultivated summer fallow (acres)	--	135	225	1,639	264	185
Other cropland, cropland idle (acres)	--	937	965	3,927	1,090	328
Total woodland (acres)	14,976	24,197	23,134	25,886	15,564	19,376
Total woodland, woodland pastured (acres)	--	23,659	21,545	23,801	14,093	13,138
Total woodland, woodland not pastured (acres)	--	538	1,589	2,085	1,471	6,238
Other land (acres)	--	209,556	136,484	223,985	398,910	205,261
Other land, pastureland/rangeland other than cropland/woodland pastured (acres)	--	199,991	132,880	219,695	392,403	201,800
Other land, land in house lots, ponds, roads, wasteland, etc. (acres)	--	9,565	3,604	4,290	6,507	3,461
Pastureland, all types (acres)	--	261,778	178,904	267,137	433,391	260,771
Land under Conservation Reserve or Wetlands Reserve Programs (acres)	--	--	--	(D)	394	(D)

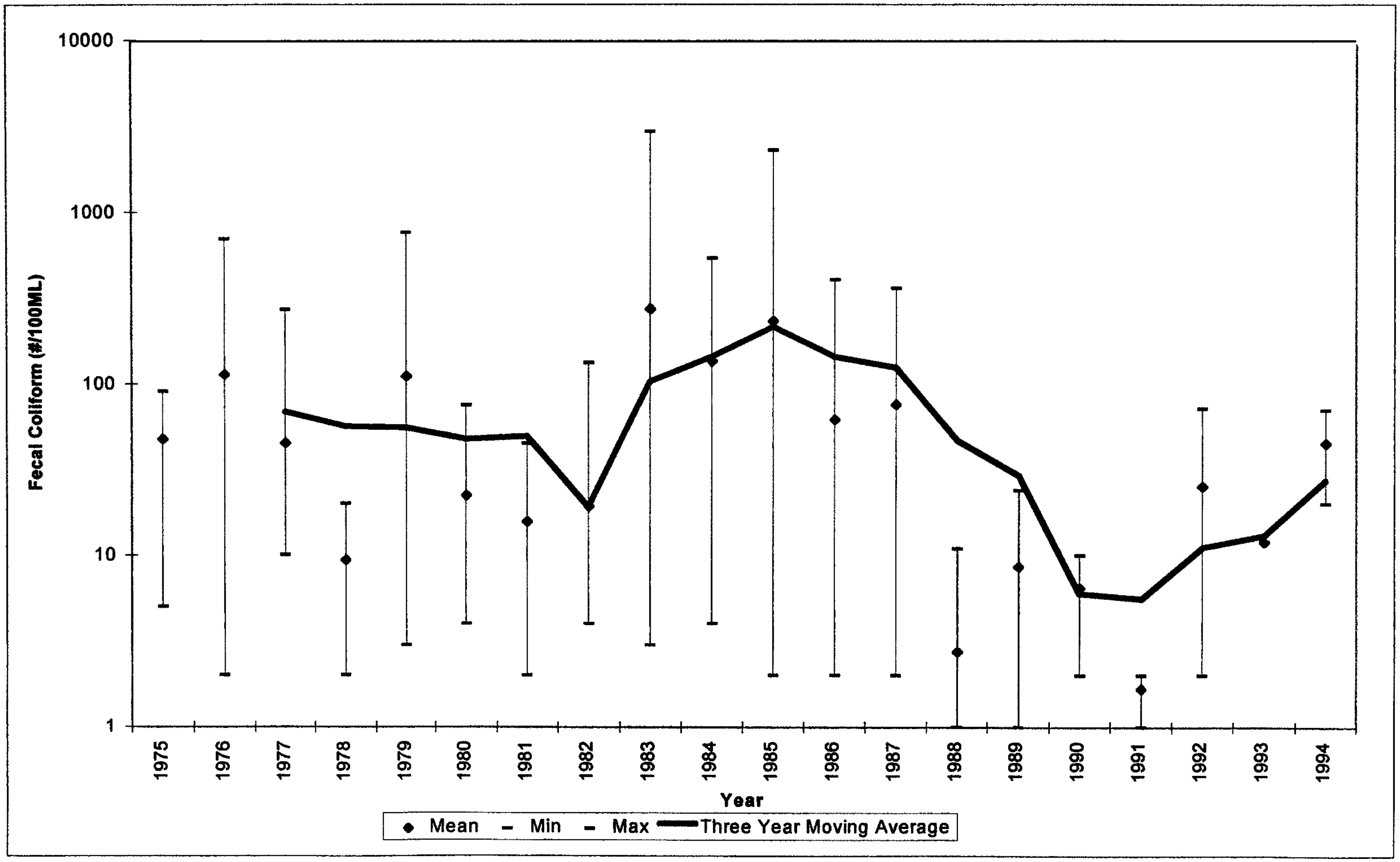
Sources: U.S. Census of Agriculture: 1974, 1978, 1982, 1987 and 1992; Washington, DC: Bureau of the Census. U.S. Census of Agriculture: 1997; Washington, DC: National Agricultural Statistics Service.

census in 1982, and well into the economic boom of the 1980s, the amount of cropland in Hays County had declined by 25% to 20,668 ha (51,050 acres). As the economic boom continued, the amount of cropland in Hays County continued to decline. However, the rate of decline slowed quite significantly falling only 7% to 19,260 ha (47,572 acres) in 1987. The rapid decline in cropland at the beginning of the economic boom followed by continued, but slower decline would seem to fit well with land speculation. Speculators would quickly purchase all the land that farmers are willing to sell. Other farmers that had not originally considered selling might be convinced to sell as the economic boom continues and land prices continue to increase. The timing of the Agricultural Census in 1987 and 1992 unfortunately straddles the economic bust of the late 1980s. An increase in cropland recorded between these two censuses would have supported the notion that land idled under speculation was returned to cropland during the bust.

While nitrogen is an important pollutant it is not the only pollutant for which non-random trends seem to exist during the study period. During the late 1970s and early 1980s fecal coliform levels in the lower portion of the Onion Creek Watershed fluctuated annually, but the multi-year average hovered around 50 fecal coliform bacteria per 100ml (figure 7.5). Between 1983 and 1987 fecal coliform tended to be higher with a multi-year average around 150 /100ml. In 1988 fecal coliform counts declined quite sharply and remained relatively low (less than 10 /100ml) for the next three years. In 1992 fecal coliform counts increased noticeably to around 30 /100ml, but not to the high levels of the mid-1980s. While individual rainfall events could have influenced individual fecal coliform measurements there is no evidence of a wet or dry years having any discernible impact on mean annual fecal coliform measurements. In fact, during the 1983 to 1987 period of

FIGURE 7.5

Annual Mean Fecal Coliform Concentrations in the Lower Onion Creek Watershed



elevated fecal coliform counts, annual precipitation in Austin was very close to normal for that station (table 7.2). In San Antonio 1985 and 1986 were notably wetter than normal, but other years in the period of elevated fecal coliform measurements were in line with annual norms.

Fecal coliform can originate from a number of urban and agricultural sources. The most obvious source of fecal coliform pollution in urban settings is from human waste, which might include inadequately treated and overflow of sewage from treatment plants, and septic systems. Another potential fecal coliform source in urban areas is pet waste. Livestock operations in agricultural areas can also be large contributes to fecal coliform concentration. While fecal coliform pollution can result from both urban and agricultural land uses, the agricultural uses seem to account for most of the fluctuations seen over the study period.

Between 1975 and 1982 year-to-year variation in fecal coliform counts seem to be random, however, 1983 marked a five-year period of elevated fecal coliform level. This period of elevated fecal coliform level coincides with a period of extremely rapid population growth in Hays County (averaging nearly 1% growth per year for four consecutive years). It might be interpreted that increased fecal coliform levels were the result of increased population and conversion of land to urban uses. This idea is supported by the platted subdivision data that indicates that 14 of the 30 subdivisions platted in the Lower Onion Creek Watershed were platted between 1983 and 1987 (table 7.3). One fact, however, seems to rule out what seems a logical interpretation: there was a sudden and sustained decline in fecal coliform counts beginning in 1988 and continuing through 1991. The Texas economy turned down in 1987 and population growth in Hays

TABLE 7.2

Annual and Mean Precipitation for
Austin and San Antonio, 1970-1993

Year	Austin mm (in)	San Antonio mm (in)
1970	778 (30.64)	578 (22.74)
1971	634 (24.95)	808 (31.80)
1972	662 (26.07)	800 (31.49)
1973	1028 (40.46)	1328 (52.28)
1974	920 (36.21)	940 (37.00)
1975	935 (36.81)	652 (25.67)
1976	1048 (41.25)	994 (39.13)
1977	562 (22.14)	753 (29.64)
1978	787 (30.97)	914 (35.99)
1979	953 (37.50)	931 (36.64)
1980	695 (27.38)	615 (24.23)
1981	1162 (45.73)	924 (36.37)
1982	676 (26.63)	583 (22.96)
1983	863 (33.98)	663 (26.11)
1984	668 (26.30)	659 (25.95)
1985	825 (32.49)	1052 (41.43)
1986	889 (35.01)	1085 (42.73)
1987	931 (36.66)	964 (37.96)
1988	488 (19.21)	483 (19.01)
1989	657 (25.87)	562 (22.14)
1990	722 (28.44)	973 (38.31)
1991	1352 (53.21)	1086 (42.76)
1992	1170 (46.05)	1181 (46.49)
1993	673 (26.50)	813 (32.00)
Mean	846 (33.30)	724 (28.52)

Source: Richard A. Wood, *Weather of U.S. Cities, fifth edition* (New York: Gale Research, 1995).

TABLE 7.3

Platted Subdivisions in the
Lower Onion Creek Watershed

	Year Platted	Area (acres)
Lifschutz Subdivision	1948	134.907
Double R Ranch	1973	25.085
Rolling Oaks	1973	1857.793
Oxbow Trails	1975	174.522
Sequoyah	1976	80.402
Hays Country Oaks	1977	1410.123
Leisurewoods	1977	349.897
Los Ranchos	1978	371.524
Mountain City Oaks	1978	199.035
Possum Trot Park	1978	4.263
Bonita Vista	1982	65.050
Davenport Addition	1982	9.613
Grape Creek Subdivision	1983	4.478
Coves of Cimmaron	1984	197.317
Cole Springs Subdivision	1985	6.044
Creeks Bend	1985	15.022
Crosshouse	1985	226.259
Dobie Lane Acres	1985	33.915
Hays County Industrial Park	1985	28.486
Hunnington Estates	1985	115.988
Rainbow's End	1985	143.846
Loop 4 Business Center	1986	1.966
Lowden Subdivision	1986	5.441
Rustic Oaks Estates	1986	10.157
The Village at Buda	1986	2.462
Goforth Road	1987	1.611
H. Cummings Industrial Park	1988	3.055
Hollowrock	1988	63.125
Tarra Subdivision	1988	1.580
Leif Johnson Ford Community	1989	9.691
Shelton Subdivision	1989	10.953

Source: Platted Subdivisions: Hays County, Texas. Hays County Environmental Health Department, 2001.

County slowed considerably, however, growth remained positive throughout the economic doldrums of the late 1980s. It does not seem to follow that human/urban sources of fecal coliform can be driving the increase in fecal coliform counts if levels can drop so substantially even as the population continues to grow, albeit much more slowly.

