Using Geographic Information Systems to Develop and Analyze Land-Use Policies

by

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Abstract

Urbanization has a profound effect on the natural environment. Decisions concerning the transformation of land from a natural to developed state take place almost exclusively on the local level in the United States. While the importance and complexity of land-use decisions are high, the resources available to local government officials are sparse. Incorporating ecological principles(stream quality protection) into local land use decisions is challenging due to the complexity of the problems and significance of the impact on the community. This research explored the use of geographic information systems (GIS) as a tool to clarify land use decisions. The method employed was a case study of the city of San Marcos, Texas where GIS technology was used to create build-out maps of three different watersheds within the city. These build-out maps provide a snapshot of the stream quality in each of the three watersheds when the city reaches build out. Impervious cover is used as the indicator for stream quality. A land-use method was used to estimate and forecast impervious cover levels in each of the three watersheds. Three working hypotheses were developed to predict whether stream quality would be consistent with community expectations under current development policies, a conservation development ordinance, or a restriction on development within the 100-year floodplain. The results indicate that when the city of San Marcos reaches build out, two of the three watersheds analyzed will not meet community expectations for stream quality under current development policies. Results also show that neither of the stream quality protection measures chosen meets community expectations.

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Chapter 1. Introduction

Research Problem

Land use is related to many of the most vital issues facing American cities today. These issues include economic growth, natural resource protection, and quality of life(Arnold C. 2000, 1). In the city of San Marcos, Texas stream quality has been identified as one of the most pressing issues by citizens and professionals alike (City of San Marcos 2007; Opinion Analysts Inc. 2007; Gil Engineering Assoc. 2002; City of San Marcos 1996). Stream quality is linked to land use through the process of converting land from a natural or agricultural state to a developed state. This type of land conversion results in the creation of impervious cover. Impervious cover is land that can not be penetrated by water; most often in the form of human development. Throughout the literature, impervious surface coverage levels have been linked to a decline in stream quality(Arnold 1996; Reilly 2004; Schueler 1996). Limiting development and designing developments to minimize the amount of impervious cover are two techniques cities can use to protect stream quality.

To mitigate the effects of development on stream quality, local city governments need to enact regulations and rules that incorporate ecological concepts (Dale 2000; Benedict 2002). While local government officials have information and knowledge concerning economic development (and to some extent, quality of life) the knowledge and information available to local officials and decision-makers concerning natural resource protection are limited(Arnold 2000; Arendt 1999; Theobald 2000).The challenge for local cities and towns is getting these ecological concepts written into the development rules of the community.

The struggle between economic development and conservation is played out on the local level each and every day in the United States. This struggle takes place in local city council meetings, planning and development board meetings, and in local natural resource departments across the country. Communities are equally dependent on the environment and growth for success. Development flourishes in beautiful communities with bountiful natural resources, but is slowed when conservation efforts restrict growth. Likewise, conservation efforts on the local level rely on money from economic growth to secure new natural areas; however, urbanization is a leading cause of environmental degradation. How do local cities and towns balance these two dominant forces?

Research Purpose

Every community is influenced by the process of balancing economic development and natural resource conservation. Finding a balance relies on the confluence of many factors. It is the job of local city governments and planning departments to compile information from stakeholder groups, scientists, developers, and community members to develop policies that represent the prevailing goals of the community. This daunting task is aided by tools that can assess the impact of local policies on the environment. Land-use policies of local governments can result in different levels of impervious cover. The quality of the rivers, lakes, and streams in a community often declines as a community's impervious cover increases. Geographic information systems (GIS) technology makes it easier to examine the relationship between impervious cover and water quality. This paper explores how GIS technology can be used to clarify the ways in which different land use policies influence future development, impervious cover, and stream quality.

Chapter Summaries

Chapter 2 reviews the literature on the problems associated with local land-use planning, and discusses the use of GIS technology as a possible solution to some of these problems. Three working hypotheses are developed to test the use of a GIS model for analyzing stream quality protection policies. In chapter 3 the specific characteristics of the San Marcos environment are discussed. Then the working hypotheses are developed and examined in light of how they will be applied in the present study. In chapter 4 the six-step method for developing a GIS model that analyzes land-use policies is explained. The first five steps make up a general model that could be applied to other potential land-use policies. In step six, each of the three working hypotheses are applied to the model. The results of the research are presented and analyzed in chapter 5. In chapter 6 the research findings are summarized, and recommendations are made for future research.

Chapter 2. Literature Review

Introduction

The purpose of this literature review is twofold. First, this review explores the use of GIS as a tool to assist communities in utilizing ecological considerations when planning for growth and protecting water quality. Second, three working hypotheses are developed to show how these maps can produce useful evidence to a community attempting to preserve its water quality while maintaining economic growth.

Transforming land cover from a natural or agricultural state to a human settlement, particularly in the form of single-family homes, has a profound and permanent effect on the local environment (Dale 2000). Development impacts the aesthetics, biodiversity, economic growth, natural resources, quality of life, and many more of the primary concerns of local communities. For this reason, land-use regulations in the United States are primarily a local concern. While land-use decisions on a piece of property affect the land surrounding it and potentially have ramifications that extend even further, the primary impacts of land-use decisions are within the local jurisdiction. Land-use decisions also may incorporate site-specific problems that can be addressed differently for each locality. For example, a local aquifer or favorite swimming hole may need special attention that isimpossible for a larger governing body to provide. Land-use decisions occur on a local level because local citizens know what is best for their community.

A complex problem handled on the local level

While local communities have the largest interest in land-use decisions, they don't have as many resources to inform their decisions. Local decisionmakers in most towns across America are volunteers "with little or no training in natural resource protection, and many lack professional assistance"(Arnold 2000, 1). To tackle the problem of water quality in local communities, leaders must have legal and scientific resources. Natural resource protection, and specifically ensuring water quality,are complex and interrelated scientific problems. Land-use regulation can often provide solutions for these problems. But enacting land-use regulations to protect these resources is often a legal challenge. Hence, the legal and scientific complexities of water quality protection are contingent on each other.

Legal issues

Communities must balance the rights of individual property owners with community goals. This is a difficult task that hinges on the rights and responsibilities of the community and the individual. Individual property owners have the right to use their land as long as they are not creating a nuisance. Nuisances are either public or private. A private nuisance (a barking dog) is generally inflicted on neighboring homeowners, while a public nuisance (pollution) is felt by the entire community. The community has the right to protect itself from public and private nuisances as well as the responsibility to protect individual property rights. Silberstein and Maser (2000, 3) point to a "duality within and between the greater good and personal well-being; that is, the more a matter encroaches on a person's perceived individual rights, the more that individual seems to have a diminished sense of community." Local jurisdictions, with little in the way of resources or expertise, are charged with making land-use decisions that uphold the rights and responsibilities of both the community and the individual. Protecting water quality involves the difficult task of limiting an individual's rights to develop and profit from their property. Even in communities highly concerned about their environment, the duality discussed by Silberstein and Maser(2000) makes limiting or "taking" an individual's property rights both politically and financially challenging.

Managing the challenge of land-use regulation begins with strong comprehensive planning based on scientific standards and an expression of community goals. When limiting or taking an individual's property rights, local governments must be able to show that this decision is not arbitrary, that it has the support of the community, and that it is part of an overall plan (Danziger 1962). Having sound scientific standards that justify a taking limits community liability. "Planning for conservation is a process that uses scientific data, but that ultimately depends on the expression of human values" (Theobald 2000, 43). The use of scientific data is the key to justifiable, well-informed choices. The challenge is getting this information into the hands of local decisionmakers and citizens in a form that can be understood and translated into regulations. In order to limit liability and effectively accomplish conservation goals, comprehensive plans must display both the goals and the methods used to achieve those goals (Arendt 2004). Having clear scientific data that back up those decisions is an essential step in the process.

Using build-out maps to aid in the education and planning process

Getting scientific information into the hands of the public in a form that is understood and can be transformed into action is challenging. GIS, a new technology that meets this challenge,is becoming available in many communities.Unfortunately, "simply providing data or maps is not enough. Impressive multi-layer maps created with Geographic Information Systems (GIS) are becoming the digital age equivalent of the300-page technical report that sits on a shelf, gathering dust" (Arnold 2000, 1251). When presented correctly, maps can provide valuable, easily understood information to educate the public and policymakers so that they can make more informed choices. A map's utility, however, depends on the presentation of the information. An effective GIS map does not show all of the data and information that goes into the analysis because "complex multi-layered GIS maps are morelikely to be effective as modern art than as a DSS (Decision Support System) component" (Arnold 2000, 1253). Build-out maps created with GIS technology can be used as planning and educational tools to demonstrate the impact of a city's development on its natural resources (Arendt 2004; Arnold 2000; CWP 1995; Lathrop 1998). A build-out map is a map that represents what a community will look like when all of its buildable land has been converted according to its current land-use policies and zoning regulations (Arendt 1999). Build-out maps are not able to predict exact future conditions, however, the utility of maps for land use decisions is in their ability to display data and provoke thoughts and ideas, not in their complex deconstruction of environmental systems.

Pragmatism and maps

Recently the philosophy of classical pragmatism has been used to approach policy problems in the field of public administration. Classical pragmatism provides public administrators a way to approach problems, consider data, and communicate across groups (Shields 2003; Shields 2008). Classical pragmatism can produce a useful approach to community planning and policy development. "The sciences, by revealing the structures and relations of nature, provide the instrumentalities of control which give humans greater ability to utilize the forces of nature in the service of increased well-being" (Boisvert 1998, 46). Although science is not considered preeminent, classical pragmatism relies on a scientific approach to collect data that can be considered by a community. GIS maps provide a community of inquiry with scientific data. These maps are also a representation of the forces of nature that Boisvert discusses. GIS maps can become part of the education experience and form the basis of an effective decision support system.

Maps, however, do not represent reality. "All maps have distortions. And, maps have practical use in resolvinghow to travel from one point to another. The tools of classical pragmatismprovide the public administrator with insights of the mapmaker and canhelp him navigate challenging problematic situations" (Shields 2005, 513). These insights include: 1) "Neither should pretend to occupy a detached, disinterested standpoint that provides *the* snapshot of the world. 2) Both involve selectivity and choice. 3) Both maps and philosophical analysis are provisional; always open to revisions improvements and emendation" (Hickman 1998, 150). Maps, when created by a community, can represent a snapshot of the community's values and goals in their physical form. When these values and goals change, GIS maps can display the change as a visual representation. Maps also allow a community to visualize whether their values are represented in practice.

Build-out maps

It is useless for a community to analyze GIS data without clearly articulated goals that incorporate their values.

> Science can help inform citizens about the basic patterns and processes of natural systems, but citizens must express personal values to determine which endpoints are most desirable. Scientists should not offer answers. Instead, they should press citizens to articulate their values and goals for the landscapes where they live. Clearly defining their goals for conservation enables scientists to select more appropriate scientific data and models to support the choices for seeking those goals (Theobald 2000, 43).

One type of GIS model that represents the built landscape in a community is a build-out map. Build-out maps are a representation of the community's physical landscape when there is no longer undeveloped land in a community. A GIS build-out map considers current development regulations or proposed development regulations and provides a digital representation of the community at build out. A project in the Willamette Valley designed to map future land and water use employed a build-out map to depict three different alternatives for growth.Figure 2.1depicts the Willamette Valley in 1850 with very little human settlement. This image allows for a comparison with current and future levels of development.

Figure 2.1 Willamette Valley in 1850

Source: Hulse, 2004

Figure 2.2 is a view of the Willamette Valley in 1990. This image gives the decisionmakers in Oregon's Willamette Valley an awareness of the changes that have taken place due to development over the past 140 years.

Figure 2.2 Willamette Valley in 1990

Source: Hulse, 2004

Awareness about the changes that development has on a community's landscape sets the stage for a decision about future levels of development. Hulse used this model to show decisionmakers in the Willamette Valley that they have a choice about what their landscape will look like in the next 60 years. Hulse uses three different scenarios based on stakeholder group inputs. Figure 2.3 is a plan trend scenario and it represents what the Willamette Valley will look like in the year 2050 under current land use trends.