An alternative interpretation of the fecal coliform data focuses on agricultural rather than urban sources of fecal coliform as the driving force over time. In this scenario the years from 1983 to 1986 are seen not as the period of most rapid growth, but as a continuation of a longer period of economic and population growth beginning in the mid-1970s. This new scenario leads us back to the role of land speculation and how land is managed in the transitional stage before development, as speculative property neither in traditional agriculture or urban use. As discussed earlier, speculators quickly bought the available agricultural land in the late 1970s. This speculation had an immediate effect on nitrogen levels in Lower Onion Creek, however, fecal coliform was not impacted at this stage. The speculative property remained idle for several years with actual urban growth still well behind the speculators' push into agricultural areas. With time speculators seeking to both maintain and make something from their idle speculative property permit livestock to be grazed as an easy-to-move source of income in the event the land is sold. Indeed, the agricultural census indicates that while cropland decreased during the economic and population boom of the 1980s pastureland increased, presumably for livestock grazing (table 7.1). When economic growth stopped and population growth slowed in the late 1980s valuable speculative land was dramatically reduced in value resulting in much being returned to agricultural uses and specifically to cropland. Just as increasing the use of speculative property for pastureland had increased fecal coliform counts in the mid-1980s the conversion back to cropland in the late 1980s caused fecal coliform counts to decrease.

Water Quality in the Upper Onion Creek Watershed

Water quality data are available from 1981 through the late 1990s for the monitoring station located on Onion Creek at CR 150. Water quality data from this monitoring station support the observation from the 1981 report that water quality in Onion Creek was excellent. No water quality data isolating the upper part of the watershed is available before 1981 so we must restrict the examination of this portion of the watershed to the 1980s and early 1990s. This period does, however, reflect several different periods in the population/demographic development of the area. The population of the region grew rapidly during the most of the early and mid-1980s in conjunction with rapid economic growth. In the late 1980s economic growth stopped and population growth slowed dramatically. This period of minimal population growth lasted only a few years and by the early 1990s the economy and population were again growing rapidly. The available water quality data does not permit an examination of the very beginning of the growth in the 1980s, however, the dramatic slowing of population growth and subsequent turn around in the late 1980s and early 1990s are covered.

An examination of some of the water quality data reveals that key water quality variables such as dissolved oxygen and fecal coliform have not shown any significant decrease or improvement in quality (figures 7.6, 7.7). Nitrogen in the form of ammonia nitrate, however, decreased quite noticeably during the study period in the Upper Onion Creek Watershed during the 1980s (figure 7.8). There nitrogen levels averaged between

FIGURE 7.6

Annual Mean Dissolved Oxygen Concentrations in the Upper Onion Creek Watershed

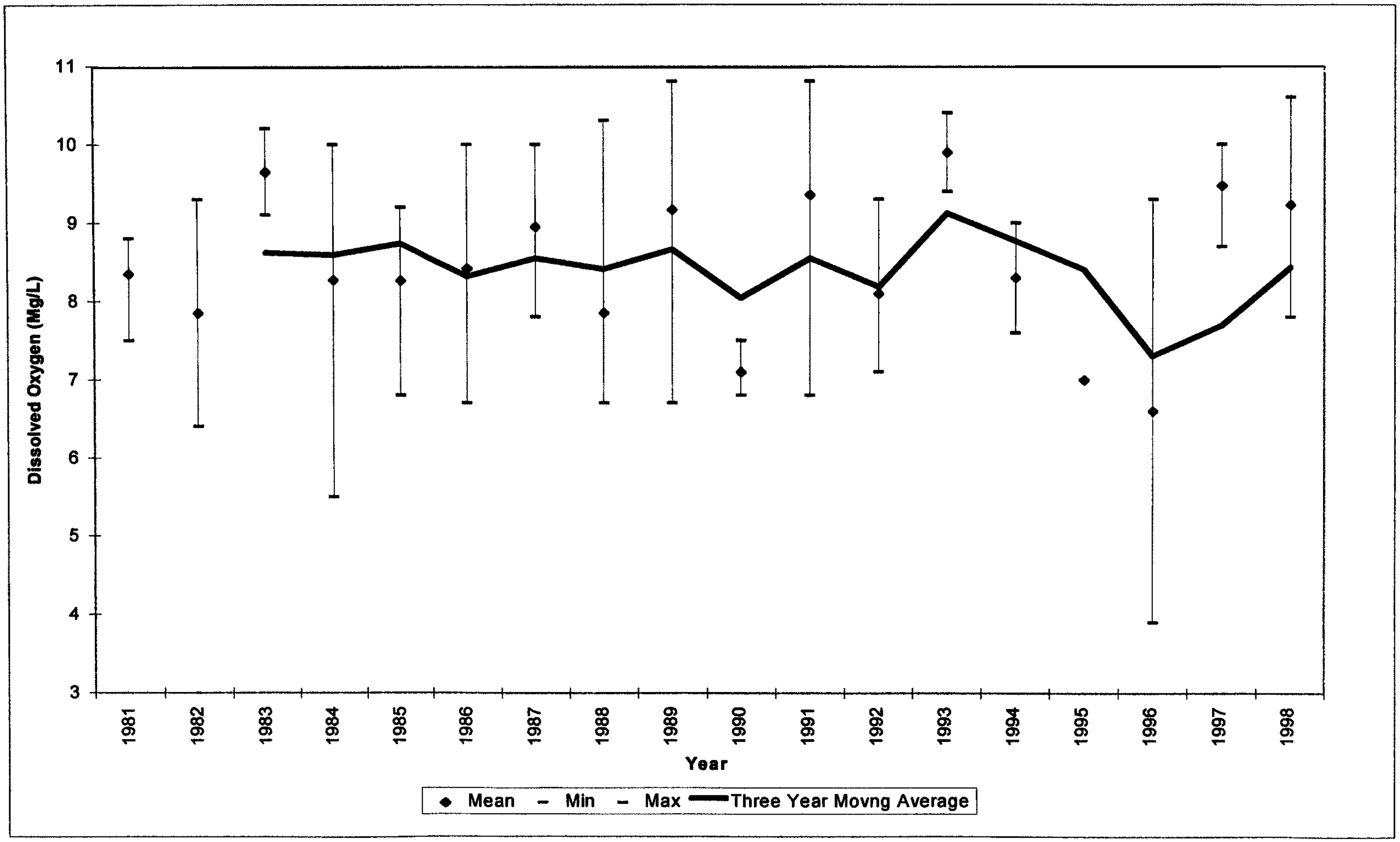


FIGURE 7.7

Annual Mean Fecal Coliform Concentrations in the Upper Onion Creek Watershed

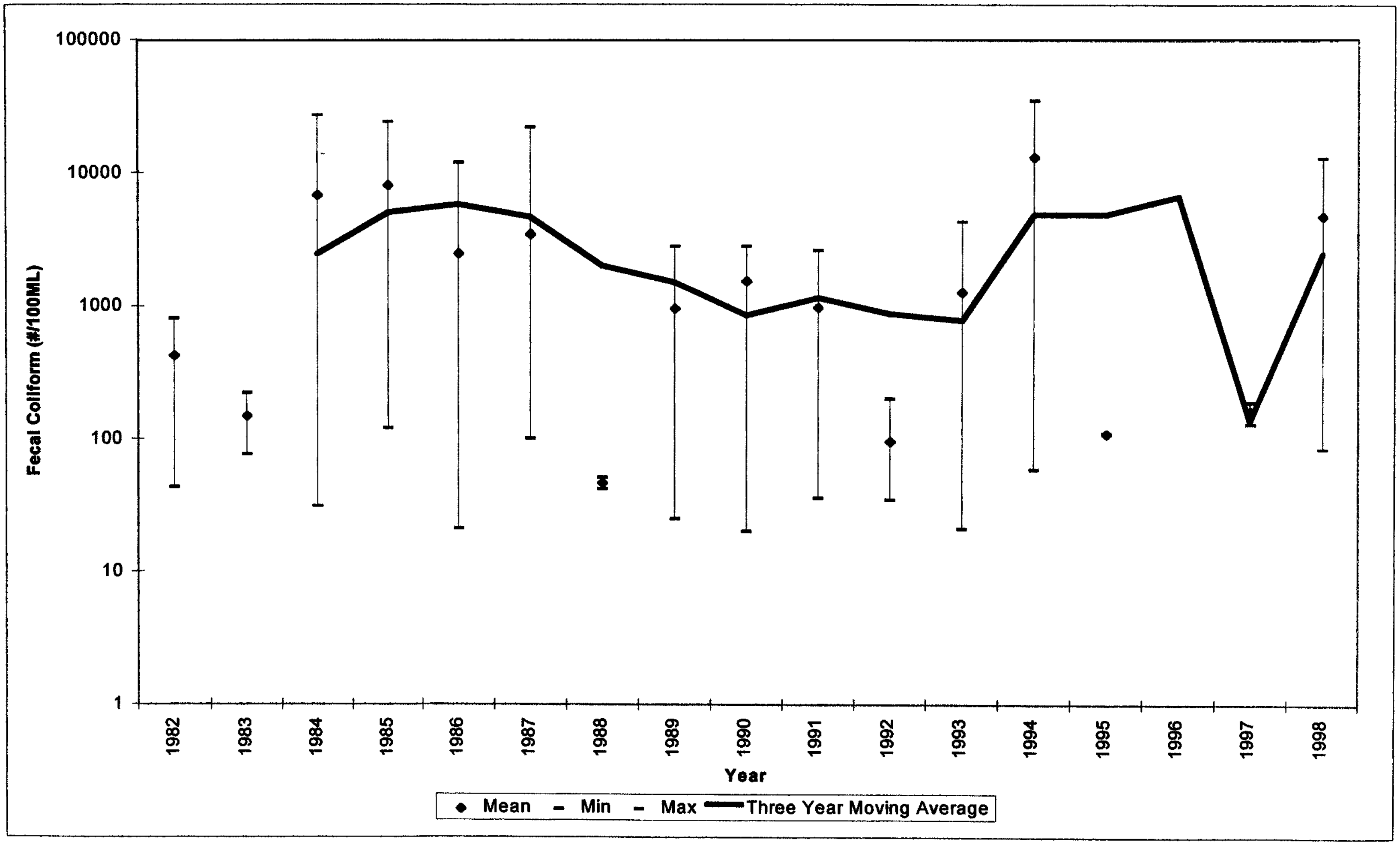
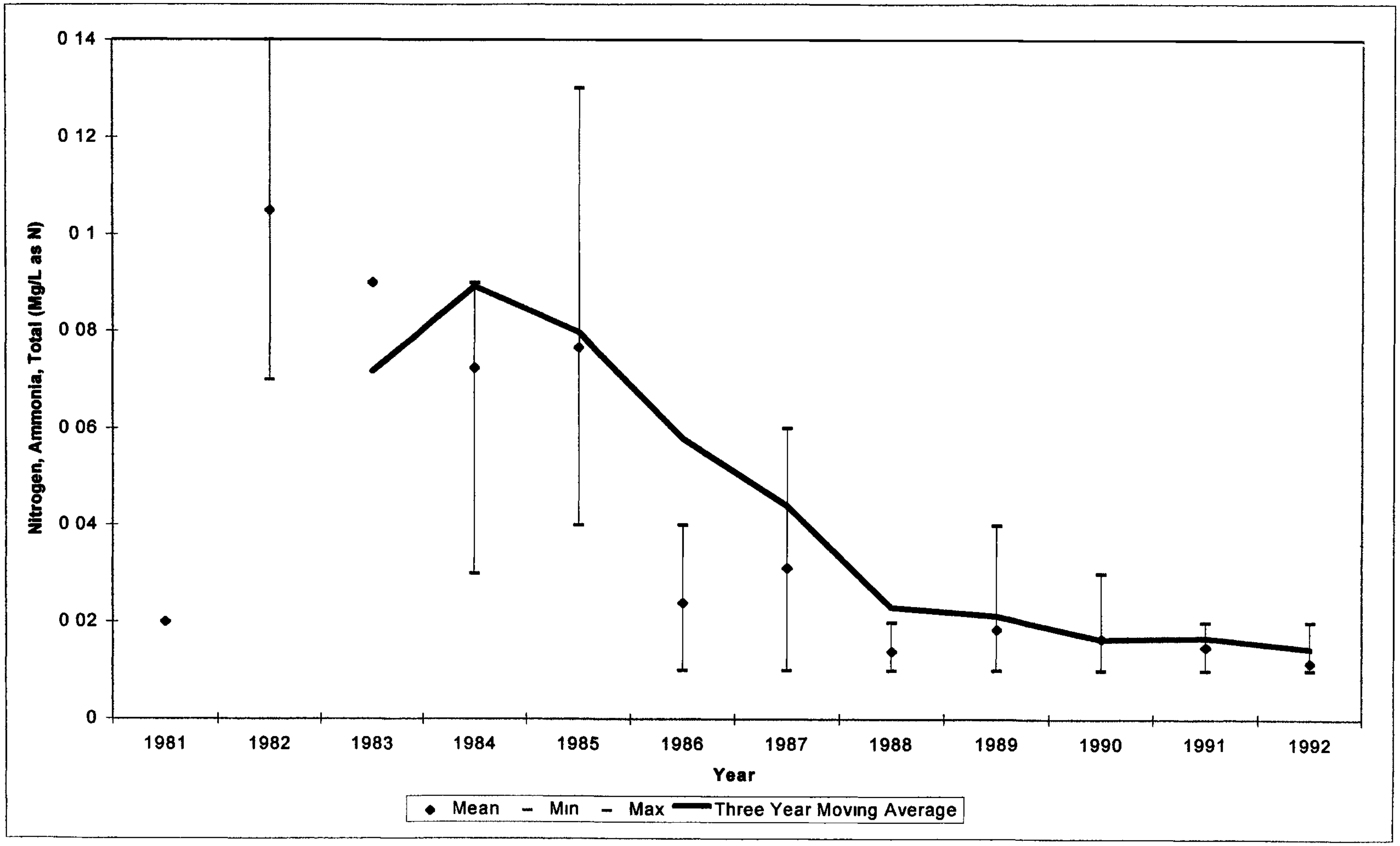