Figure 2.3 Plan Trend Scenario 2050

Source: Hulse, 2004

The plan trend scenario represents the current trend in land-use planning. Decisionmakers in the Willamette Valley were presented with a choice about whether they want their community to follow the path it is on, or if they want to allow more or less development. Figure 2.4 is a representation of the community if they choose land-use planning policies that are more favorable to development. Data and statistics accompanied each of these maps showing the projected financial and environmental state of the area under these plans.

Figure 2.4 Development Trend 2050

Source: Hulse, 2004

The Willamette Valley project analyzed a conservation trend as well. This trend was based on the conservation goals of stakeholder groups in the community and is represented in Figure 2.5.

Figure 2.5 Conservation Trend 2050

Source: Hulse, 2004

Scenario planning as a tool to reach consensus

The use of build-out maps to forecast future land use is also known as *scenario planning*(Lathrop 1998, 28). Scenario planning has been frequently used in the public planning and decision making process. "One of the first uses of scenarios was to influence public attitudes, as when Herman Kahn built scenarios about the effect of a possible nuclear war as a way of preventing it happening" (Ringland 1998, 131). "The use of scenarios as a way of developing recommendations for public policy has proved its worth: by providing a range of possible plausible futures, the effect of actions can be made explicit in a non-threatening way"(Ringland 1998, 165). Build-out maps can provide both a view of the scientific analysis and the expression of citizen values. "Theprocedure for connecting the understanding of landscapeprocesses from the sciences to the value ladenpublic policy making and land planning processes thatshape and influence land use" (Hulse 2004, 325). The processes and assumptions that go into the creation of different scenarios must be inclusive of multiple different stakeholder groups in order to be plausible and accepted by each group. Diverse citizen involvement is key to the formulation of policies and plans that will not just sit on a shelf collecting dust.

Citizen involvement in the land-use planning process

Diverse citizen involvement in the land-use planning process is essential to producing plans that can be implemented. Building consensus for policies that are controversial and lack what Burby(2003) refers to as public is a challenging task. Scenario planning has the potential to be an effective tool for building consensus and issue awareness. Administrators can use build-out maps as a type of scenario planning to educate the public and diverging interest groups on issues that are frequently underrepresented in local politics. "Local land-use planning affords a great opportunity for protecting natural systems because local communities can develop land-use plans that are proactive rather than reactive, thereby providing stewardship before restoration or mitigation is necessary" (Theobald 2000, 36). While this opportunity exists, mobilizing the public to implement policies that are not immediately pressing and serve to protect an ambiguous future is difficult. Water pollution is an important issue, but it often fails to reach the public's radar because it involves scientific data locked in charts or words. Public interest is not usually raised until the problem is too large to handle with preventive measures alone (Burby 2003). The public does not become active until a crisis raises awareness.

> In the case of issues and policies that do not attract this attention, debate over the merits of policy proposals never occurs, which can create uncertainty among elected officials about public preferences and the necessity for governmental action. It can also lead planners to unwittingly put forward proposals that mobilize latent publics, who realize their interests are involved only when plans are being considered for adoption and who then work to see that the offending planning proposals are dropped or never implemented(Burby 2003, 35).

Even though it is hard to mobilize the public, it is the responsibility of administrators and active interests groups to educate the public and involve diverse stakeholders in the process. Without citizen involvement, plans will attract a significant amount of dissention and skepticism from the public. Build-out maps and scenarios are a good way to raise the needed awareness and create a vision of the future before the situation becomes a crisis.

Preserving community identity and economic growth at the local level

More important than the number of citizens involved is the representativeness of the group. Too often, "local government decision making about urban development is dominated by either a growth machine or corporate regime made up of government officials and people whose livelihoods are strongly affected by planning actions" (Burby 2003, 42). Economic growth is a valuable and strong concern of local government and its citizenry. Nevertheless, in order for plans to be effective, a diverse group of citizens must be involved; including those whose livelihoods are not dependent on development and growth. In fact, Burby(2003, 43) found that "when property owners and environmental groups participated, plans were stronger on average, and proposals made in plans stood a much higher than average chance of being implemented. Since these two groups often have conflicting interests, it seems possible that citizen involvement processes that included them provided a forum in which consensus about appropriate policies could be achieved."

Protecting water quality is a goal with which few groups can argue. The problem is not that people object to protecting water quality. The problem is that the sacrifices to development can be high in watershed protection plans. Educating the public about the ecological principles behind the protection of water quality can help produce a water quality growth tradeoff that meets community environmental goals while minimizing sacrifices to economic development.

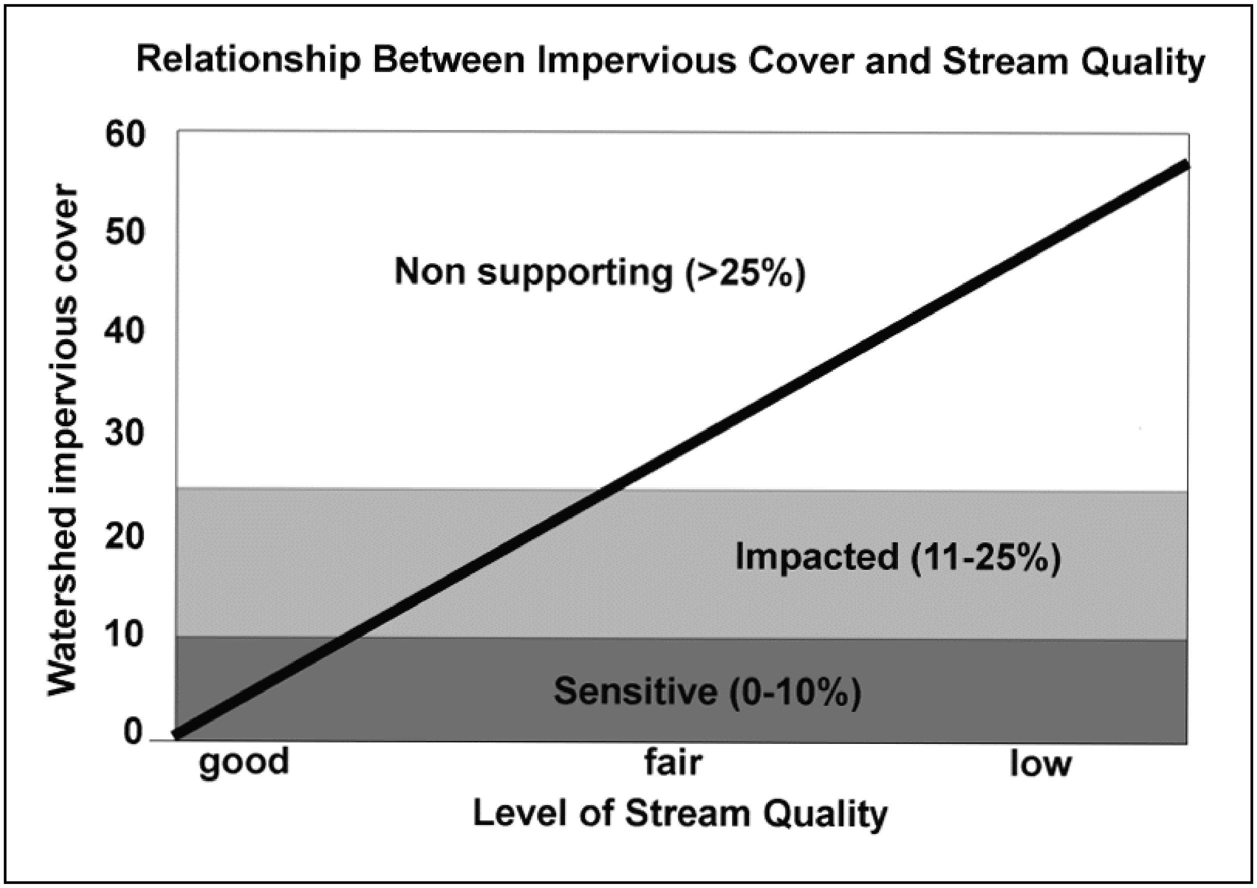
Incorporating ecological principles into land-use regulations

The first step to incorporating ecological principles into land-use decisions is recognizing their importance. In many cases, land-use policies are created without any regard to ecological principles. Many scientists advocate “using the ecological principles and guidelines to shape municipal ordinancesfor land use practices” (Dale 2000, 643). Unfortunately, “Researchers and policy analysts recognize that most land-management decisionscurrently have little relation to ecological science, beinginfluenced more strongly by economics, values, traditions,politics, and other factors” (Dale 2000, 644). This is due to the dominance of people whose livelihoods are dependent on development in the planning process, and a lack of will on the part of government officials in obtaining a diverse group of decisionmakers (Burby 2003). Decisions can’t be made solely from an ecological or economic perspective. “The single most effective step planners can take to secure broader involvement by stakeholders is simply to invite a variety of groups to take part in the planning process” (Burby 2003, 46). Encouraging an ecological perspective in land-use planning goes a long way toward incorporation of ecological principles in land-use regulations.

How impervious cover is linked to water quality

One important ecological principle tied to water quality is the negative relationship between impervious cover and water quality. In other words, as a community grows and the number of its streets, parking lots, and buildings increases, the purity and quality of its streams and rivers will decrease. Studies show that as the percent of impervious cover in a watershed rises, the water quality is reduced. The following graph (figure 2.6) shows the impact of impervious cover on stream quality.

Figure 2.6 An Inverse Relationship between Impervious Cover and Stream Quality



Source: Capiella 2005

Impervious cover is indirectly related to water quality; as the percentage of impervious cover within a watershed rises, the level of stream quality deteriorates from good to fair to low. Figure 2.6 is a summary of the different factors that represent a stream's overall quality. Three of these factors are displayed in table 2.1.

Table 2.1 Relationship between Stream Quality and Impervious Cover

	Impervious Cover 0% -10%	Impervious Cover 10% - 25%	Impervious Cover >25%
Water Quality	Good	Fair	Fair-Poor
Channel Stability	Stable	Unstable	Highly Unstable
Stream- biodiversity	Good – Excellent	Fair – Good	Poor

Source: Schueler 1996, 9

This type of scientific data can be used to guide land-use regulations. "Watershed management and impervious cover thresholds are tools available to assist the planner with wise land use decisions to protect water supplies" (Kauffman 2000, 9). When impervious cover threshold data are incorporated into land use plans, regulations can be designed to limit the total amount of impervious coverage in sensitive areas.

Many communities desire to maintain their current level of water quality, but they are also interested in growth. These two goals often conflict, since growth necessitates the development of more impervious cover. Communities can, however, mitigate the effects of growth if ecological considerations for minimizing the effect of impervious cover are considered. There are many regulations and considerations that can be taken into account to protect water quality without significantly reducing economic growth. However, if a community does not take ecological considerations into account and development continues using standard regulations, the effects of this type of growth can push the watersheds beyond threshold levels and significantly lower stream quality. Hence one would expect:

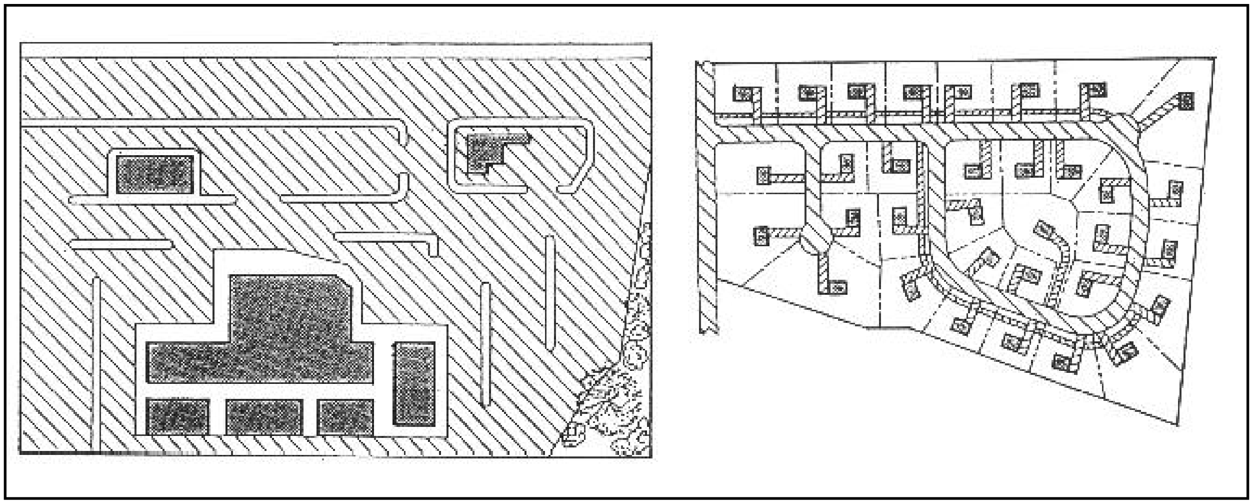
> Working Hypothesis 1: Standard development regulations implemented over the long term will result in water quality that is not consistent with community environmental expectations.