FIGURE 7.8

Annual Mean Concentrations of Nitrogen as Ammonia Nitrate in the Upper Onion Creek Watershed



0.08 and 0.1 mg/l during the first half of the 1980s. Throughout the later half of the 1980s and extending into the 1990s nitrogen levels averaged around 0.02 mg/l. This represents a substantial decline in nitrogen levels over a relatively short time period.

The magnitude of the decline in nitrogen levels observed in Upper Onion Creek is very similar to the decline seen in Lower Onion Creek. The time of the downward movement of the nitrogen concentration, however, is different with the decline in nitrogen occurring in the late 1970s in Lower Onion Creek and in the mid-1980s in Upper Onion Creek. As was the case in the Lower Onion Creek Watershed, land speculation and discontinuing farming appear to be the primary forces behind the decline in nitrogen concentrations. What is not at first clear is why the impact of speculation would lag behind the Lower Onion Creek Watershed.

There are at least two ways to explain the lag between decline in nitrogen levels in the Lower and Upper Onion Creek Watersheds. One possibility is that since the Upper Onion Creek Watershed has relatively little cropland, the more abundant and less agriculturally valuable range and forestland would have been bought up by speculators first. The more limited supply of cropland would only have entered the speculative market later. This scenario would have resulted in a lag in nitrogen reduction since farming would have continued longer. A second explanation is that speculation simply started later.

Evidence supports both of these proposed explanations. Speculation was not delayed, but rather focused initially on rangeland and other non-cropland. This supported by the large decline in pastureland in Hays County observed between the 1978 and 1982 agricultural censuses (table 7.1). The agricultural census does indicate a decline in total cropland between 1982 and 1987 as well as a four-fold increase in the amount of idle cropland. A reduction in cropland paralleling a decline in nitrogen pollution is assumed in both of the scenarios and does not directly support either.

Evidence to support the second explanation that land speculation in the Upper Onion Creek Watershed simply started later can be found in the timing of new subdivisions being platted. County subdivision plat data indicates that 54% of the subdivisions platted in the Upper Onion Creek Watershed during the economic boom beginning in the late 1970s were platted after 1985 (about the time of the decline in nitrogen concentrations) (table 7.4). This is compared to the Lower Onion Creek Watershed where only 33% of the subdivision were platted after 1985. This seems to indicate that land speculation was particularly intense in the Lower Onion Creek Watershed in the early years of the economic boom. This might account for the very rapid decline in nitrogen seen there. In the Upper Onion Creek Watershed subdivision platting and presumably land speculation seem to have increased later in the 1980s with aggressive platting of new land extending through the period of slowed economic and population growth in the late 1980s. This observation is further supported by census mobility data discussed in Chapter 6. The 1990 census mobility data that indicate place of residence in 1985 (five years before the census) show that only 21% of the people in the Upper Onion Creek Watershed lived in the same house in 1985 (table 6.6). This is compared with 41% of the 1990 population in the Lower Onion Creek Watershed who lived in the same house in 1985. In addition Ann Hurt (2001), a long time local real estate agent, observed that their was little interest in the upper Onion Creek Watershed in the early 1980s. According to Hurt it was not until significant numbers of Californian migrants began arriving in the

TABLE 7.4

Platted Subdivisions in the
Upper Onion Creek Watershed

	Year Platted	Area (acres)
Springlake	1953	695.576
Hill Country Ranches	1972	2512.232
Dripping Springs Heights	1973	49.388
Harmon Hills	1974	407.881
Springwood	1977	151.835
Oak Springs	1978	151.814
Blue Ridge	1978	74.728
Hays County Acres	1978	203.347
B.M. Needham Estates	1979	188.010
Green Hills	1980	157.711
Fieldstone	1981	180.264
Sunset Canyon	1982	1355.280
Onion Creek Drive Estates	1982	38.748
Sunset Canyon	1982	389.742
Ryan Hills	1984	14.350
Forest Woods	1985	180.935
Meadow Oaks	1985	83.500
Driftwood Falls Estates	1986	66.245
Creek at Driftwood	1986	75.747
Pier Branch	1986	20.048
Candledancer	1988	8.359
Sundbeck/La Truffierfa	1988	60.258
Teichelmanns Subdivision	1989	4.892
Bill's Hill	1989	14.453
Olliewood	1989	37.713
Shoemaker Ranch	1989	0.000
Blue Creek Ranch	1989	170.366
Kirby Springs	1989	899.196
St. Martin's Subdivision	1989	19.079
Penn Addition	1990	0.000
Meadow Creek Ranch	1990	248.871
Allen Subdivision	1990	49.334

Source: Platted Subdivisions: Hays County, Texas. Hays County Environmental Health Department, 2001.

mid-1980s that interest in the Hill Country (including, the upper Onion Creek Watershed and Dripping Springs) really accelerated.

Plum Creek

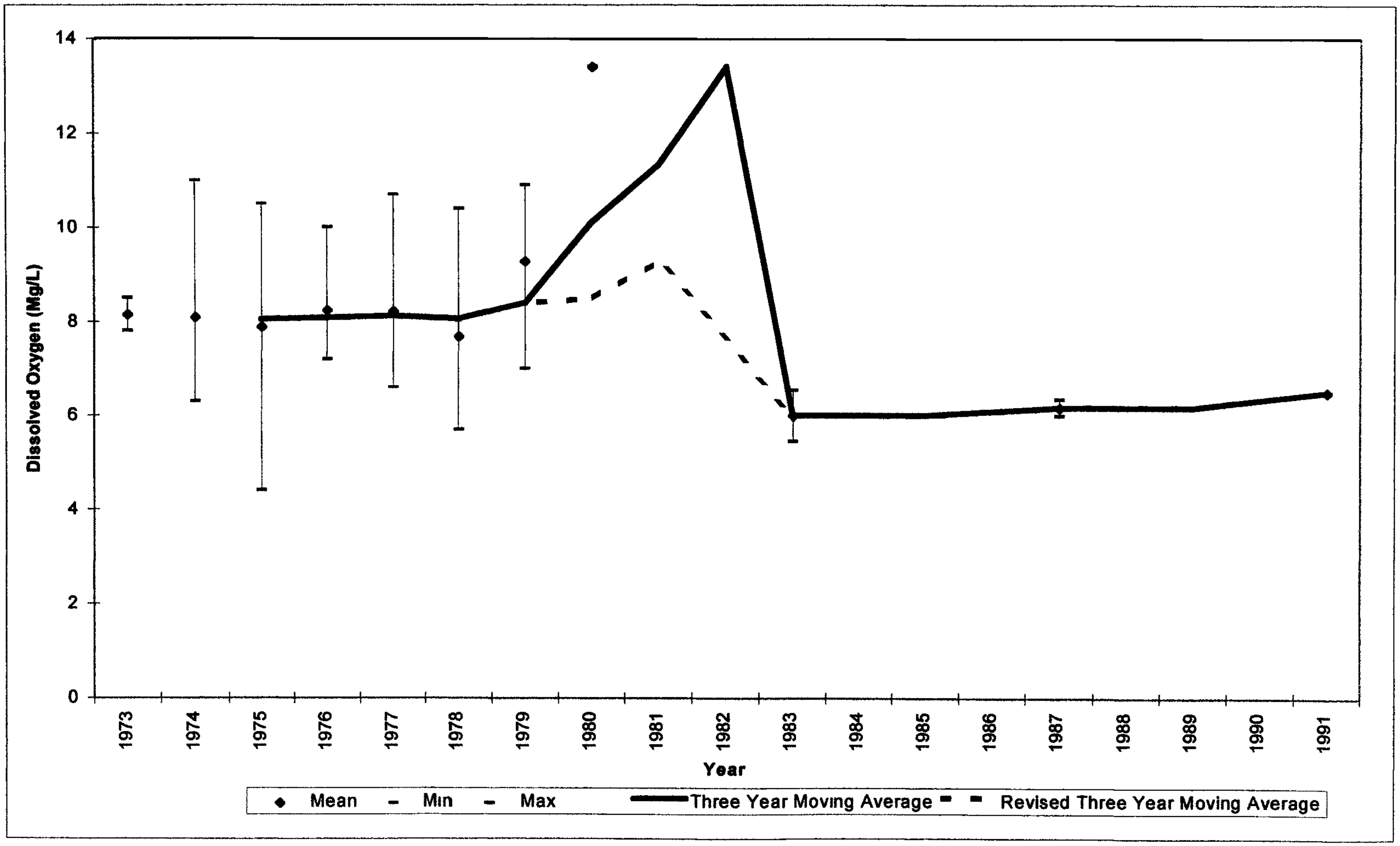
Water quality data for Onion Creek was not as good as might have been hoped for, however, it was superior to the data available for Plum Creek. The only long term water quality monitoring station (TNRCC Station 12642 / USGS Gage 08173000) used in this study of the Plum Creek Watershed is located on Plum Creek at County Road 131 northeast of Luling (figure 4.7). This monitoring station is situated on the main channel of Plum Creek that has several major upstream branches including Clear Fork Plum Creek, Tenney Creek, and Plum Creek. One other significant branch of the larger Plum Creek system is West Fork Plum Creek that flows parallel and between Clear Fork Plum Creek and the San Marcos River. The West Fork Plum Creek meets the main channel of Plum Creek downstream of the one good monitoring station. As a result West Fork Plum Creek and its drainage area are not included in this analysis. The data, from 1973 to 1991, appears good at first glance. This seems comparable to the time periods covered by the monitoring stations in the Onion Creek Watershed, but closer inspection reveals that after 1980 water samples where taken at this location very inconsistently. Indeed monitoring data after 1980 is only available for 1983, 1987, and 1991. In an effort to evaluate the data from the one long term monitoring station and to provide slightly more geographic detail of the watershed, data from three other monitoring stations having limited data were also examined.

Data collected at all three of the secondary stations on September 7, 1983 and September 8, 1987. A single monitoring event in each of the two years does little to increase confidence in the value of any upward or downward movement in the values over the five-year period. However, the fact that data were collected at all three locations on the same date helps control for confounding factors such as weather and enhances their use for comparison between locations rather than over time.

Water quality data supports a slight dissolved oxygen content decline in the early 1980s and stability through the remainder of the observation period (figure 7.9). The rather extreme spike in dissolved oxygen observed in the three-year moving average is most certainly an anomaly resulting from a single monitoring event in 1980 with an unusually high dissolved oxygen measurement followed by several years with no monitoring at all. This combination results in a spike in the trend line equal to the unusually high measurement three years after the monitoring occurred since no other years are available to include in the three-year average. The dashed line in figure 7.9 shows the result of removing the 1980 data and probably more accurately reflects the change in annual mean dissolved oxygen levels over the period. This revised trend line seems to show a decline from around 8 mg/l mean annual dissolved oxygen between 1973 and 1980 to around 6 mg/l dissolved oxygen from 1983 through the end of the study period. The limited data available after 1980 combined with relatively small decline in dissolved oxygen concentrations make it difficult to justify this as a real trend in the data. Rejecting the dissolved oxygen data as containing any meaningful patterns is supported by the fact that dissolved oxygen had not shown anything but random variation for any of the locations considered in this study.

FIGURE 7.9

Annual Mean Dissolved Oxygen Concentrations in the Plum Creek Watershed



Difficulties in establishing confidence in the trends that at first appear in the fecal coliform data are similar to those for dissolved oxygen. Despite some indication that fecal coliform declined in the late 1970s and early 1980s, the complete absence of any monitoring data between 1980 and 1991 makes it impossible to proceed with any confidence in that observation (figure 7.10).

Both dissolved oxygen and fecal did not show any significant trends due to the limited data. Data were no more available for nitrogen than for dissolved oxygen, but changes in nitrogen levels were quite clear and were supported by monitoring data from the three secondary stations in the watershed as well as similar patterns observed in the Lower Onion Creek Watershed. Beginning at the end of the 1970s and continuing through the early 1980s annual mean nitrogen measurements declined in the Plum Creek Watershed (figures 7.11, 7.12). Nitrogen concentrations reached their lowest levels around 1982 and stabilized through the remainder of the study period. This pattern is very similar to that of the Lower Plum Creek Watershed. In the Lower Onion Creek Watershed evidence suggested that land speculation was a powerful factor in the declining nitrogen concentration. Similar to parts of the Onion Creek Watershed, land speculation was rampant in the Plum Creek Watershed during the late 1970s and the 1980s (Bell 2001). As the speculators bought and sold parcels of land, former cropland stood idle (Caskey 2001). The decreasing amount of agricultural activity resulted in significant declines in nitrogen pollution in Plum Creek. Most of the actual decline was concentrated in a two or three-year period in the late 1970s when the first speculators on the scene bought most of the agricultural land that could be easily acquired. Speculation continued until the economic bust in the late 1980s with speculative property bought and sold

FIGURE 7.10

Annual Mean Fecal Coliform Concentrations in the Plum Creek Watershed

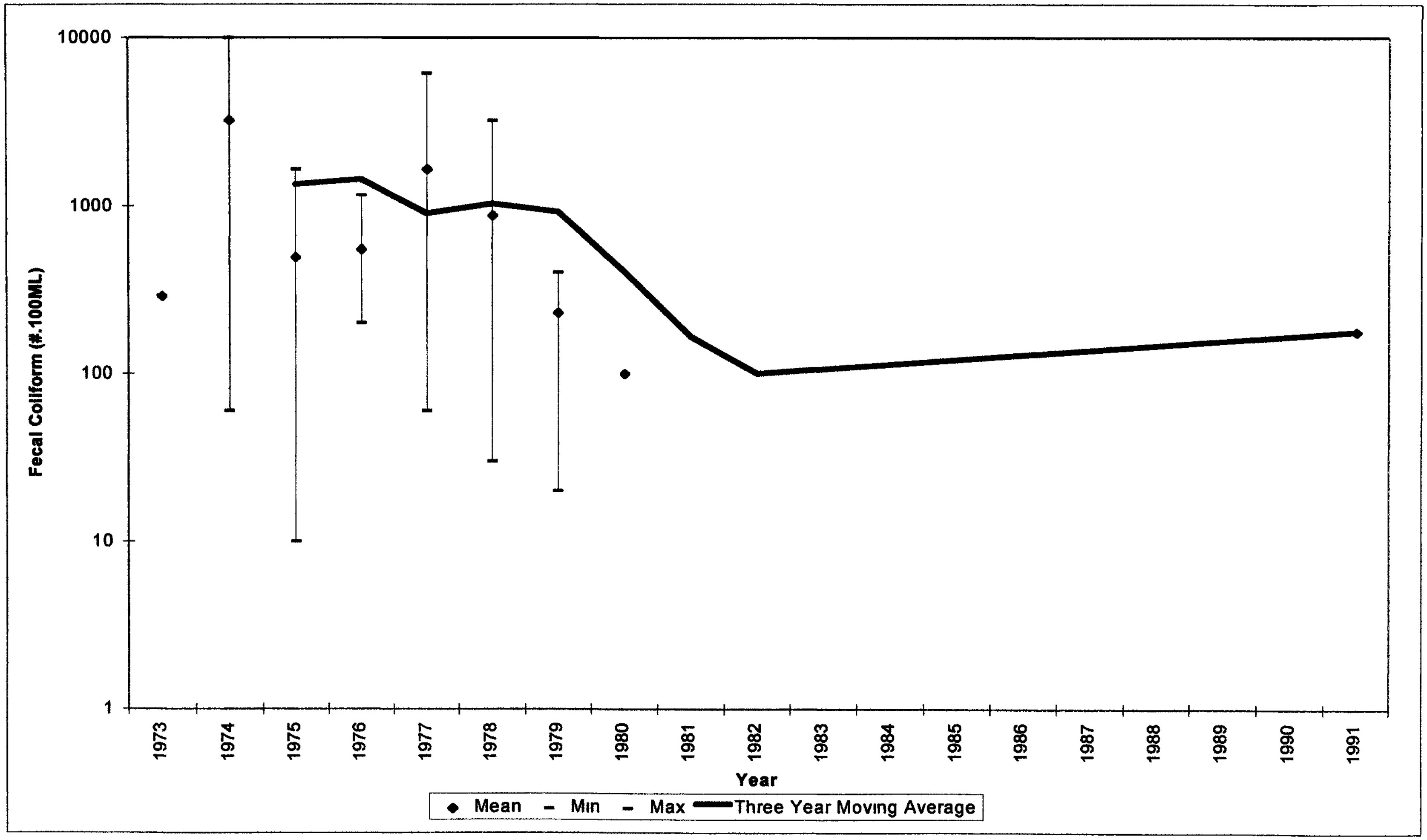


FIGURE 7.11

Annual Mean Concentrations of Nitrogen as Ammonia Nitrate in the Plum Creek Watershed

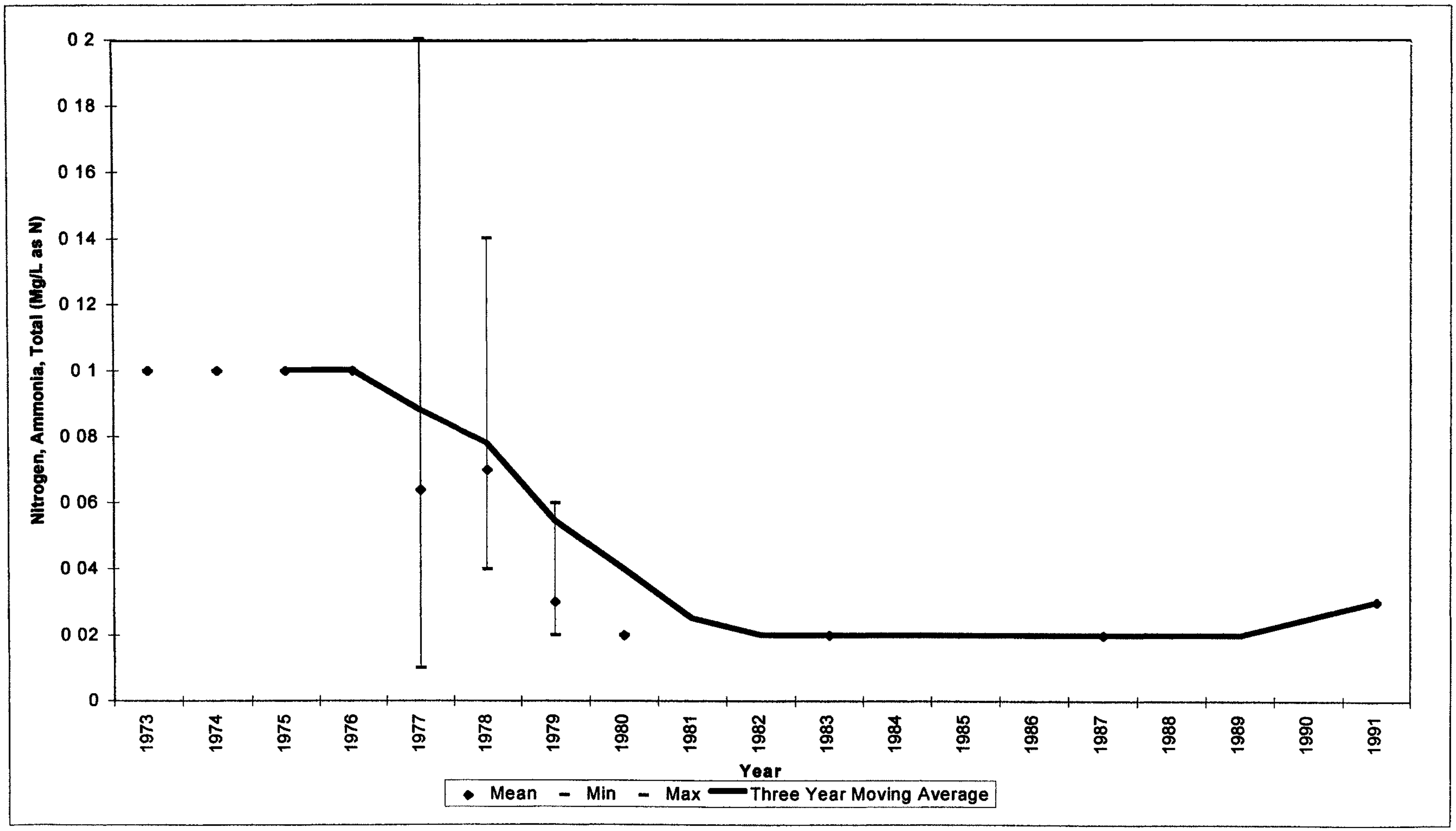
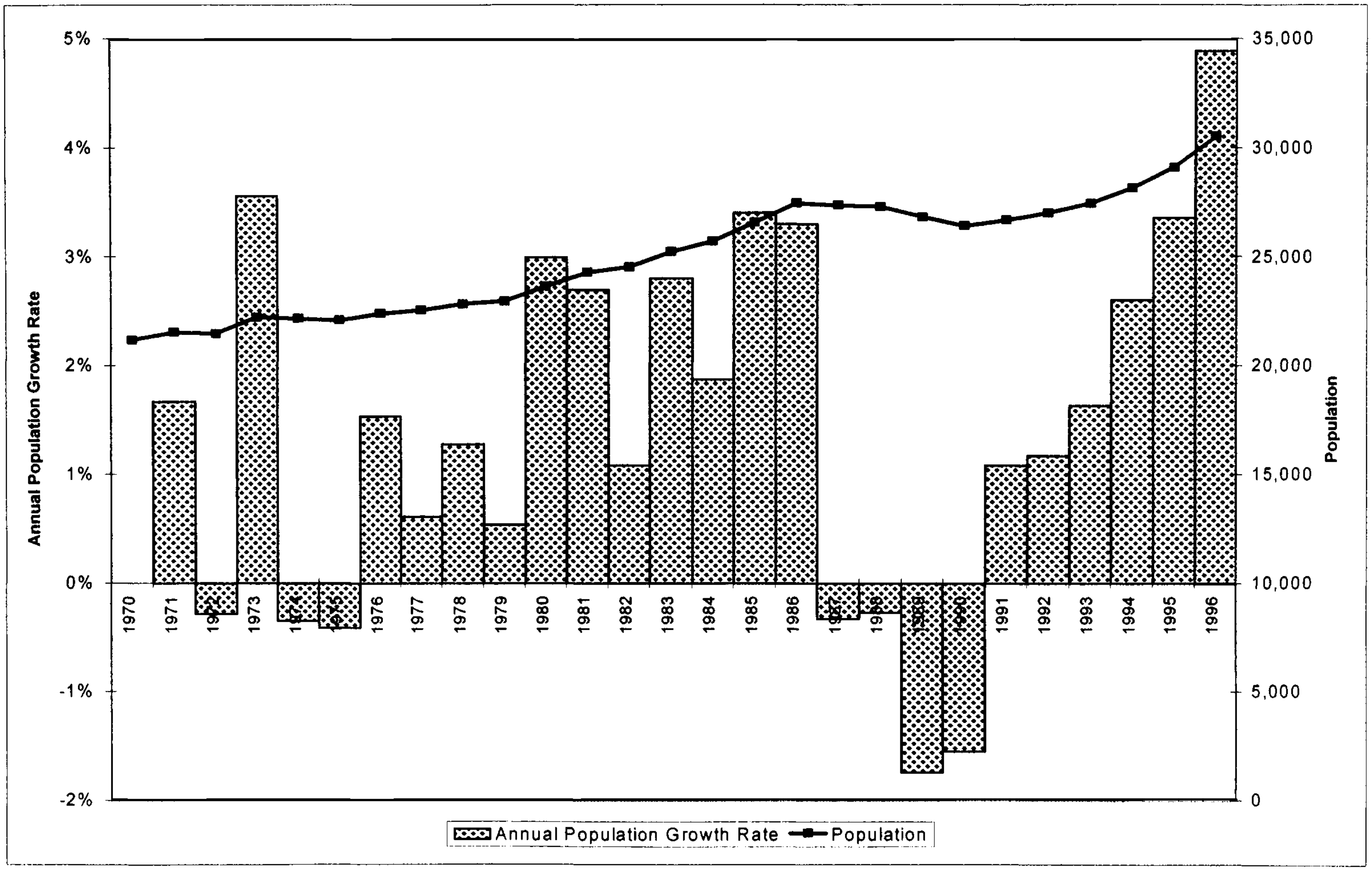