Conservation Development

Conservation development is an approach to subdivision design that has the potential to balance growth and environmental goals (Ellis 2006). Subdivisions that use conservation development principles are designed to maintain the density of a subdivision while decreasing lot size regulations(Arendt 1999).A subdivision generally encompasses a set acreage. Traditional development practice uses the entire acreage for homes and lots. The larger the lot, the less dense the development. Conservation development takes the acreage allotted for a subdivision and sets aside land for parks or nature preserves. The remaining land would be more densely developed. Impervious cover is reduced because there are fewer roads. Developer costs are lower because the infrastructure (sewer, water, roads) is reduced. Hence economic and environmental concerns are both addressed.

Development creates two types of impervious cover, rooftops and transportation networks. As communities sprawl and the reliance on the automobile increases, the impervious cover that results from transportation networks has begun to exceed that from rooftops. Figure 2.7 illustrates the two components of impervious cover.

Figure 2.7 Car and Rooftop Components of Impervious Cover



Source: The Center for Watershed Protection 1995, p. 20

Conservation development reduces the impervious area contributed by the transportation system by clustering a subdivision's development into a smaller area on the total lot. In this way, conservation development ordinances can reduce impervious cover while maintaining the same number of lots. Conservation development can reduce the total impervious cover in a subdivision by 10% -50% depending on the original lot size (CWP 1995, 5). Hence one would expect:

> Working Hypothesis 2: Incorporating conservation development ordinances will result in water quality that is more consistent with community expectations.

Restricting floodplain development

Impervious cover can also be reduced through the incorporation of stream buffers or setbacks. Austin's Regional Water Quality Plan (Naismith Engineering Inc. 2005) recommends that, where 100-year floodplains have been determined by the Federal Emergency Management Agency (FEMA), the stream buffer should incorporate the entire floodplain plus 25 feet on either side of the floodplain. The benefits of buffer zones to water quality are twofold. First, buffers reduce the amount of impervious cover within a watershed; and second, buffers provide a vegetative layer for runoff to be absorbed and filtered before it becomes part of the stream. Both of these benefits combined protect the water quality within a watershed. Due to the difficulties presented in land acquisition and the legality of limiting development, Austin's Regional Water Quality Plan allows for property owners to transfer the development rights from the floodplain to less environmentally sensitive areas of the subdivision. This increase in density and impervious cover in other areas of the watershed is offset by the filtration benefits of stream buffers. Hence one would expect:

> Working Hypothesis 3: Incorporating a restriction on floodplain development will result in water quality that is more consistent with community environmental expectations.

Table 2.1 summarizes the working hypotheses and links them to the corresponding literature

Table 2.2 Conceptual Framework Table

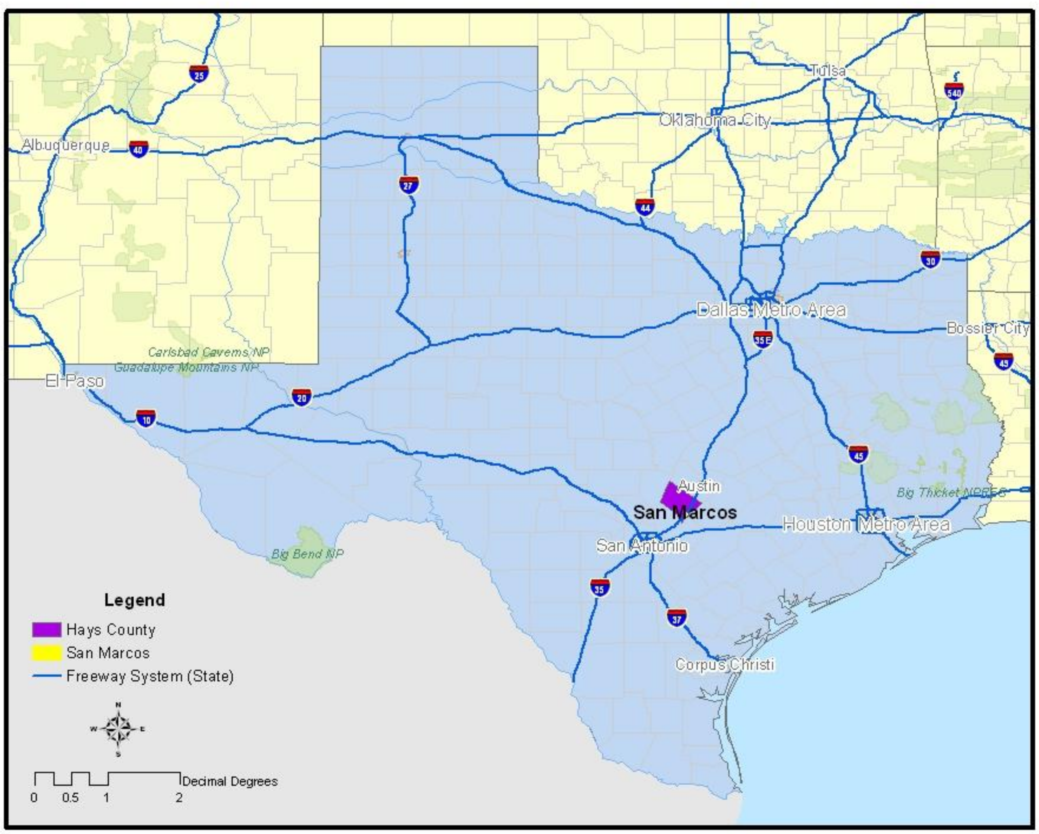
Working Hypotheses	Scholarly Support
Working Hypothesis 1: Existing development regulations implemented over the long term will result in water quality that is not consistent with community expectations.	(Arendt 1999) (Arendt 2004) (Benedict 2002) (Arnold 1996) (Arnold 2000) (Capiella 2005) (Dale 2000) (Kauffman 2000) (Lathrop 1998) (Reilly 2004) (Schueler 1996) (CWP 2000) (Theobald 2000)
Working Hypothesis 2: Conservation development ordinances will result in water quality that is more consistent with community expectations.	(Arendt 1999) (Arendt 2004) (Benedict 2002) (Dale 2000) (Ellis 2006) (Kaplan 2004) (Schueler 1996) (CWP 1995)
Working Hypothesis 3: Restricting floodplain development will result in water quality that is more consistent with community expectations	(Arendt 2004) (Arnold 1996) (Capiella 2005) (Dale 2000) (Kauffman 2000) (Lathrop 1998) (CWP 1995)

The working hypotheses developed in this chapter are reexamined in chapter 3 for their compatibility with the goals of the city of San Marcos. San Marcos was used to test the working hypotheses developed in this chapter for protecting water quality, and GIS technology was used as the tool for testing these hypotheses.

Chapter 3. Setting: City of San Marcos

This paper examines the use of build-out maps as a tool to explore how different land use policies effect stream quality. This chapter begins by describing the characteristics of San Marcos and its natural environment. Figure 3.1 displays the location of San Marcos within the state of Texas. San Marcos is where the working hypotheses developed in chapter 2 were tested. The current policies and trends behind land use in San Marcos are discussed followed by a site specific exploration of the three working hypotheses.

Figure 3.1 Map of Texas



Source: See Description of Data (Appendix A)

Characteristics of San Marcos

San Marcos is a midsized city located in Hays County, Texas(see figure 3.1) with a population of roughly 50,000. Census Bureau records indicate that the city of San Marcos is growing rapidly. Table 3.1 illustrates that there has been a 61% growth in population between 1990 and 2006(United States Census Bureau 2008).

Table 3.1 Population Growth

Year	2006	2000	1990
Population	47,181	34,733	28,743

Source: United States Census Bureau, 2008

Rapid growth is exerting pressure on the community to protect watersheds from degradation. This pressure is partly due to the city's fight to retain its individuality and small-town charm. San Marcos was established in 1847 after earlier attempts were thwarted by floods and raids by Native Americans. Traffic along important trade routes led to the growth of the city, and this continued in 1962 when Interstate Highway 35 was opened and the city was linked to the larger San Antonio and Austin metropolitan areas (Schneider-Cowan 2007).

San Marcos is also home to Texas State University, a 471-acre university with 28,000 students. The university has a significant impact on the community and its goals. Texas State provides a great opportunity for research and collaboration on important issues in the community. The university attracts a diverse student body and faculty from all over the country to the town of San Marcos.

The San Marcos Outlet Center is the largest outlet mall in Texas and is the fourth most-visited attraction in the State of Texas (San Marcos Chamber of Commerce 2005). Tourism is important to San Marcos. Visitors come to San Marcos from all over to enjoy the natural beauty and small-town charm as well as the shopping. The vitality of San Marcos relies on the tourist industry, natural beauty, and recreational opportunities.

Characteristics of the Natural Environment

Water in Texas is a valuable resource, and is predominantly located in underground reservoirs or aquifers. The water stored in these aquifers surfaces as natural springs. The San Marcos River, shown in figure 3.2, begins at one of these springs in San Marcos' Spring Lake.

Figure 3.2 San Marcos River at Rio Vista Dam

Source: Anders, 2004

Natural springs are an important resource and historical feature across the State of Texas. Human settlement in Texas follows the paths created by the Native Americans when moving from spring to spring across the State. Unfortunately, as the Texas population grew and wells were drilled to pump groundwater, springs have rapidly disappeared. Of the two hundred and eighty-one major and historical Texas springs Gunnar Brune documented, half of those had either failed or were failing by 1981(Texas Parks and Wildlife Department 2007). In the Texas Parks and Wildlife Department's (TPWD's) documentary presentation *Texas the State of our Springs* Joseph Fitzsimmons notes, "Springs are a direct indication of how well we're doing in managing Texas' natural resources. Simply put, if we do not do a good job of managing the health of our springs in Texas, we're not doing a good job of managing Texas, of managing our natural resources" (TPWD 2007, 3). This statement represents the feelings of Texans across the State as well as here in San Marcos towards the rivers, springs, and aquifers that distinguish Texas towns.

San Marcos Trends in Land-Use Policy

San Marcos springs and rivers have drawn human settlement to the area for centuries and are still the main attraction for the current population. Residents value the river and its contribution to the community. When Hays County or San Marcos citizens have a chance to vote on an issue related to water resources and the preservation of open space, the results have been decidedly in favor of conservation. For example, Opinion Analysts, Inc. described the support for a $30 million bond toward the purchase and preservation of parks and natural areas as "widespread and consistent, even when the tax implications of the bonds were made explicit" (Opinion Analysts Inc. 2007, 1).

Hays County residents in the area not only support conservation, but are willing to pay for it. This sentiment held true in the City of San Marcos 2007 citizen summit. The summit included ten different stakeholder groups in the community. During the summit, when participants were asked what the council's top priority should be, "protect the natural environment,beautify the City, and provide parksand recreational activities" was chosen over all other categories. The summit also revealed that a significant number of participants were more willing to pay additional taxes for natural resource protection than any other activity including traffic mobility which came in at a distant second. The citizen summit results also showed that the only issue where citizens wanted the government to pass more laws was in the protection of natural areas. A majority of residents voted for stricter rules concerning development over the Edwards Aquifer. For a complete summary of the results of the 2007 citizen summit see Data and Graphs from the 2007 Citizen Summit(City of San Marcos 2007). The results from these polls and focus groups clearly show residents' expectations of the local government. Their willingness to pay taxes to receive water quality and natural resource protection are evident(City of San Marcos, 2007).

Just 30 miles to the north of San Marcos, Austin has seen similar levels of growth over the past decade. Austin is a much larger city whose growth has already begun to negatively impact its stream quality. In response, Austin has developed a comprehensive water quality protection planto combat the negative effects of rapid growth on stream quality. The goal of Austin's Regional Water Quality Protection Plan is to:

> Develop an implementable Regional Water Quality Management Plan that preserves and protects resources and manages activities within the planning regionso that existing and future land use, land management, and development activitiesmaintain or enhance the existing water quality of the groundwater and surfacewater within both the Barton Springs segment of the Edwards Aquifer and thecontributing portion of the watersheds within the Planning Region, for the benefitof people and the environment (Naismith Engineering Inc. 2005, 14).

The goal of maintaining or enhancing existing water quality is similar to the more informally stated goals of the City of San Marcos.

San Marcos' citizens have displayed a high level of commitment to conservation when water quality and natural resource issues have been presented. While the City of San Marcos has not formalized plans for water quality protection, it's master plan recognizes the importance of maintaining the natural environment. The citizen action committee responsible for the master plan's goals envisions "a community that recognizes its unique environmental setting and actively works toprotect the Edwards Aquifer, the San Marcos Springs, the San Marcos River, andother natural resources" (City of San Marcos 1996, 4-5). The city's Land Development Code delineates environmental considerations, including water quality. Three of the six findings in chapter 5 of the Land Development Code state that:

> (4) The San Marcos River, the Blanco River, the Edwards Aquifer, and other rivers, streams and waterways must be protected in order to preserve the health, safety and welfare of the citizens of the City and surrounding areas.
>
> (5) The continued economic growth of the City and the surrounding area is encouraged by a pleasing natural environment, protection of watersheds and groundwater, and recreational opportunities in close proximity to the City.
>
> (6) The City Council desires to adopt site development rules and regulations for development within the City and within its extraterritorial jurisdiction for the purpose of protecting the San Marcos River, the Blanco River, the Edwards Aquifer, rivers, streams and waterways from the effects of water quality deterioration related to development activities (City of San Marcos 2008, 5.1.1.1 d).

These findings indicate that the City of San Marcos acknowledges the importance of protecting sensitive environmental features from rapid urbanization. The city also recognizes that environmental threats from urbanization can compromise the economic growth, health, and safety of the city and its citizens(City of San Marcos, 2008).

Protection Measures

While it is apparent that San Marcos wants to implement laws that protect its natural resources, it is not clear how they should proceed. The first step in creating an effective plan is to identify the major threats to water quality. Austin's Regional Water Quality Protection Plan for the Barton Springs section of the Edwards Aquifer identifies ten major threats to water quality in the Central Texas area:

- Urbanization
- Long-term groundwater withdrawal exceeding recharge
- Point source discharges
- Storm water/non-point source pollution
- Domestic wastewater collection, treatment and discharge
- Lack of water quality protection measures on existing development
- Failure to implement/enforce existing regulations
- Use, storage and disposal of harmful materials
- Improper vegetative management
- Improper agricultural practices(Naismith Engineering Inc. 2005)

All of these threats to water quality result from human activity. Many are the direct result of the number one threat: urbanization. Urbanization threatens water quality by removing natural vegetation and replacing it with impervious cover, thus increasing sedimentation and erosion in nearby streams and rivers. Increased impervious cover also increases storm water runoff rates, leaving less time and surface area for water to be absorbed into the ground. Non-point-source pollution is the result of storm water runoff from streets and roofs that pick up pollutants and carry them directly into rivers and lakes before the pollutants get a chance to be released into the soil. Urbanization also increases the incidence of all other water quality threats related to human activity. As more people move into an area, the threat of water pollution rises (Naismith Engineering Inc. 2005, 89; Schueler 1996; Arnold 1996; Kauffman 2000).

Figure 3.3 Water Flowing directly into the Edwards Aquifer

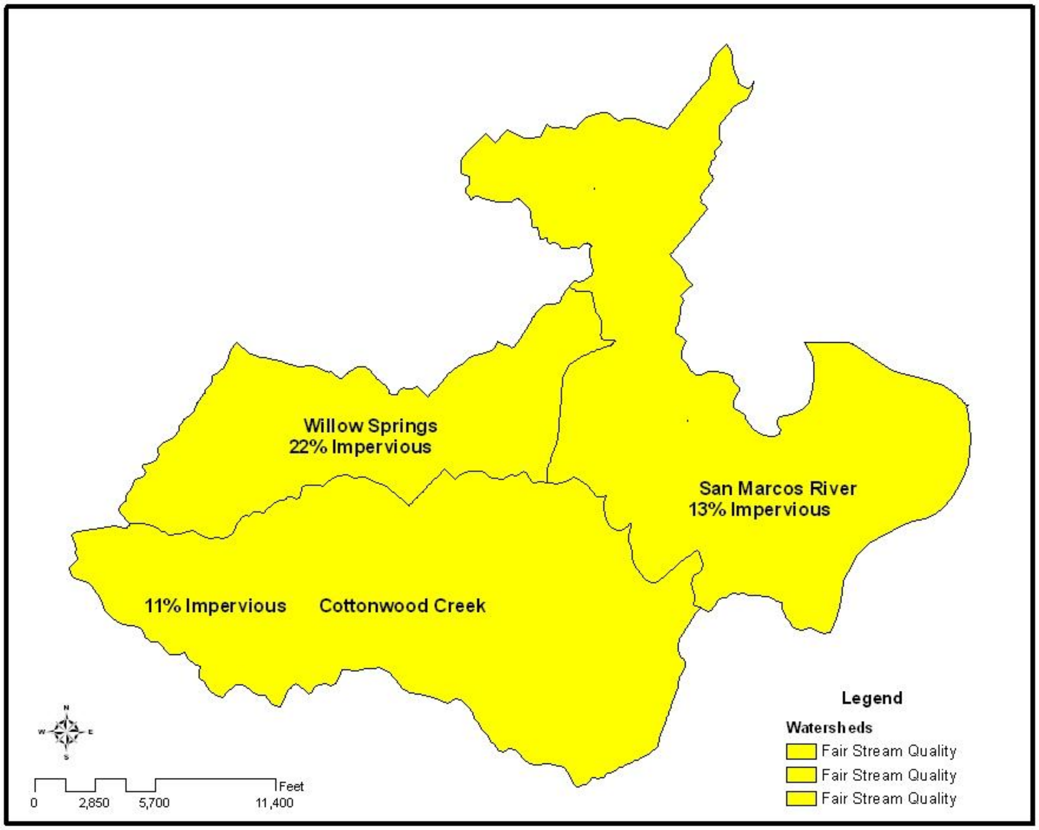
Source: TCEQ 2008

In Central Texas, the threat of water pollution due to impervious cover is exaggerated by the regions geologic composition. The region over the Edwards Aquifer is classified in terms of a recharge zone and a contributing zone. As displayed in Figure 3.3, the Edwards Aquifer recharge zone water flows directly into the aquifer via cracks in the limestone rock or caves. "The Edwards Aquifer Recharge Zone is the outcrop of the geologic unit known as the EdwardsGroup. The Edwards Group consists of complex carbonate formations with characteristic karstfeatures, formed by solution of limestone by water" (Naismith Engineering Inc 2005, 15). When impervious cover is added to this environment, non-point-source pollution can be added directly to the underground aquifer (TCEQ, 2008). Impervious cover also reduces the amount of water able to flow through the cracks and recharge the aquifer. This creates a cycle of withdrawing more and more water to support urbanization while replacing less and less. To protect water quality in San Marcos the threat of urbanization must be addressed.

San Marcos – The Working Hypotheses Revisited

Numerous policies aimed at protecting stream quality and limiting impervious cover have been developed for local governments. A comprehensive policy that addresses all relevant threats is the most effective way for a community to combat watershed degradation (Arendt 2004). The purpose of this study is to show how build-out maps and GIS technology can assist the city in choosing a combination of policies most effective at balancing stream quality and economic growth. Figure 3.4 shows the current stream quality in the three watersheds analyzed in San Marcos. This map was derived using the methodology discussed in chapter 4.

Figure 3.4 Current Stream Quality



Source: See Description of Data (Appendix A)

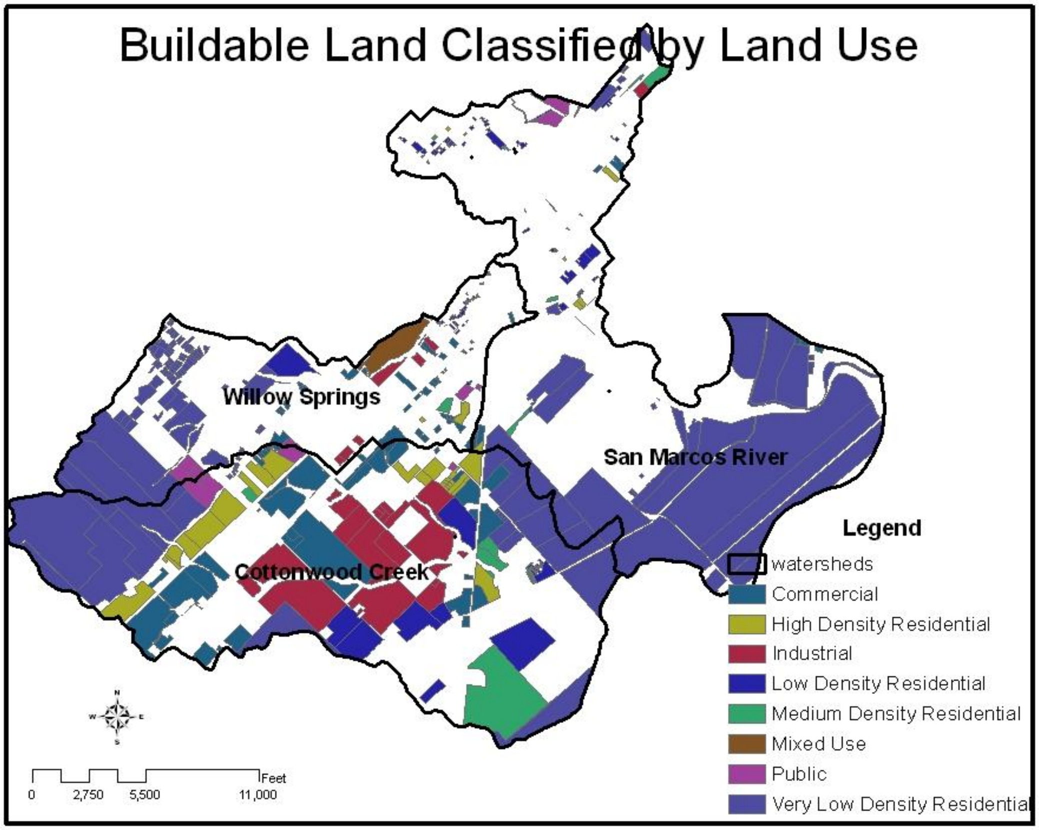
The graduated color scheme moves from green to yellow to red. Green indicates impervious levels from 0 -10% and good stream quality. Yellow indicates impervious cover levels between 11% and 25% and fair stream quality. Red indicates levels above 26% and degraded stream quality. All three watersheds in the study area are currently in the fair range, however, the Willow Springs watershed at 21.6% is close to degraded, and Cottonwood Creek at 11.3% and San Marcos at 12.8% are closer to good water quality. The City of San Marcos wants to maintain its current level of stream quality.