FIGURE 7.12

Population Growth and Annual Rate of Change for Caldwell County, 1970 to 1996.



repeatedly as land prices increased. New land entered the speculative market more slowly after the first few years of the economic boom as farmers and ranchers that were willing to sell became harder to find. This helps explain the lack of further decline in nitrogen pollution.

One aspect of the nitrogen data from the Lower Onion Creek that does not seem to be paralleled in the Plum Creek Watershed is the three-year increase in nitrogen pollution following the economic bust in the late 1980s. One possible reason for the absence of this brief jump in the water quality data is that it simply did not occur in Plum Creek as it did in Onion Creek. It is also possible, however, that a short period of increased nitrogen levels that was missed by the very limited monitoring of the 1980s. The last two years for which monitoring data are available are 1987 and 1991, which perfectly straddle the three years (1988 through 1990) of elevated nitrogen in Lower Onion Creek. The agricultural census also provides little help since its data also straddles the years of interest, with censuses having occurred in 1987 and again in 1992 (table 7.5). The only information supporting the existence of a brief period of increased nitrogen levels at the end of the 1980s comes from one of the secondary water quality monitoring stations (table 7.6). This station, located in the northern part of the watershed, has a single elevated nitrogen measurement in 1987. One elevated measurement occurring a year earlier than the 1988 onset of elevated measurements in Lower Onion Creek is not particularly convincing. Nonetheless, the northern part of the Plum Creek Watershed is some of the most fertile cropland in the study area squarely located in the Blackland Prairie. As prime cropland it seems logical that it would have been among the very first

TABLE 7.5

Agricultural Land Use in Caldwell County

	Caldwell					
	1974	1978	1982	1987	1992	1997
Farms (number)	802	877	977	1,026	957	1,068
Land in farms (acres)	255,287	266,965	255,504	265,788	263,925	265,269
Land in farms, average size of farm (acres)	318	304	262	259	276	248
Total cropland (acres)	112,151	119,743	101,013	110,207	101,865	105,263
Total cropland, harvested cropland (acres)	40,401	46,075	38,542	33,008	37,901	36,392
Total cropland, cropland used only for pasture or grazing (acres)	65,955	67,612	56,246	59,090	59,714	64,650
Total cropland, other cropland (acres)	--	6,056	6,225	18,109	4,250	4,221
Other cropland, cropland in cover crops (acres)	--	1,665	1,003	1,849	822	3,358
Other cropland, cropland on which all crops failed (acres)	--	425	1,275	981	1,457	335
Other cropland, cropland in cultivated summer fallow (acres)	--	501	1,286	3,360	502	85
Other cropland, cropland idle (acres)	--	3,465	2,661	11,919	1,469	443
Total woodland (acres)	32,306	37,677	35,221	33,809	29,555	25,330
Total woodland, woodland pastured (acres)	--	35,693	31,813	28,266	25,683	20,752
Total woodland, woodland not pastured (acres)	--	1,984	3,408	5,543	3,872	4,578
Other land (acres)	--	109,545	119,270	121,772	132,505	134,676
Other land, pastureland/rangeland other than cropland/woodland pastured (acres)	--	103,418	112,705	117,108	128,664	131,008
Other land, land in house lots, ponds, roads, wasteland, etc. (acres)	--	6,127	6,565	4,664	3,841	3,668
Pastureland, all types (acres)	--	206,723	200,764	204,464	214,061	216,410
Land under Conservation Reserve or Wetlands Reserve Programs (acres)	--	--	--	87	417	816

Sources: U.S. Census of Agriculture: 1974, 1978, 1982, 1987 and 1992; Washington, DC: Bureau of the Census.
U.S. Census of Agriculture: 1997; Washington, DC: National Agricultural Statistics Service.

TABLE 7.6

Water Quality Data From Secondary Monitoring Stations
in the Plum Creek Watershed

	North	East	West
Oxygen, Dissolved (mg/l)			
September 6, 1983	--	--	11.30
September 8, 1987	--	--	7.05
Nirtogen, Ammonia, Total (mg/l as N)			
September 7, 1983	0.02	0.02	0.02
September 8, 1987	0.85	0.02	0.02

Source: Surface Water Quality Monitoring (SWQM) Database. Texas Natural Resource Conservation Commission (TNRCC), 1999.

land to be returned to agricultural use as land prices slumped with the economic slow down.

It is not typically good practice to assume much about trends in water quality based on a single measurement; however, other factors make this leap slightly less tenuous than it might seem. On the same day that the monitoring event in question occurred samples were taken at all four of the Plum Creek monitoring stations used in this study. Samples collected at all three of the other stations indicated low levels of nitrogen pollution. The single most important confounding variable in NPS pollution is rainfall-induced runoff. The absence of any elevation in the other samples supports the notion that the increase was not the result of rain induced runoff. This discussion has not been intended to argue that the increase in nitrogen level in the late 1980s did occur, but rather to show that it could have happened. In showing how the increase could have been hidden in the data it becomes less of an argument against the much better supported observation made in the Lower Onion Creek Watershed.

Water Quality in Plum Creek: Secondary Monitoring Stations

The Plum Creek Watershed is larger than the Onion Creek Watershed yet only one monitoring station is available for this large area with data over a longer period of time. Water quality is not the same throughout such a large area. Plum Creek's more complicated hydrology with several large tributaries, each with unique sub-watersheds of their own also makes reliance on a single monitoring station a less satisfactory option. To partially compensate for this deficiency in the water quality monitoring data, three additional monitoring stations were identified each on one of the tributaries of Plum

Creek. These three stations divide the watershed into approximately equally sized subsheds. However, water quality data are only available for 1983 and 1987. With only two data points separated by only five years the data can provide only partial evidence of trends over time on their own. They may however provide evidence to support or perhaps contradict the data available from the primary monitoring station. In addition any differences between the three monitoring stations might provide a hint of the spatial variation in water quality within the watershed.

For the most part, the water quality data collected at the three secondary monitoring stations support the data at the primary monitoring station. The only significant exception is for ammonia nitrate at the monitoring station representing the northern end of the watershed (table 7.6). The 1983 measurement for ammonia nitrate was 0.02 mg/l, a value consistent with both the primary and other secondary monitoring stations at the same time. In 1987, however, ammonia nitrate levels shot up to 0.85 mg/l while values from the other monitoring stations remained low at 0.02 mg/l. Rainfall events can cause spikes in many water quality variables, including ammonia nitrate. This anomaly may be the result of rain in the area at the time the water quality measurements were taken (table 7.7). Given the presence of rain in the area the elevated measurement of ammonia nitrate can not be considered indicative of any real trends or spatial patterns of water quality change in the area.

Water Quality Change in Review

The objective of this chapter was to try to explain trends in water quality change in the Onion and Plum Creek Watersheds in the context of population change. The

TABLE 7.7

Precipitation at Selected Cities in the
Austin-San Antonio Area: September 7-8, 1987

	09/07/87 mm(in)	09/08/87 mm(in)
Austin	10 (0.38)	--
Dripping Springs	--	3 (0.12)
Lockhart	7 (0.27)	--
Luling	--	17 (0.68)
New Braunfels	13 (0.50)	--
San Antonio	38 (1.50)	--
San Marcos	14 (0.55)	--

Source: Climatological Data: Texas September 1987 92(9) / prepared by the National Oceanic and Atmospheric Administration. -Washington: NOAA, 1987.

hypothesis was that changes in the characteristics of the population and not just population growth itself could be shown to be a significant force in water quality change. In reality population composition did not seem to factor into the explanation of the forces driving water quality change. No direct connection between population growth or size seemed to exist either, however, population growth did play a role albeit it indirect as a factor driving land speculation. Land speculation and the movement of land in and out cropland and pastureland seemed to be the most important single factor in water quality change in the Onion and Plum Creek Watersheds.

Over the study period (the 1970s through the early 1990s) nitrogen levels in both Plum and Onion Creek declined. The transition from higher nitrogen levels (around 0.1 mg/l) to lower concentrations (around 0.02 mg/l) tended to happen very quickly, usually in just two years. In the Lower Onion and Plum Creek Watersheds the transition from higher to lower nitrogen concentrations coincided with the beginning of an extended period of economic and population growth beginning in the late 1970s. Land speculation was rampant and all available land, much of which was cropland was quickly bought up. Speculators whose primary objective is to resell the property for a profit rarely have reason to continue planting cropland. With no motivation to plant crops speculative land often stands idle. Idle cropland does not require fertilizer which means that less nitrogen will end up in area stream from runoff. Nitrogen levels remained low in both Lower Onion and Plum Creek through the late 1980s. Toward the end of the 1980s the economy began to stall and population growth slowed significantly. The stalled economy and slowed population growth caused land values to plummet and cropland was once again planted. This return to agriculture created a noticeable increase in nitrogen concentration.

This increase in cropland and related increase in nitrogen pollution was short lived and again decreased as economic and population growth returned in the early 1990s. This basic pattern holds for both the Lower Onion and Plum Creek Watersheds, however, the Upper Onion Creek Watershed was slightly different.

The pattern of water quality change observed in Upper Onion Creek was similar in many respects to that of the other areas examined. The major difference between the patterns observed in Upper Onion Creek and the other areas was in the timing of the decline in nitrogen levels. In Upper Onion Creek nitrogen levels declined several years after similar declines were observed in the other areas. The conclusion that seems to fit the data best is that population growth and land speculation came later to the Upper Onion Creek Watershed. It is not clear, however, why this would have been the case.