Moving from yellow to red, or from fair to degraded stream quality, means that the system will not be able to sustain current levels of plant and animal life. Degraded stream and river quality causes a change in the shape of streams and in turn, the habitat they are able to maintain. The amount of sediment or other pollutants associated with non-point-source pollution, and the frequency and severity of damaging floods, will also increase.

Existing Regulations – Working Hypothesis 1 Revisited

The first scenario for GIS analysis is simply a projection of what the impervious cover levels in each of the watersheds will be when the city reaches build out. This analysis is based on the assumption that current policies are maintained throughout the build-out process. Figure 3.5 illustrates the amount of buildable land, classified by land use, in each of the three watersheds. Buildable land is defined as undeveloped land where development is permitted by current land-use policies.

Figure 3.5 Buildable Land Classified by Land-Use



Source: See Description of Data (Appendix A)

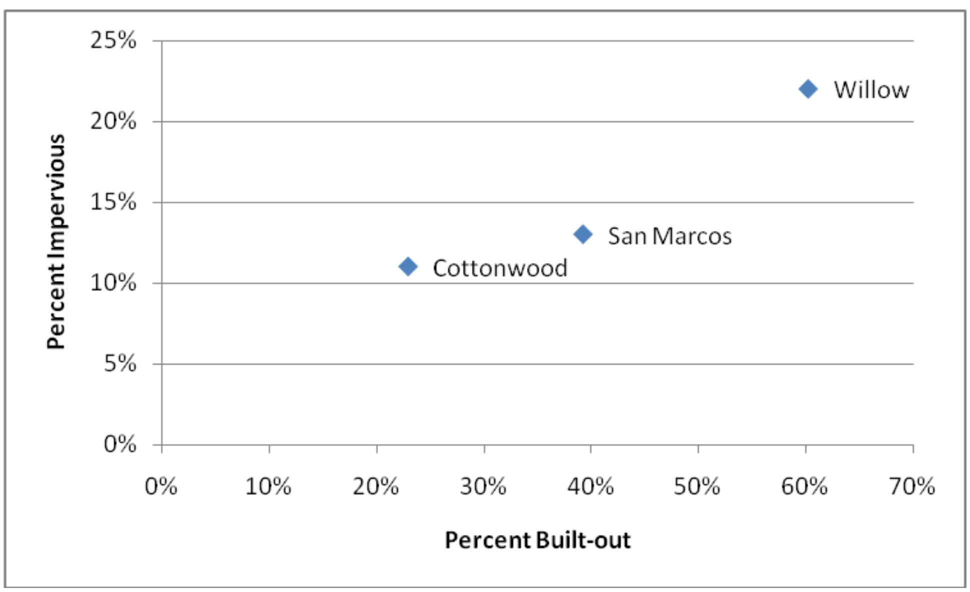
Figure 3.5 shows that, while the Willow Springs and San Marcos watersheds have small amounts of buildable land predominantly located along the outskirts of the watersheds, the Cottonwood Creek watershed has not come close to its build-out potential.According to figure 3.4 the San Marcos stream quality is fair in all three watersheds. Because all three watersheds are not built out to their potential, however, this level of stream quality may not persist when these watersheds reach build out. For example, table 3.2 shows that the percentage of impervious cover in the Willow Springs watershed is 22%, while 32% of the watershed remains buildable. When the remaining buildable land is developed, the percentage of impervious cover will rise.

Table 3.2 Comparison between the Amount of Developed Land and the Percentage of Impervious Cover of the Watersheds

Watersheds	Developed Land	Buildable Land	Total Acres at Build-Out	Percent built-out	Percent Impervious
San Marcos	1390	2152	3542	39%	13%
Cottonwood Springs	1007	3388	4395	23%	11%
Willow Creek	1236	815	2051	60%	22%

Figure 3.6 shows the comparison between the level of build out and the amount of impervious cover in a watershed.

Figure 3.6 The Relationship between Percentage of Impervious cover and the amount of Developed Land in each Watershed



Source: See Description of Data (Appendix A)

It follows that, as a greater percentage of buildable land is developed, the percentage of impervious cover of the watershed increases. The rate at which the percentage of impervious cover increases is dependent on the development policies within the watershed's jurisdiction. Due to the sensitivity of the San Marcos River Corridor (SMRC), some additional attention has been paid to conserving land within this watershed and imposing some limitation on impervious cover levels. According to figure 3.6 the additional scrutiny in this watershed does seem to have made an impact on the rate of change in impervious cover.

While the quantity of buildable acres is an important factor in determining impervious cover at build out, the type of buildable land is also important. The type of buildable land is identified by its land-use designation. Some land uses, such as very low density residential, contribute significantly less impervious cover than intensely developed lots such as a commercial land use.

Policies that attempt to decrease impervious cover in a watershed can either limit the amount of development or the type of development permitted. When considering both the current level of imperviousness as well as the amount of buildable land left in each watershed, the following subhypotheses are drawn about the watershed's level of imperviousness at build out.

Table 3.3Working Hypothesis 1

Working Hypothesis 1: Existing San Marcos development regulations implemented over the long term will result in stream quality that is not consistent with community expectations.
Working Sub-hypothesis 1a. (Willow Springs): Due to the high level of imperviousness, if existing development regulations are implemented over the long term the Willow Springs watershed will move from a fair level of imperviousness to a degraded level.
Working Sub-hypothesis 1b. (San Marcos): Due to the low level of imperviousness and small amount of buildable acres, if existing development regulations are implemented over the long term the San Marcos watershed will remain at the same fair level of imperviousness.
Working Sub-hypothesis 1c. (Cottonwood Creek): Due to the high amount of buildable acres that remain within the Cottonwood Creek watershed, if existing development regulations are implemented over the long term this watershed will move from a fair level of imperviousness to a degraded level.

Conservation Developments – Working Hypothesis 2 Revisited

Conservation developments focus on changing the design of developments without affecting the total amount of development that takes place in a watershed. Recent studies have shown that streets, driveways, and parking lots actually contribute a greater amount of impervious cover to the built environment than rooftops, sidewalks, and walkways (Capiella 2005). Impervious cover dedicated to cars is referred to as *car habitat*. Table 3.4 shows the amount of impervious cover dedicated to car habitat in each of San Marcos' land-use categories.

Table 3.4San Marcos Impervious Cover Dedicated to Car Habitat by Land Use

Land Use	Sample Number	Car Habitat (%)	Building (%)
Commercial	21	56.8	19.4
High Density Residential	15	40.6	20.4
Industrial	10	37.9	21.4
Low Density Residential	23	17.9	21.1
Medium Density Residential	15	25.0	24.4
Mixed Use	10	26.7	18.9
Very Low Density Residential	16	11.7	12.2
Public / Institutional	10	37.7	10.8

Source: see Description of Data (Appendix A)

Innovative design for the car habitat in a community can be an effective way to reduce impervious cover without affecting growth. While there are many benefits to conservation development, this study focuses on conservation development as a method for reducing impervious cover dedicated to car habitat. Conservation development can reduce the amount of car habitat by clustering development on the lot. When development is clustered into a particular area on the lot, density in that region increases while the rest of the lot is left undeveloped. As displayed in table 3.5 the land-use category with the largest number of buildable acres in each of the three watersheds is very low density residential.

Table 3.5 Number of Buildable Acres by Land Use Type and Watershed

Land Use	Willow Springs		San Marcos		Cottonwood Acres	
	Acres	Percent	Acres	Percent	Acres	Percent
Very Low Density Residential	534	65%	2006	93%	1221	36%
Mixed Use	71	9%	51	0%	0	0%
Low Density Residential	52	6%	51	2%	310	9%
Commercial	70	9%	25	1%	640	19%
High Density Residential	10	1%	12	1%	288	9%
Industrial	33	4%	8	0%	622	18%
Public	39	5%	30	1%	53	2%
Medium Density Residential	7	1%	28	1%	252	7%
Total	815		2159		3387	

Source: See Description of Data (Appendix A)

Without a conservation development ordinance, large lots of very low density residential land contribute a significant amount of impervious cover due to the long streets and driveways that are needed to make these homes accessible. If conservation development was enforced on all lots large enough to make the approach practical, the amount of impervious cover due to car habitat could be reduced by as much as 50%. However, other factors, including the size of the original lot and the design of the street network, affect the amount of savings realized by conservation development (Center for Watershed Protection 1995, 61). Larger original lots with well-designed street networks will reduce the percentage of impervious cover more effectively than smaller lots with poorly designed street networks; as the original lot size increases, the potential for savings increases. When 50% or more of a lot is left undeveloped, road networks have half as much ground to cover. As lot sizes diminish, the length of driveways also diminishes.

The three watersheds analyzed in this study have a large percentage of very low density residential land that would be affected by a conservation development ordinance. But implementation of these types of restrictions involves complex policy analysis. The design of the ordinance plays a large role in its success in a community. In a study of the compatibility of conservation development in the Blanco River Basin, which includes San Marcos, Ron Ellis found "that residential land use policies are generallyincompatible with conservation development, but that alternative policy methods existthat may be able to permit its practice"(Ellis, 2006). The effort involved in developing a conservation development ordinance is worth the trouble if enough savings are realized in impervious cover levels.

A benefit of conservation development ordinances is that growth is not affected. The same number of homes can be placed on the lot while the individual lot sizes shrink. For example, where very low density zoning in San Marcos requires a minimum lot size of two acres, a conservation development would maintain the same number of homes but decrease the lot size to one acre; thus 50% of the lot is conserved. Conservation development ensures that the conserved land is left in its natural state through conservation easements or other forms of binding deed restrictions. Using this form of watershed protection can decrease impervious cover without affecting economic growth. Table 3.6 describes working hypothesis 2 and its sub-hypotheses.

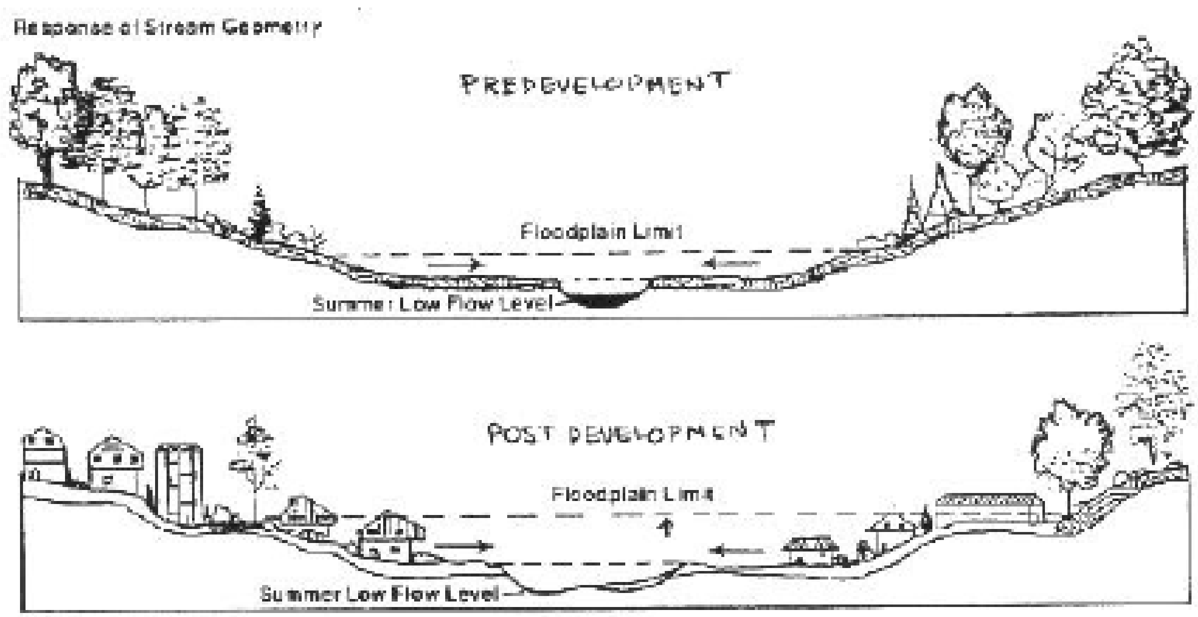
Table 3-6 Working Hypothesis 2

Working Hypothesis 2: Conservation development ordinances will result in water quality that is more consistent with community expectations.
Working Sub-hypothesis 2a. (Willow Springs): Due to the percentage of buildable land appropriate for conservation developments the Willow Springs watershed will experience some improvement in the level of imperviousness when a conservation development ordinance is in place.
Working Sub-hypothesis 2b. (San Marcos): Due to the percentage of buildable land appropriate for conservation developments the San Marcos watershed will experience significant improvement in the level of imperviousness when a conservation development ordinance is in place.
Working Sub-hypothesis 2c. (Cottonwood Creek): Due to the percentage of buildable land appropriate for conservation developments the Cottonwood Creek watershed will experience little improvement in the level of imperviousness when a conservation development ordinance is in place.