CHAPTER 8

CONCLUSIONS

This research was undertaken to contribute to the scholarly debate regarding the relationship between human population and the environment. Two questions drove this research. Does population growth lead directly to environmental degradation in the context of a rapidly growing region in the United States? And, does migration play a role in modifying the relationship between population growth and environmental change?

This research sought to expand our understanding of the relationship between population and the environment by exploring the idea that migration does more than simply increase (or decrease) the number of people. Migration also changes the demographic composition of that population. The thinking was that if the demographic composition of the population changed, then land use, as a reflection of the population's ideals, might change as well. Changes in land use might in-turn bring about changes in environmental quality and water quality specifically. The research questions and the theorized relationship were translated into four separate but related hypotheses:

1. There is a significant relationship between migration and water quality.
2. Migration creates significant changes in the demographic and socio-economic composition of a population.

3. Changes in the population composition creates significant changes in land use patterns.

4. Changes in land use significantly affects water quality.

Review of Research Findings

This research consisted of two parts. The first part of the research was a quantitative analysis of the Austin-San Antonio Corridor. The second part of the research focused on two specific watersheds within the larger region and used a more descriptive research design. The research was designed with two parts to compensate for limitations in the water quality and population data, and so each part could serve as verification and possibly explanation of the other's findings.

This study supports the first hypothesis that a relationship existed between migration and water quality. Significant differences were found in the change in dissolved oxygen and nitrate concentration between watersheds based on migration data. The results were particularly strong for changes in nitrate levels. Interestingly, however, the relationship between intensity of in-migration and changes in nitrate concentrations was not a direct linear relationship. The relationship can be better described as "U"-shaped. The watersheds with the most in-migration tended to have notable declines in nitrate levels. In sharp contrast, the watersheds with the second-most in-migrants had dramatic increases in nitrate levels. Change in nitrate levels for watersheds with the fewest in-migrants fell somewhere between the other two groups of watersheds, with both small increases or decreases in nitrate concentrations.

While not as strong as those dealing with nitrate pollution, the results of the analysis of dissolved oxygen's relationship to migration also yielded some significant, but unexpected results. Watersheds with the most in-migration tended to have the largest increases in dissolved oxygen (improving water quality). Watersheds with the fewest in-migrants tended to have very little increase or even declining dissolved oxygen (degrading water quality). While this relationship is linear, it is opposite of what might be expected with increasing in-migration connected with improved water quality.

The study partially supports the second and third hypotheses that migration changes the demographic composition of a population which, in turn, results in changes in land use. Census data reviewed in Chapter Six clearly showed that the demographic composition of the populations living in both the Plum and Onion Creek Watersheds changed during the study period. What is not clear from the evidence is whether the demographic change was significant enough to be reflected in the population's land use practices. Some evidence points towards "new residents" (having arrived in the last 25 years) being more open to outsiders and growth (Bell 2001). While an increased openness to growth reflects changing ideals of the population as a whole, it is not necessarily a change in thinking concerning how land will be used when growth occurs.

Similar to the second and third hypotheses the fourth hypothesis stating that land use affects water quality could be neither completely rejected nor supported. Only speculative evidence was found creating a link between land use change as a reflection of the population's ideals. More solid evidence in the form of agricultural census and land use/land cover data was able to link land use and water quality change. This evidence while supporting the well-established link between land use and water quality change did not actually correspond to the relationship conceived in the original conceptual research model. In the model forces driving land use changes were conceived of primarily in terms of lifestyle choices such as residential densities or landscaping practices. The data, however, points to the transition of rural land in and out of crop and pasture, in response to land speculation, as the main factor in water quality change and not to the actual conversion of rural land to urban or suburban use.

The Hypothesized Model in Light of Research Findings

Without evidence to support several of the key hypotheses it would be easy to reject the proposed model of the relationship between migration and water quality. No effort here will be given in defense of the model based on the results of this study, however, this does not imply that the model should be thrown out entirely. In retrospect several factors made testing the model difficult and undoubtedly contributed to the less than satisfactory results. First, the watersheds used in this analysis were simply too large to have the degree of population homogeneity necessary to affect change in water quality that could easily be associated with a particular demographic group. For example, parts of the Lower Onion Creek Watershed developed into predominantly wealthy older Anglo neighborhoods. Other areas within the same watershed had rapidly growing poor minority populations. It is conceivable, even likely, that each of these demographic groups would impact water quality differently, however, the effects of each group cannot be isolated within a single unit of analysis. Theoretically it would be possible to divide the watersheds into smaller and smaller subsheds, but water quality data simply do not exist for these small geographic units.

A second issue hindering an accurate assessment of the hypothesized model was related to the data. One problem with water quality data has already been mentioned, that being the lack of monitoring data particularly for the lowest order streams. Another issue related to water quality was the lack of continuous data from a single location. Tracking meaningful trends in water quality requires data over an extended period of time, but in many instances data from a monitoring station would only be available for a relatively short period of time. Even when water quality data were available at a single location for a longer period of time it was often limited to a small set of variables that might not always adequately reflect different aspects of water quality.

Water quality presented the greatest data problem, but was by no means the only issue concerning data. Census data, which were used for determining demographic change, was available for longer periods of time and was relatively consistent, but could only very roughly be matched to watershed geography. The crudeness of the fit between census and watershed geography could in some situations create problems in accurately interpreting the demographic change that occurred in the watershed.

Efforts were made particularly in the context of the second part of this research to counter some of confounding factors that might have been hindering accurate results. In hindsight it appears that some of these obstacles may simply have been too great. In short, the model was not supported by the results of this research, however, nothing was found that would seem to indicate that the model should be rejected in its entirety. If smaller units of analysis could be found with adequate demographic and water quality data, the model would seem to justify further examination.

Other Observations and a New Model

One of the more interesting findings in this research was the role that land speculation seemed to play in changes in certain aspects of water quality, most notably nitrogen and fecal coliform pollution. These observations were discussed in detail in the context of Chapter Seven where the observation was first made. The basic pattern, however, is that economic and population growth spawns land speculation which at least in the short term takes what had been crop or pastureland out of active use. In a different context and time the economist Henry George (1929) made a similar observation noting that speculative held land would tend to be kept out of productive use. Speculation thus permits large amounts of agricultural land to be taken out of production very quickly resulting in rapid and large declines in pollutants such as nitrogen, fecal coliform, and sediment which are closely related to agricultural activities. Agricultural land, which had been idle for several years, appeared to have been used in some situation for livestock grazing resulting in a slight increase in fecal coliform levels. However, cropland was only returned to its former use after an economic slowdown and slower or declining population growth.

By the time that land speculation was identified as a key player in the water quality patterns observed in part two of this research, the quantitative analysis of part one had already been completed. The fact that land speculation was not identified until later does not change the results of part one or their meaning in the context of the research questions originally posed. What is interesting and appropriate here, in these final pages, is a reinterpretation of part one's results in light of the new understanding of forces which drove water quality change in the Onion and Plum Creek Watersheds.

One of the most interesting observations from part one was the U-shaped relationship between nitrate pollution and migration. Those watersheds with the most intense in-migration had declining nitrate concentration, watersheds with moderate amounts of in-migration had increasing nitrate pollution, and watersheds with the least in-migration tended to either have modest increases or decreases in nitrate pollution. Land speculation seems to provide at least a partial explanation of this unusual "U"-shaped relationship. Speculators quickly identified those areas with the most intense in-migration, and cropland was taken out of production as speculators bought the land. More than likely speculation was also prevalent in the group of watersheds with more moderate in-migration and cropland was likely taken out of production there as well. The difference in these two groups in the quantitative analysis, however, is that the higher rates of migration in the first group of watersheds may have actually been associated with significant amounts of land converted to urban or suburban uses. In contrast, the somewhat less desirable areas which had only moderate amounts of in-migration would have had a smaller proportion of land converted to urban use. The combination of lower desirability and more land still held in speculation would result in more land being converted back into active cropland with an economic bust. More land actively being cropped would result in increased nitrate levels. Those watersheds with high in-migration would have seen considerablly less speculative land put back into cropland because less would still exist since it had been developed and that which had not been developed might continue as speculative land given its location in what was obviously a highly desirable area to live.

The last group of watersheds with very little in-migration likely experienced little land speculation to begin with and the more modest changes in water quality were likely the result of factors other than speculation.

How important is land speculation to water quality change? After repeated cycles of boom and bust it seems logical that all the land would eventually be developed since some of the speculative land would be developed during each of the boom cycles. Presumably at this point a model of water quality change based on land speculation would lose relevance and be replaced by a model more appropriate to the new urban setting. This new urban-based model might possibly incorporate migration and changing demographic character as a significant component.

Final Thoughts

Both the scale and completeness of the data were critical in this study. This research, which sought to identify the relationship of migration to water quality change, drew upon human and environmental data. Creating a usable research database from these two vastly different types of data proved to be a significant challenge in itself. Demographic data are available at a variety of geographic scales, but none correspond to natural spatial units. Water quality data are essentially point data located along a liner feature without any direct association to a two-dimensional area. Even attempting to bring this jumble of data and spatial units together in a usable form was a significant methodological contribution to the study of the role of humans on water quality and environmental geography.

Of all the challenges faced the most formidable was the lack of appropriate data. Not unique to any one category of data, this problem plagued every type of data used. The problem was most obvious with respect to water quality data, which suffered from both inconsistent collection and gaps in coverage. Demographic data (from the census) are reported primarily for administrative units that do not match physiographical units such as watersheds. This problem was particularly acute prior to the 1990 census when the smallest geographic units available in non-urban counties were minor civil divisions. In the case of the agricultural census this problem is taken to an extreme as data are only available at the county level. The tragedy is that these problems need not exist. In the case of census data this is particularly so since data are collected at the individual level and can be tabulated for any given spatial unit, including environmental units such as watersheds. Given the importance of environmental issues, efforts need to be made to better coordinate data collection and tabulation of human and environmental data so they can more easily be compared.

In one respect, the results of this research were disappointing, providing only limited evidence supporting a relationship between migration and water quality change. However, in this seeming failure two things emerged as significant contributions to the literature pertaining to the human processes underlying water quality change. The first is the identification of land speculation as a potentially important factor in water quality change in regions witnessing rapid population growth and urban sprawl. The second contribution of this study is a more refined, albeit untested, idea of how, and more importantly under what conditions, migration might contribute to water quality change.

APPENDIX

WATER QUALITY AND NONPOINT SOURCE POLLUTION CONTROL

Legislation enacted exclusively for controlling water quality in the United States dates back to at least 1948 and the Federal Water Pollution Control Act which proved not to be effective. The modern era of water quality control came in 1972 when the original Water Pollution Control Act underwent a major overhaul. This version of the Water Pollution Control Act along with some alterations in 1977, which among other things renamed the legislation the Clean Water Act (CWA), resulted in significant improvements in the nation's water quality (Griffin 1991).

The success of the CWA can principally be attributed to the ability of the legislation and the programs it created to control municipal and industrial discharges. Section 401 of the CWA created a permit system called the National Pollutant Discharge Elimination System to enforce limitations of point source pollution. Under the new legislation all unpermitted point source pollution discharges are prohibited. Obtaining a permit requires that the applicant to first obtain state certification that the discharge would not violate state water quality standards. After this requirement has been met, a permit can be granted for up to five years. The permit itself has three primary parts: effluent limitations, a compliance schedule, and a reporting requirement. The permit system has always allowed discharge of some pollutants; however, the original objective of complete elimination of all discharge still exists.

The importance of the CWA in improving the overall quality of the nation's water has been impressive. The CWA of 1977, however, left some areas for improvement, particularly in the area of NPS pollution. Section 208 and 303(e) of the CWA of 1972 established a basic framework for addressing NPS pollution. Under these sections of the CWA, states and local planning agencies analyzed the extent of NPS pollution and developed water quality management programs to control it with USEPA funding. Best management practices were evaluated, assessment models and methods were developed, and other types of technical assistance were made available to state and local water quality managers (USEPA 2000b). While laying the framework for NPS pollution control, these efforts lacked the structure and focus to produce any substantial reduction in NPS pollution. Partially in an attempt to address these inadequacies the CWA was amended again in 1987and called the Water Quality Act (WQA) (Griffin 1991).