Prohibit Building in the Floodplain – Working Hypothesis 3 Revisited

Prohibiting development within the 100-year floodplain serves multiple purposes when trying to protect water quality. First, this approach provides for more conserved land. "Natural area conservation accomplishes the objective of no net increase in pollutant loadings byrestricting development activities that would generate these additional pollutant loadings" (Naismith Engineering Inc. 2005, 107). Conserving land in a watershed provides benefits to the water quality by decreasing the amount of impervious cover that is possible in the watershed. A second benefit of restricting development in the 100-year floodplain is that this natural area creates a stream buffer. Stream buffers assist in removing pollutants from runoff water. Due to the number of factors involved, there has not been enough research done to ascertain the average amount of pollution removal that could be applied to this study. A third benefit to restricting development within the 100-year floodplain is that it prevents peak discharge rates from increasing. This phenomenon is displayed in figure 3.7.

Figure 3.7 Movement of the 100-Year Floodplain



Source: The Center for Watershed Protection 2005, 36

Figure 3.7 clearly shows how allowing development within a floodplain can raise the level of the floodplain; thereby endangering property and lives, and creating an enormous financial burden on the community.

The City of San Marcos allows development within the floodplain as long as the structure is raised to one foot above the 100-year floodplain. The following diagram (figure 3.8) comes from the city's Land Development Code.

Figure 3.8 City of San Marcos Floodplain Development Policy

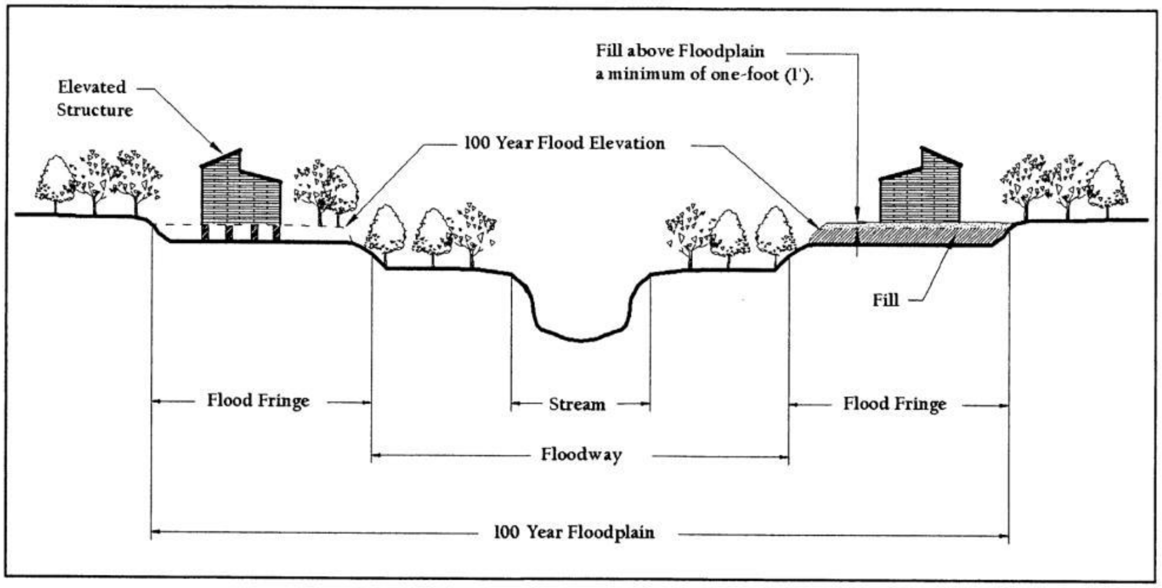
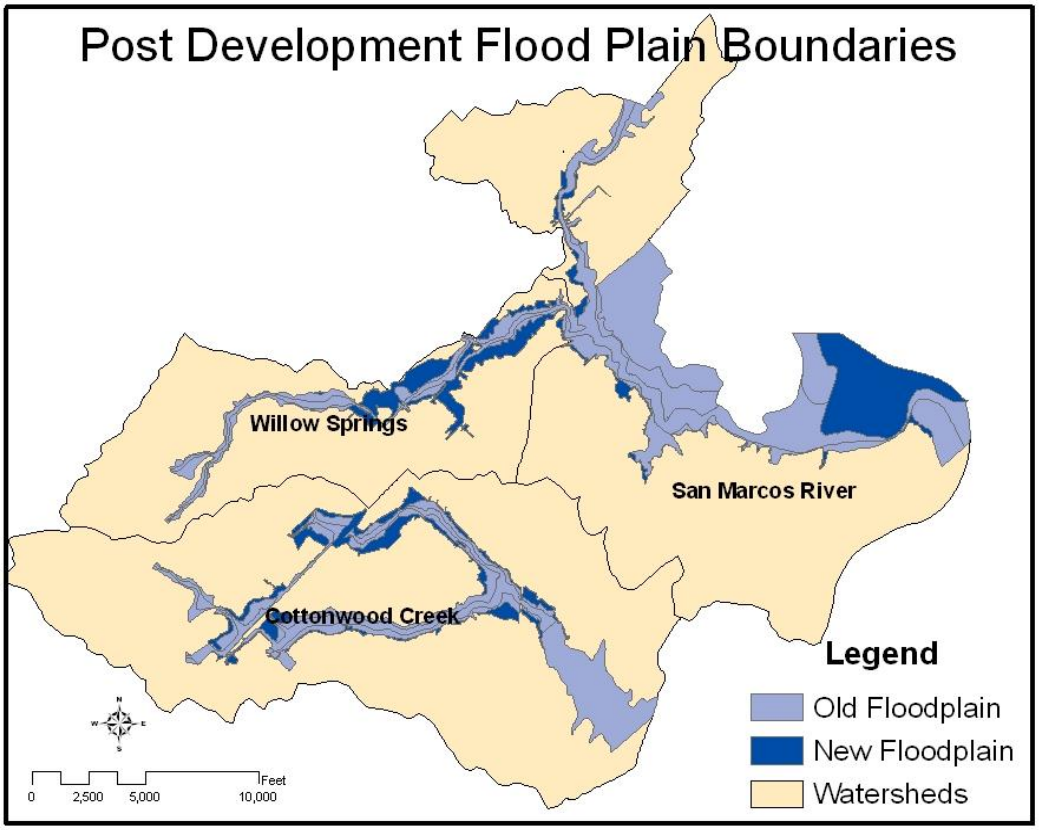


Figure 5-1: Illustration of 100-Year Floodplain Elevation

Source (City of San Marcos 2008, 5.1)

When fill is brought in to raise the floodplain for development less room is left for water during a flood. This is one key cause of the widening of the 100 year floodplain. Due to development within the floodplain, new floodplain data raises the 100-year floodplain in several areas throughout all three watersheds. Figure 3.9 displays the current 100-year floodplains under the old floodplains to show which floodplains have been affected and where.

Figure 3.9 New 100 Year Floodplain Boundaries



Source: see Description of Data (Appendix A)

Floodplains have been dramatically affected in the Willow Springs and Cottonwood Creek watersheds. An increase in peak discharge rates occurs when impervious cover increases anywhere within a watershed, however development within the floodplain leaves less room for this discharge and thus the floodplain is widened.

While restricting development in the floodplain serves social and environmental purposes, it hinders growth when an entire parcel is located within a floodplain. Prohibiting development on a parcel is equivalent to a taking, and the city would be responsible for buying any properties that are located completely inside the 100-year floodplain. For properties that are partially within the floodplain, density transfers or other programs can be utilized to make these parcels buildable. Table 3.7 shows how many parcels would be affected in each of the three watersheds.

Table 3.7 Benefits of Restricted Floodplain Development per Watershed

Watershed	Parcels in Floodplain	Acres in Floodplain
Willow Springs	44	135
San Marcos	29	474
Cottonwood Creek	1	974

Source: see Description of Data (Appendix A)

The effectiveness of a policy that restricts development in the floodplain would have to conserve a large percentage of the watershed while requiring that few properties be rendered unbuildable. Table 3.8 summarizes working hypothesis three and its sub-hypotheses.

Table 3.8 Working Hypothesis 3

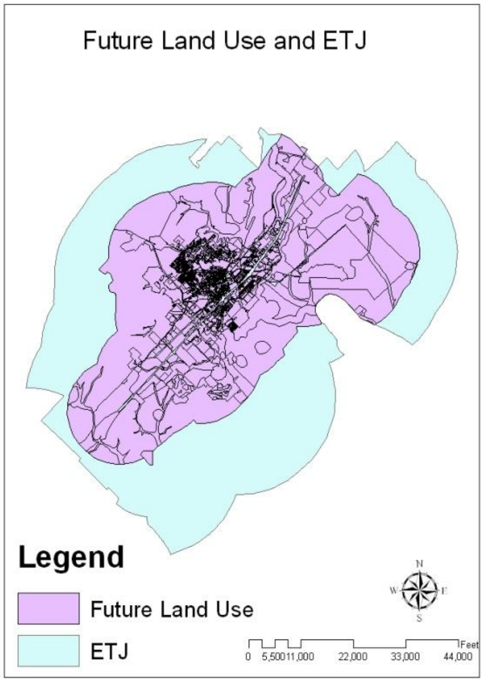
Working Hypothesis 3: Restricting floodplain development will result in water quality that is more consistent with community expectations.
Working Hypothesis 3 (Willow Springs): Restricting floodplain development in the Willow Springs watershed will result in a policy that is not consistent with community expectations.
Working Hypothesis 3 (San Marcos): Restricting floodplain development in the San Marcos watershed will result in a policy that is consistent with community expectations.
Working Hypothesis 3 (Cottonwood Creek): Restricting floodplain development in the Cottonwood Creek watershed will result in a policy that is significantly more consistent with community expectations.

Chapter 4. Methodology

The methodology for this research used a build-out map to analyze the imperviousness of three watersheds in San Marcos under three different policy scenarios. The map was constructed using GIS technology. This chapter outlines the five general steps involved in preparing a build-out map with GIS technologies. The specific methods used to analyze the three different hypothetical watershed protection policies are outlined in step six. Finally, the connections between the working hypotheses and data collection are made explicit.

Build-out maps rely on data accuracy and availability. Data availability limited this study to three of the seven watersheds in San Marcos. If zoning maps are expanded to cover San Marcos' extra territorial jurisdiction (ETJ), more watersheds may be considered for build-out analysis.The City of San Marcos has not designated a land-use category for its entire ETJ; figure 4.1 shows how the future land-use zoning boundary fits within San Marcos' ETJ. One of the difficulties in protecting stream quality is that water does not follow jurisdictional boundaries. When trying to administer programs for sensitive environmental regions, regulations must cover several jurisdictions.