Section 319 of the 1987 WQA established a concentrated national program for the purpose of controlling NPS pollution. Section 319 created a three-stage national program to be implemented by the states with federal approval and assistance. States were to address nonpoint source pollution by: (1) developing NPS assessment reports, (2) adopting NPS management programs, and (3) implementing the management programs over a multiyear time frame (USEPA 2000b). The three-stage program created a structure for states to control NPS pollution, however, it did not dictate specific management approaches. Instead individual states, territories, and American Indian tribes were given considerable leeway in creating individual programs.

The Texas Clean Rivers Act of 1991 created the framework for Texas to meet Section 319 requirements and address NPS pollution problems. The Clean Rivers Act established the Clean Rivers Program (CRP) which is a partnership between the Texas Natural Conservation Commission (TNRCC) and the Texas State Soil and Water Conservation Board (TSSWCB), regional water authorities, other state and federal agencies, and the public (TNRCC and the Texas State Soil and Water Conservation Board 2000). Using a watershed management approach, CRP partner agencies work to identify and evaluate surface water quality issues and to establish priorities for corrective action.

The TNRCC, as the state's lead water quality agency, has overall responsibility for maintaining the state's CWA section 303(d) list streams and rivers not meeting quality standards for their designated uses (TNRCC 1999). From this list, the state prioritizes specific water bodies for restoration and protection. The state in collaboration with stakeholders and appropriate federal and regional agencies develops total maximum daily loads (TMDLs) of pollutants that the stream or river can accept and still be in compliance with the streams designated use requirements. These TMDLs are then used by stakeholder groups in the development and implementation of Watershed Action Plans. These action plans outline specific actions that need to be made to meet TMDL guidelines for the watershed. In agricultural areas the TSSWCB assist individual agricultural operations in developing Water Quality Management Plans (WQMPs) that are specific to that operation. Since Texas Senate Bill 503 in 1993 WQMPs have had the same legal status as point source pollution permits. Once the Watershed Action Plans and/or WQMPs are in place the state through either the NPS Program of the TNRCC or the TSSWCB can distribute CWA section 319(h) grant funds for specific projects.

WORKS CITED

Agbo, V., N. Sokpon, J. Hough, and P. C. West. 1993. Population-environment dynamics in a constrained ecosystem in northern Benin. In *Population-environment dynamics: Ideas and observations*, eds. G. D. Ness, W. D. Drake, and S. R. Brechin, 283-300. Ann Arbor, MI: University of Michigan Press.

Alternatives to Growth Oregon. 2000. About AGO: Mission Statement. URL:http://www.aporegon.org/aboutago.htm.

Armitage, D. 1995. An integrative methodological framework for sustainable environmental planning and management. *Environmental Management* 19: 469-479.

Bailey, Robert. G. 1991. Design of ecological networks for monitoring global change. *Environmental Conservation* 18: 173-175.

_______. 1995. *Ecosystem Geography*. New York: Springer.

Barbour, M. T., J. B. Stribling and J. R. Karr. 1995. Multimetric approaches for establishing biocriteria and measuring biological condition. In *Biological assessment and criteria: Tools for water resource planning and decision making*, eds. W. S. Davis and T. P. Simon, 63-77. Boca Raton: Lewis Publishers.

Bell, J. Fredric, executive secretary of Plum Creek Conservation District. 2001. Interviewed by author, 14 August, Lockhart, TX.

Berry B. J. L., E. C. Conkling, and D. M. Ray. 1993. *The global economy: Resource use, location choice, and international trade*. Englewood Cliffs, NJ: Prentice Hall.

Blaikie P. and H. Brookfield. 1987. *Land degradation and society*. London: Methuen.

Boserup, E. 1965. *The Conditions of Agricultural Progress*. London: Allen and Unwin.

_______. 1981. *Population and Technology Change: A Study of Long-Term Trends*. Chicago: University of Chicago Press.

Brechin, S. R., S. C. Surapaty, L. Heydir, and E. Roflin. 1993. Protected area deforestation in south Sumatra, Indonesia. In *Population-environment dynamics: Ideas and observations*, eds. G. D. Ness, W. D. Drake, and S. R. Brechin, 225-251. Ann Arbor, MI: University of Michigan Press.

Californians for Population Stabilization. 2000. CAPS Vision, Mission and History. URL:http://www.cap-s.org/vision.html.

Carpenter, B. J. 1999. An analysis of stormwater runoff from single family residential neighborhoods. Master's Directed Research. Department of Geography, Southwest Texas State University.

Caskey, Cliff, Hays County extension agent (retired). 2001. Telephone conversation with author, 8 October 2001.

Cockerham, W.C. and A.L. Blevins Jr. 1977. Attitudes towards land-use planning and controlled population growth in Jackson Hole. *Journal of the Community Development Society* 8(1): 62-73.

Colten, Craig E. 1992. Illinois river pollution control, 1990-1970. In *The American Environment: Interpretations of Past Geographies*, eds. L.M. Dilsaver and C.E. Colten, 193-214. Lanham, MD: Rowman & Littefield Publishers.

_______. 1993. *Site histories: Documenting hazards for environmental site assessments*. Des Plaines, IL: Cahner Publishing Company.

Commoner, B. 1972. *The closing circle: Confronting the environmental crisis*. London: Jonathan Cape.

Davis, K. 1945. The demographic transition. *Annals of the American Academy of Political and Social Science* 237: 1-11.

_______. 1991. Population and resources: Fact and interpretation. In *Resources, Environment and Population: Present Knowledge, Future Options*, eds. K. Davis and M.S. Bernstam, 1-21. New York: Oxford University Press.

Demeny, P. 1988. Social science and population policy. *Population and Development Review* 14: 451-480.

Donaldson, Peter J. and Amy Ong Tsui. 1990. The international family planning movement. *Population Bulletin* 45(3).

Dzurik, A. A. 1996. *Water resource planning*. 2d ed. Savage, MD: Rowman & Littlefield.

Ehrlich, Paul. R. 1968. *The population bomb*. New York: Ballantine Books.

_______ and A. H. Ehrlich. 1990. *The population explosion*. New York: Simon and Schuster.

_______, _______, and G. Daily. 1993. Food security, population ad environment. *Population and Development Review* 19: 1-32.

Fuguitt, G.V., T.A. Heberlein, and P.R. Rathbun. 1991. Migration consequence for household energy consumption in a nonmetropolitan recreation-retirement area. *Rural Sociology* 56: 56-69.

Gaffin, S.R., N. O'Neill, and J. Bongaarts. 1996. Population growth could affect global warming. *EDF Newsletter* XXVII(6).

George, Henery. 1929. *Progress and poverty: Fiftieth anniversary edition*. New York: Robert Schalkenbach Foundation.

Good, J. C. 1993. Roof runoff as a diffuse source of metals and aquatic toxicity in stormwater. *Water Science Technology* 28: 317-322.

Graber, E.E. 1974. Newcomers and oldtimers: Growth and change in a mountain town. *Rural Sociology* 39: 504-513

Graf, W. I. 1985a. The Colorado River: instability and basin management. *Resource Publications in Geography*. Washington: Association of American Geographers.

_______. 1985b. Mercury transport in stream sediments of the Colorado Plateau. *Annals of the Association of American Geographers* 75: 552-65.

Griffin, Robert Jr. 1991. Introducing NPS water pollution. *EPA Journal* 17(5): 6-9.

Hodgson, D. 1988. Orthodoxy and revisionism in American demography. *Population and Development Review* 14: 541-470.

Homer-Dixon, T. F., J. H. Boutwell, and G. W. Rathjens. 1993. Environmental change and violent conflict. *Scientific America* 268, no. 4: 38-45.

_______ and M. A. Levy. 1995. Environment and security. *International Security* 20:189.

Hua, C. and Porell, F. 1979. A critical review of the development of the gravity model. *International Regional Science Review* 4: 97-126.

Hurt, Ann, real estate broker in San Marcos, TX.. 2001. Telephone conversation with author, 25 September 2001.

Ives, J.D., and B. Messerli. 1989. *The Himalayan dilemma: Reconciling development and conservation.* London: Routledge.

Karr, J. R. 1981. Assessment of biotic fish communities. *Fisheries* 6: 21-27.

_______. 1991. Biological integrity: A long neglected aspect of water resource management. *Ecological Applications* 1: 66-84.

Kates, R. W. 1987. The human environment: The road not taken, the road still beckoning. *Annals of the Association of American Geographers* 77: 525-534.

_______. 1996. Population, technology and the human environment: A thread through time. *Daedalus* 125: 43-71.

Kay, J. 1985. Preconditions of natural resource conservation. *Agricultural History* 59: 127-135.

Kirk, D. 1944. Population change and the postwar world. *American Sociological Review* 9: 28-35.

Lassailly-Jacob, V. 1999. The environmental impact of refugee settlements: a case study of an agricultural camp in Zambia. In *People and their planet: Searching for balance*, eds. B. S. Baudot and W. R. Moomaw, 187-203. New York: St. Martin's Press.

Lee, R.D. 1987. Population dynamics of humans and other animals. *Demography* 24: 443-465.

_______. 1997. Population dynamics: Equilibrium, disequilibrium, and consequences of fluctuations. In *Handbook of Population and Family Economics*, eds. M.R. Rosenzweig and O. Stark, 1063-1109. New York: Elsevier Press.

Lotspeich, L. B. 1980. Watersheds as the basic ecosystem: This conceptual framework provides a basis for a natural classification system. *Water Resource Bulletin* 16: 581-586.

Malthus, T. R. 1798. *An essay on the principle of population.* New York: Augustus Kelley.

Marcus, W. A. 1987. Copper dispersion in ephemeral stream sediments. *Earth Surface Processes* 12: 217-28.

Marsh, G. P. 1864. *Man and nature; or physical geography as modified by human action*. New York: Scribners.

Mason, C. 1991. *Biology of freshwater pollution*. 2d ed. Essex, UK.: Longman Scientific and Technical.

McKendrick, J. H. 1999. Multi-method research: An introduction to its application in population geography. *Professional Geographer* 51: 40-50.

McNicoll, G. 1990. Social organization and ecological stability under demographic stress. In *Rural Development and Population: Institutions and Policy*, eds. G. McNicoll and M. Cain, 147-160. New York: Oxford University Press.

Meadows, D. H., D. L. Meadows, J. Randers and W. W. Bherens III 1972. *The limits to growth*. New York: The American Library.

Meyer, William. B. and B. L. Turner II, eds. 1994. *Changes in land use and land cover: A global perspective*. Cambridge, UK: Cambridge University Press.

Montgomery, D. R., G. E. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. *Water Resources Bulletin* 31: 369-386.

Myers, N. 1990. The world's forest and human populations: the environmental connections. *Population and Development Review* 16:1-14.

National Academy of Sciences. 1986. *Population Growth and Economic Development: Policy Questions*. Washington DC: National Academy Press.

National Research Council. 1999. *Human dimensions of global environmental change: Research pathways for the next decade*. Washington DC: National Academy Press.

Natural Fibers Information Center. 1987. *The climates of Texas counties*. Austin, Texas: Bureau of Business Research.

Ness, G. D., W. D. Drake, and S. R. Brechin, eds. 1993. *Population-environment dynamics: Ideas and observations*. Ann Arbor, MI: University of Michigan Press.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77: 118-125.

_______ and G. E. Griffith. 1991. Ecological regions vs. hydrologic units: Frameworks for managing water quality. *Journal of Soil and Water Conservation* 46: 334-340.

_______ and R. G. Bailey. 1997. Distinguishing between watersheds and ecoregions. *Journal of the American Water Resource Association* 33: 935-949.

Organization for Economic Cooperation and Development. 1986. *Control of water pollution from urban runoff.* Paris, France: Organization for Economic Cooperation and Development.

Panayotou, T. 1996. And inquiry into population, resources, and environment. In *The Impacts of Population Growth on Well-Being in Developing Countries*, eds. D.A. Ahlburg, A.C. Kelley, and K. Oppenheim, 259-298. New York: Springer-Verlag.

Palloni, A. 1994. The relation between population and deforestation: Methods for drawing causal inferences from macro and micro studies. In *Population and Environment: Rethinking the Debate*, eds. L. Arizpe, M.P. Stone, and D.C. Major, 125-165. Boulder: Westview Press.

Parsons, J.J. 1960. Fog drip from coastal stratus. *Weather* 15: 58.

Pebley, Anne R. 1998. Demography and the environment. *Demography* 35(4): 377-389.

Pereira, H.C. 1973. *Land-use and water resources.* Cambridge, UK: Cambridge University Press.

Perry, J. and E. Vanderklein. 1996. *Water quality: Management of a natural resource.* Cambridge, UK: Blackwell Science.

Phillips, Jonathan D. 1988. Nonpoint source pollution and spatial aspects of risk assessment. *Annals of the Association of American Geographers* 78(4): 611-623.

_______. 1989. Nonpoint source pollution risk assessment in a watershed context. *Environmental Management* 13(4): 493-502.

Platt, R. H. 1996. *Land use and society: Geography, law, and public policy.* Washington, DC: Island Press.

Ploch, L.A. 1978. The reversal in migration patterns: Some rural development consequences. *Rural Sociology* 43: 293-303.

Pope, W. 1980. Impact of man in catchments (II) road and urbanisation. In *Water quality in catchment ecosystems*, ed. A. M. Grower, 73-112. Chichester, UK: Wiley.

Preston, S.H. 1994. Population and the environment: the scientific evidence. In *Population - The Complex Reality. A Report on the Population Summit of the World's Scientific Academies*, eds. F. Graham-Smith. London: The Royal Society. Quoted in Anne R. Pebley. Demography and the environment. *Demography* 35(4): 377-389, 1998.

_______. 1996. The effects of population growth on environmental quality. *Population Research and Policy Review* 15: 95-108

Price, M.L. and D.C. Clay. 1980. Structural disturbances in rural communities: Some repercussions of the migration turnaround in Michigan. *Rural Sociology* 45: 591-607.

Repetto, R. 1987. *Population, resources, environment: An uncertain future.* Washington, DC: Population Reference Bureau.

Respess, Richard O. 1982. *Intensive survey of Onion Creek segment 1427.* Austin, TX: Texas Department of Water Resources. IS-36.

Ridker, R.G., ed. 1972. *Population, Resources, and the Environment.* Washington, DC: U.S. Government Printing Office.

Rockwell, Richard C. 1994. Culture and cultural change. In *Changes in land use and land cover: A global perspective*, eds. W. B. Meyer and B. L. Turner II, 263-286. Cambridge, UK: Cambridge University Press.

Rogers, Peter. 1994. Hydrology and water quality. In *Changes in land use and land cover: A global perspective*, eds. W. B. Meyer and B. L. Turner II, 263-286. Cambridge, UK: Cambridge University Press.

Rome, Adam. 2001. *The Bulldozer in the Countryside: Suburban Sprawl and the Rise of American Environmentalism.* New York: Cambridge University Press.

Ruttan, Vernon W. 1993. Population growth, environmental change, and innovation: Implications for sustainable growth in agriculture. In *Population and Land Use in Developing Countries*, eds. C.L. Jolly and B.B. Torrey. Washington, DC: National Academy Press.

Sage, Colin. 1994. Population and income. In *Changes in land use and land cover: A global perspective*, eds. W. B. Meyer and B. L. Turner II, 263-286. Cambridge, UK: Cambridge University Press.

Saha, S. K. 1981. River basin planning as a field of study: Design of a course structure for practitioners. In *River basin planning: Theory and practice*, eds. S. K. Saha and C. J. Barrow, 9-40. New York: John Wiley & Sons.

Sambrook, R. A., B. W. Pigozzi, and R. N. Thomas. 1999. Population pressure, deforestation, and land degradation: A case study from the Dominican Republic. *Professional Geographer* 51: 25-40.

Schmink, M. 1992. *Contested frontiers in Amazonia*. New York: Columbia University Press.

_______. 1994. The socioeconomic matrix of deforestation. In *Population & environment: Rethinking the debate*, eds. L. Arizpe, M. P. Stone, and D. C. Major, 253-276. Boulder, CO: Westview Press.

Schnaiberg, A. 1986. Reflections on resistance to rural industrialization: Newcomers' culture of environmentalism. In *Differential Impacts of Rural Resource Development*, eds. P.D. Elkind-Savatsky, 229-258. Bolder, CO: Westview Press.

Sidhu, R. 1993. *Current status of watershed management in the United States*. Washington, DC: American Petroleum Institute.

Simon, J. L. 1977. *The Economics of Population Growth*. Princeton, NJ: Princeton University Press.

_______. 1981. *The Ultimate Resource*. Princeton, NJ: Princeton University Press.

Smail, J.K. 1997. Beyond population stabilization: The case for dramatically reduced global human numbers. *Politics and the Life Sciences* 16(2): 183-192.

Smith, C. T. 1969. The drainage basin as an historical basis for human activity. In *Water, Earth, and Man: A Synthesis of Hydrology, Geomorphology, and Socio-economic Geography*, ed. R. J. Chorley, 101-110. London: Methuen.

Smith, M.D. and R.S. Krannich. 2000. "Culture clash" revisited: Newcomer and longer-term residents' attitudes towards land use, development, and environmental issues in rural communities in the Rocky Mountain West. *Rural Sociology* 65(3): 396-421.

Sokolow, A.D. 1977. California's new migration to the towns of the 'cow counties.' *California Journal* (October): 14-16.

Stocking, M. 1987. Measuring land degradation. In *Land Degradation and Society*, P. Blaikie and H. Brookfield, 49-63. London: Methuen.

Tarr, Joel A. and Robert U. Ayres. 1993. The Hudson-Raritan Basin. In *The Earth as Transformed by Human Action*, eds. B.L. Turner II, William C. Clark, Robert W. Kates, John F. Richardson, Jessica T. Mathews, and William B. Meyer, 623-639. New York: Cambridge University Press.

Theodori, G.L., A.E. Luloff, and F.K.Willits. 1998. The association of outdoor recreation and environmental concern: Reexamining the Dunlap-Heffernan thesis. *Rural Sociology* 63: 94-108.

TNRCC (Texas Natural Resource Conservation Commission). 1997. *The statewide watershed management approach for Texas: The TNRCC's framework for implementing water quality management.* Austin, TX: Texas Natural Resource Conservation Commission.

_______. 1999. *State of Texas: 1999 Clean Water Act section 303(d) list and schedule for development of total maximum daily loads.* Austin, TX: Texas Natural Resource Conservation Commission, Water Quality Division. SFR-58/99.

_______ and Texas State Soil and Water Conservation Board. 1999. *Texas nonpoint source pollution assessment report and management program.* Austin, TX: Texas Natural Resource Conservation Commission, Water Quality Division. SFR-68/99.

_______ and _______. 2000. *1999 annual report: Texas nonpoint source pollution management program.* Austin, TX: Texas Natural Resource Conservation Commission, Water Quality Division. SFR-66/99.

Trimble, S. W. and R. U. Cooke. 1991. Historical sources for geomorphological research in the United States. *Professional Geographer* 43: 212-228.

Tuan, Y.-F. 1968. Discrepancies between environmental attitude and behavior: Examples from Europe and China. *Canadian Geographer* 12: 176-191.

Turner, B. L. II. et al. 1990. *The Earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years.* Cambridge, UK: Cambridge University Press.

Twidwell, Steve, Texas Natural Resource Conservation Commission Water Quality Division. 2000. Telephone conversation with author, 1 May 2000.

U. S. Census Bureau. 1999a. Metropolitan area population estimates for July 1, 1998 and population change for April 1, 1990 to July 1, 1998. URL:http://www.census.gov/population/estimates/metro-city/ma98-01.txt.

_______. 1999b. Metropolitan area population rankings by population size and percent change for July 1, 1997 to July 1, 1998 and April 1, 1990 to July 1, 1998. URL:http://www.census.gov/population/estimates/metro-city/ma98-04.txt.

USEPA (U. S. Environmental Protection Agency). 1984. *Report to congress: Nonpoint source pollution in the U.S.* Office of Water Policy, Environmental Protection Agency, Washington D.C.

_______. 1996a. *Nonpoint source pollution: The Nation's largest water quality problem.* Washington, DC: U. S. EPA Office of Water. EPA841-F-96-004A.

_______. 1996b. *The nonpoint source management program.* Washington, DC: U. S. EPA Office of Water. EPA841-F-96-004D.

_______. 1996c. *Managing nonpoint source pollution from agriculture.* Washington, DC: U. S. EPA Office of Water. EPA841-F-96-004F.

_______. 1997. *Volunteer stream monitoring: A methods manual.* Washington, DC: U. S. EPA Office of Water.

_______. 2000a. *The quality of our nation's waters.* Washington, DC: U. S. EPA Office of Water. EPA841-S-00-001.

_______. 2000b. *National water quality inventory: 1998 report to congress.* Washington, DC: U. S. EPA Office of Water. EPA841-R-00-001.

_______. 2000c. *Water quality conditions in the United States.* Washington, DC: U. S. EPA Office of Water. EPA841-F-00-006

USGS (U. S. Geological Survey). 1994. *Nonpoint and point sources of nitrogen in major watersheds on the United States*, by Larry J. Puckett. Washington, DC: U. S. Geological Survey. Water-Resources Investigations Report 94-4001.

_______. 1999a. *The quality of our nation's waters - nutrients and pesticides.* Washington, DC: U. S. Geological Survey. Circular 1225.

_______. 1999b. *Review of phosphorus control measures in the United States and their effects of water quality*, by David W. Litke. Washington, DC: U. S. Geological Survey. Water-Resources Investigations Report 99-4007.

_______. 2001. *Selected findings and current perspectives on urban and agricultural water quality by the national water-quality assessment program.* Washington, DC: U. S. Geological Survey. FS-047-01.

Waite, Michael K., real estate broker in Dripping Springs, TX. 2001. Interviewed by author, 9 April, Dripping Springs, TX.

Waite, T. D. 1984. *Principles of water quality.* New York: Academic Press.

Weeks, J. R. 1999. *Population: An introduction to concepts and issues*. 7th ed. Belmont, CA: Wadsworth Publishing Company.

Wischmeier, W. H. 1976. Use and misuse of the Universal Soil Loss Equation. *Journal of Soil and Water Conservation* 31:5-9.

Wolpert, J. 1966. Migration as an adjustment to environmental stress. *Journal of Social Issues* 22: 92-102.

Yin, R. K. 1989. *Case study research: Design and methods*. Revised Edition. Newbury Park, CA: SAGE Publications.

Zero Population Growth. 2000. About ZPG: Mission Statement. URL:http://www.zpg.org/About_zpg.

VITA

Paul Daniel Sutton was born in Indianapolis, Indiana, on October 31, 1970, the son of Tommy Sutton and Sara Sutton. After graduating from in 1988 from Tates Creek High School, Lexington, Kentucky, he entered the University of Kentucky, Lexington, Kentucky. He received the degree of Bachelor of Arts from the University of Kentucky in 1992. In August, 1992 he entered the Graduate School of Southwest Texas State University, San Marcos, Texas. He received the degree of Master of Applied Geography from Southwest Texas State University in 1994. In 1996 he returned to Southwest Texas State University as part of the first doctoral class at the University. While a doctoral student he taught world regional geography and worked as a research assistant. He received the degree Doctor of Philosophy in 2001.

Permanent address: 149 Vanderbilt Drive
Lexington, Kentucky 40517

This dissertation was typed by Paul Daniel Sutton