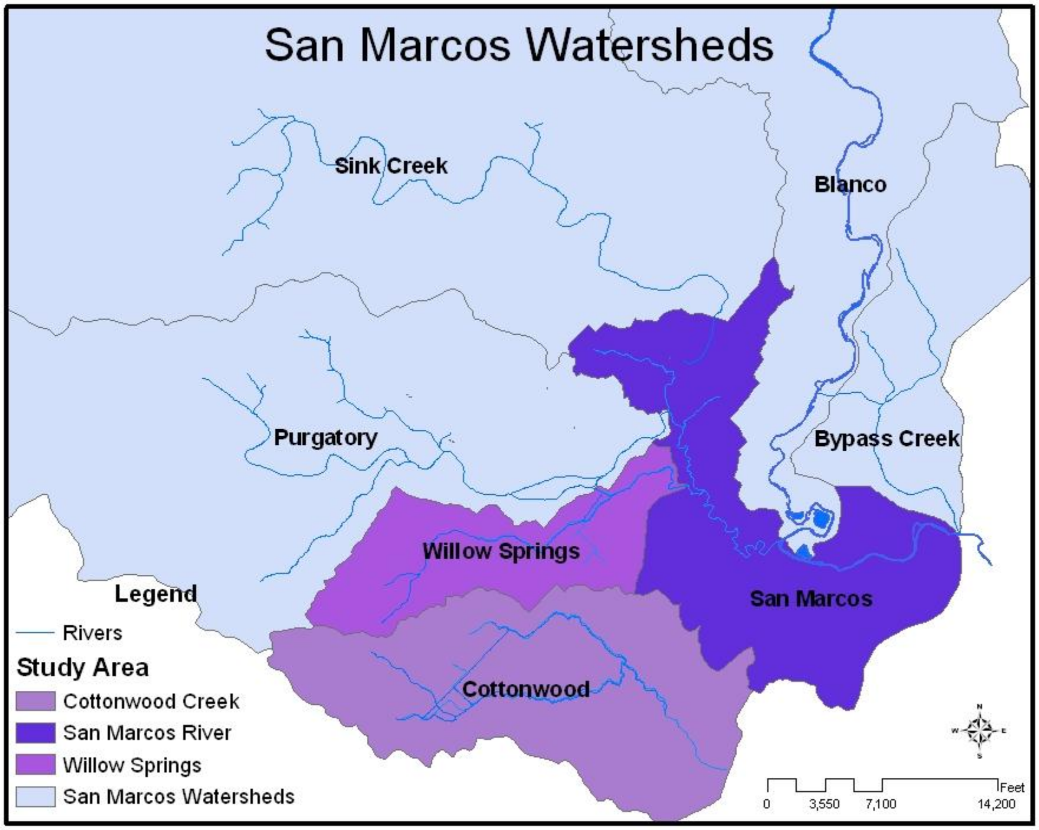
Figure 4.1 Future Land Use and ETJ Map



Source: See Description of Data (Appendix A)

A watershed comprises all of the land that contributes to a certain river or segment of a river. Watersheds can be broken up into subwatersheds to further evaluate the hydrologic system. There are seven different watersheds in San Marcos. For the purposes of this study, three watersheds were chosen and are displayed in figure 4.2. The three watersheds are the San Marcos, Cottonwood Creek, and Willow Springs watersheds. These three watersheds were chosen based on data availability.

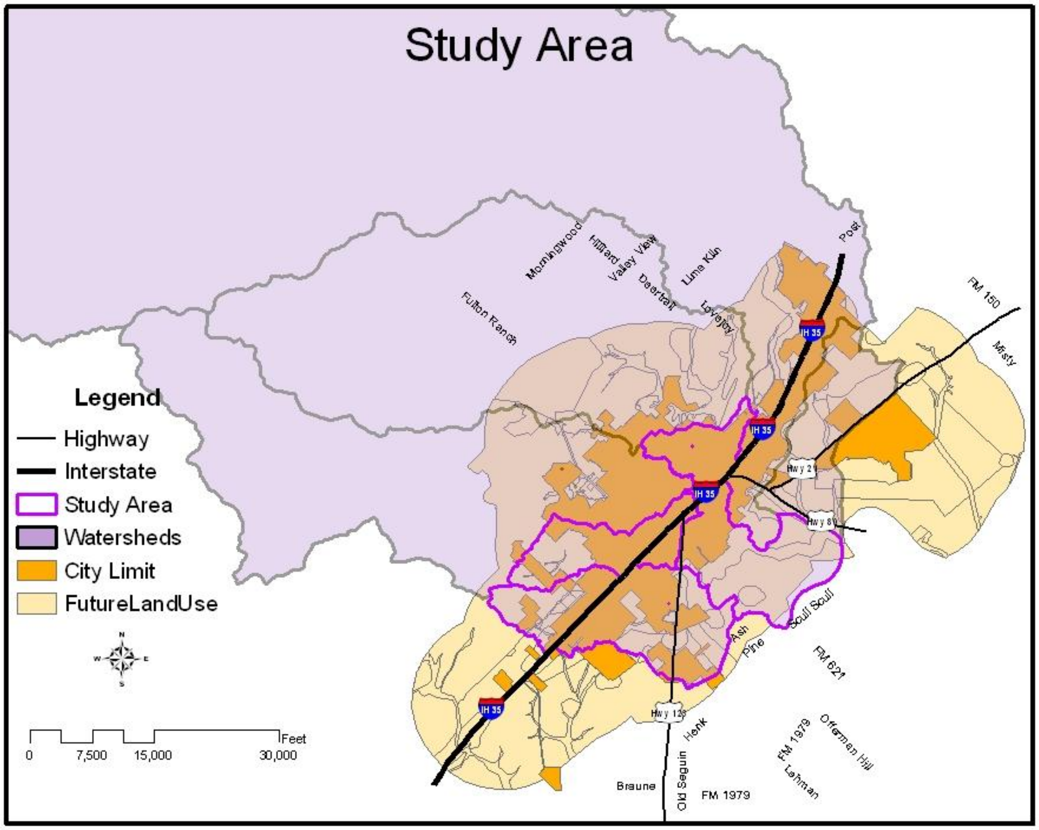
Figure 4.2 San Marcos Watersheds and Study area



Source: see Description of Data (Appendix A)

Figure 4.3 shows the three chosen watersheds, the city of San Marcos, and the region that is currently zoned for future land use. Location was an important factor since future impervious cover scenarios are based on the land-use type. One watershed that is completely within the future land-use zoning area, but which was eliminated from the study, is the Blanco Bypass watershed. This watershed was eliminated because the stream quality within this watershed is predominantly influenced by the Blanco River, which is located in a different jurisdiction up stream.

Figure 4.3 Study area and City Limit



Source: See Description of Data (Appendix A)

The methodology for this research consisted of six steps derived from the methodologies of other build-out maps(Arnold 2000; The Center for Watershed Protection 2000).These steps are listed below then described in detail as they pertain to the city of San Marcos.

1. Identify the land use code for each parcel.

2: Identify developed and undeveloped parcels.

3. Identify and subtract protected land from undeveloped land for each zoning category.

4. Calculate the area of each zoning category for developable land in each watershed.

5. Derive impervious cover coefficients by zoning category.

6. Use the impervious cover coefficients to determine the percentage of impervious cover in each watershed assuming the four different scenarios (Arnold 2000; CWP 2005).

Step 1: Identify the land-use code for each parcel

Each parcel in the study area must be categorized for a particular land use. Because the study area extends outside the city limits, the City of San Marcos zoning map does not apply to all of the study area. The city's future land use map, however, does cover the entire study area. The future land use map was used to identify the land-use code of each parcel in the study area. This was accomplished by extracting a point at the center of each parcel in the study area called a *centroid*. The GIS was then asked to interpolate the land-use category for each centroid. When the centroid and parcel tables were joined, each parcel was given a future land-use code.

San Marcos' future land use map combines several zoning districts into eight different general land uses. Table 4-1 identifies the land-use category, its code, description, notes, and the City of San Marcos zoning districts that are included in that category.

Table4.1Classification of Land Use Categories for the Purposes of this Study

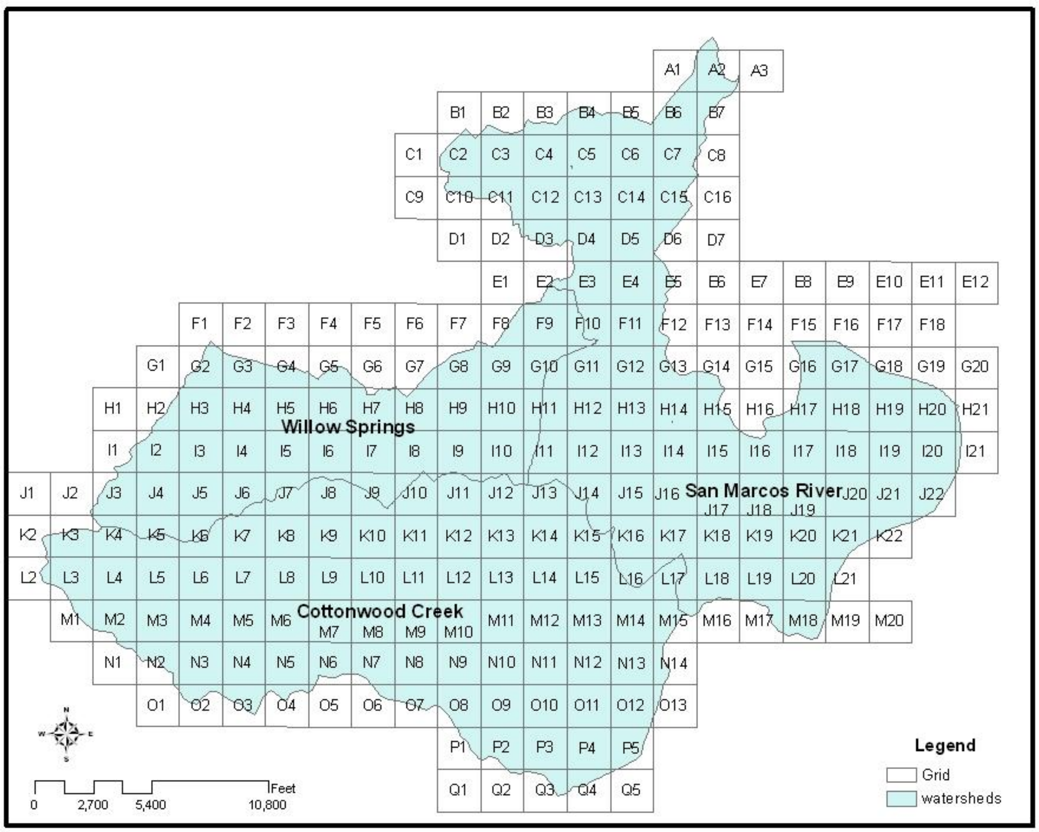
Code	Description	Notes	San Marcos Zoning Districts included
C	Commercial	Area generally used for the sale of goods and services	Office Professional Neighborhood Commercial Community Commercial General Commercial Heavy Commercial Central Business Area
I	Industrial	Areas associated with manufacturing and storage of goods	Light Industrial Heavy Industrial
MU	Mixed Use	Combines residential with non-residential activities. Designed to promote pedestrian traffic	Mixed Use PDD Overlay District
P	Public/ Institutional	Includes government, civic, or public service activities including Texas State University	Public
HDR	High Density Residential	Multifamily Apartments	Multi-Family Residential-18 (dwelling units/acre) Multi-Family Residential-24 (dwelling units/acre)
MDR	Medium Density Residential	Residential use of either small lot single family detached or apartments at not more than 12 units per acre.	Single Family 4.5 (4,500 ft lots) Duplex Restricted Townhouse Residential Patio-Home Zero Lot Line Residential Multi-Family Residential-12 (dwelling units/acre)
LDR	Low Density Residential	Single family detached residential activities with less than 6 dwelling units per acre.	Single Family-11 (11,000 square foot lots) Single Family-6 (6,000 square foot lots) Duplex Residential
VLD	Very low Density Residential	Large lot single family development.	Future Development Agricultural Ranch Rural Residential

Source: (City of San Marcos, 2008)

Step 2: Identify developed and undeveloped parcels.

San Marcos had no data that identified parcels as developed or undeveloped. Hence, it was necessary to identify developed and undeveloped parcels individually. To help ensure accuracy, a 2,000 by 2,000 square foot grid was draped over the study area. The grid was projected over aerial photos shot in October of 2006. Figure 4.4 displays the grid that was used as well as the name of each cell.

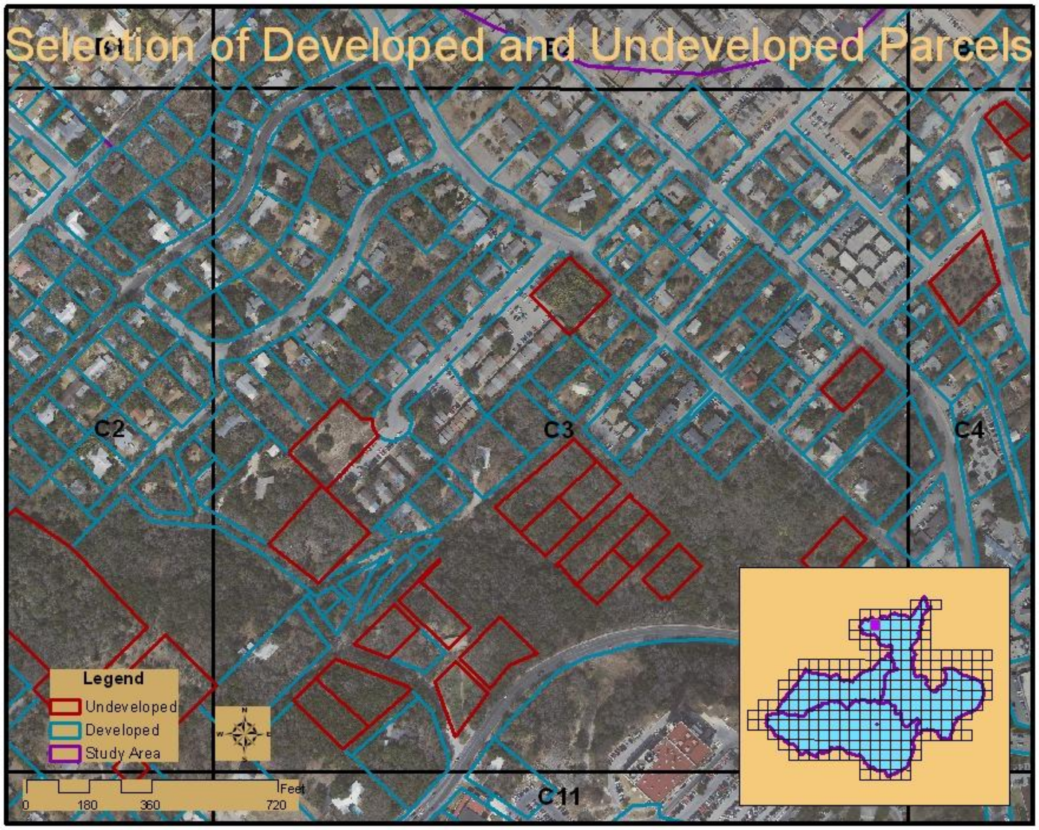
Figure 4.4 Grid Used for Identification of Developed and Undeveloped Parcels



Source: see Description of Data (Appendix A)

Each square was analyzed independently for undeveloped parcels. Every parcel was categorized as either developed (DEV) or undeveloped (UnDev) in the attribute table.

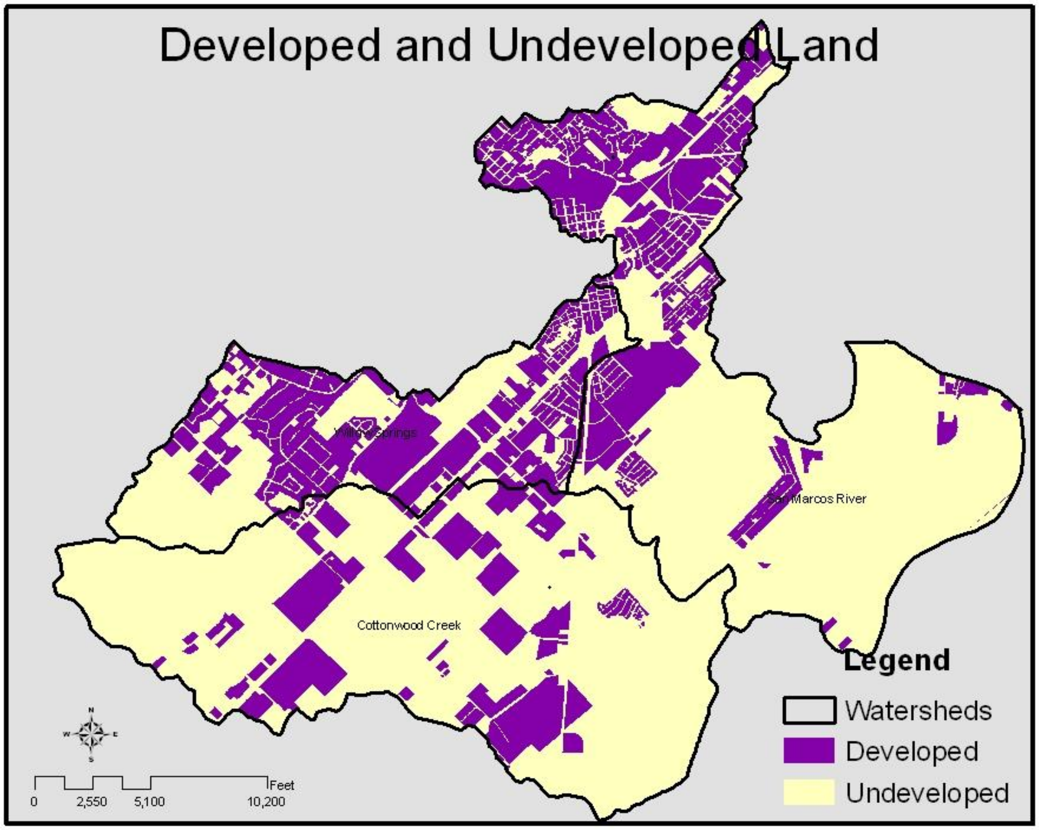
Figure 4.5 Selection of Developed and Undeveloped Parcels



Source: see Description of Data (Appendix A)

Figure 4.5 displays the selection of undeveloped parcels show in cell C3 of figure 4.5. Two new layers were created from the parcel data, one containing developed parcels and the other containing undeveloped parcels. Figure 4.6 displays these two layers.

Figure 4.6 Map of Developed and Undeveloped Land

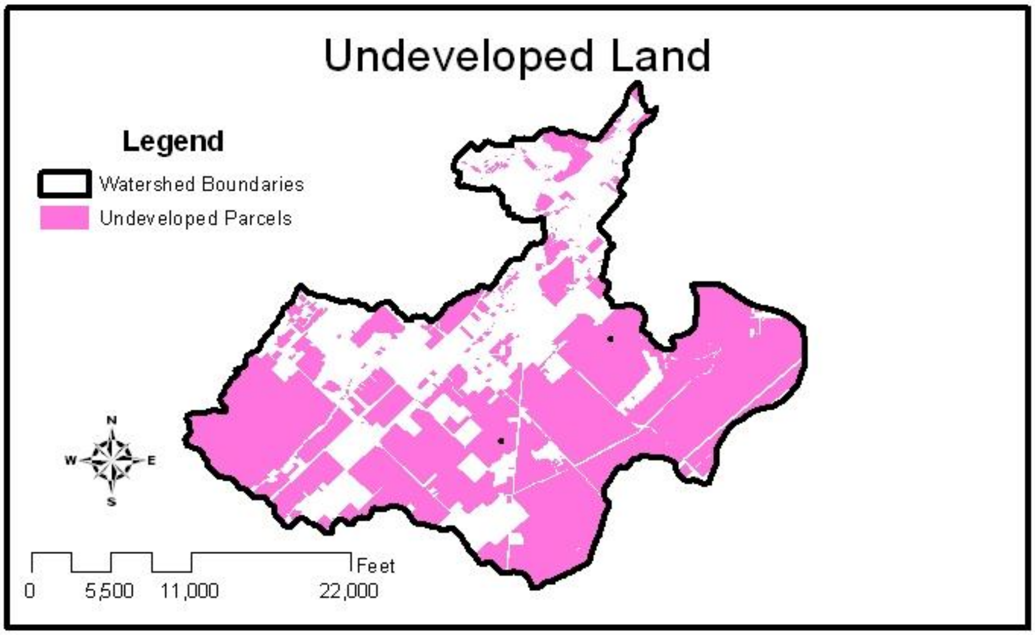


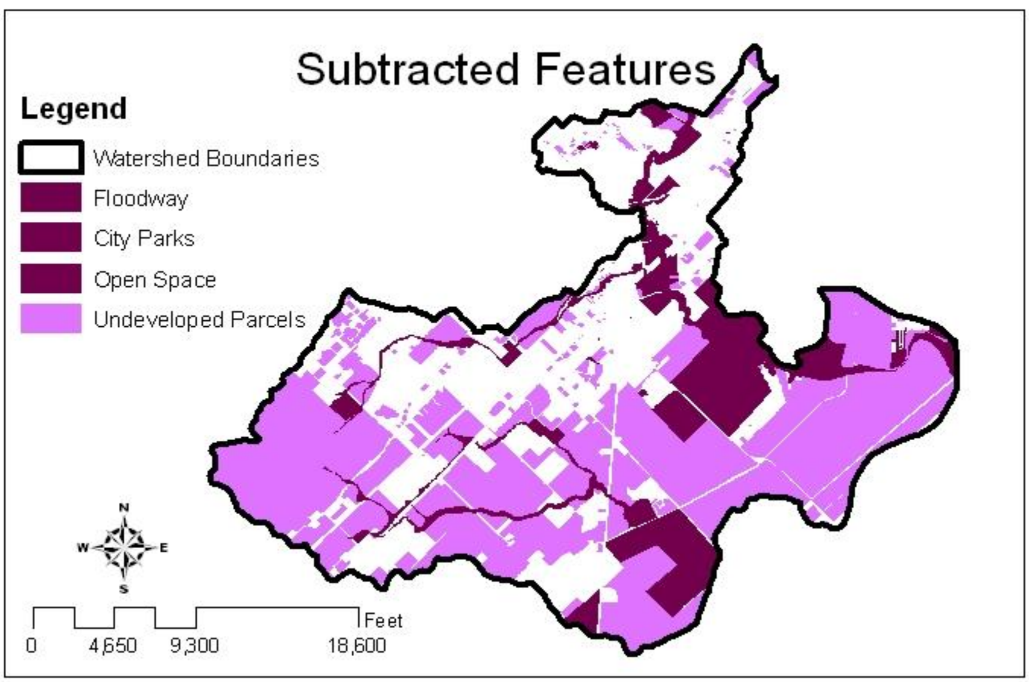
Source: see Description of Data (Appendix A)

Step 3: Identify and subtract protected land from undeveloped land

Not all undeveloped land will eventually be developed. Hence, this step involved identifying land that will not be developed because it is reserved as open space, parks,or flood way. After land where development is prohibited was identified, it was erased from the map. When city parks or land zoned as open space are erased the entire parcel disappears, however, when floodways are erased, parcels may be split in two or shrunk to a smaller size. In this case only the area that remains is buildable. Figure 4.7 shows the process of establishing a buildable land layer.

Figure 4.7 Process for Identifying Buildable Land from Undeveloped Land





Source: See Description of Data (Appendix A)

Buildable land is undeveloped land that has the potential of being converted to developed land. The open-space land use category in San Marcos is not necessarily land that is protected from development; however, for the purposes of this study, open space was not included as buildable land. Open space represents the amount of land that may be conserved in the future. Currently, San Marcos uses different initiatives to conserve parkland; this study assumed that those practices will continue. Hence, the open space land-use category represents future conservation efforts.

Step 4: Calculate the area of each land-use category for developed and buildable land in each watershed.

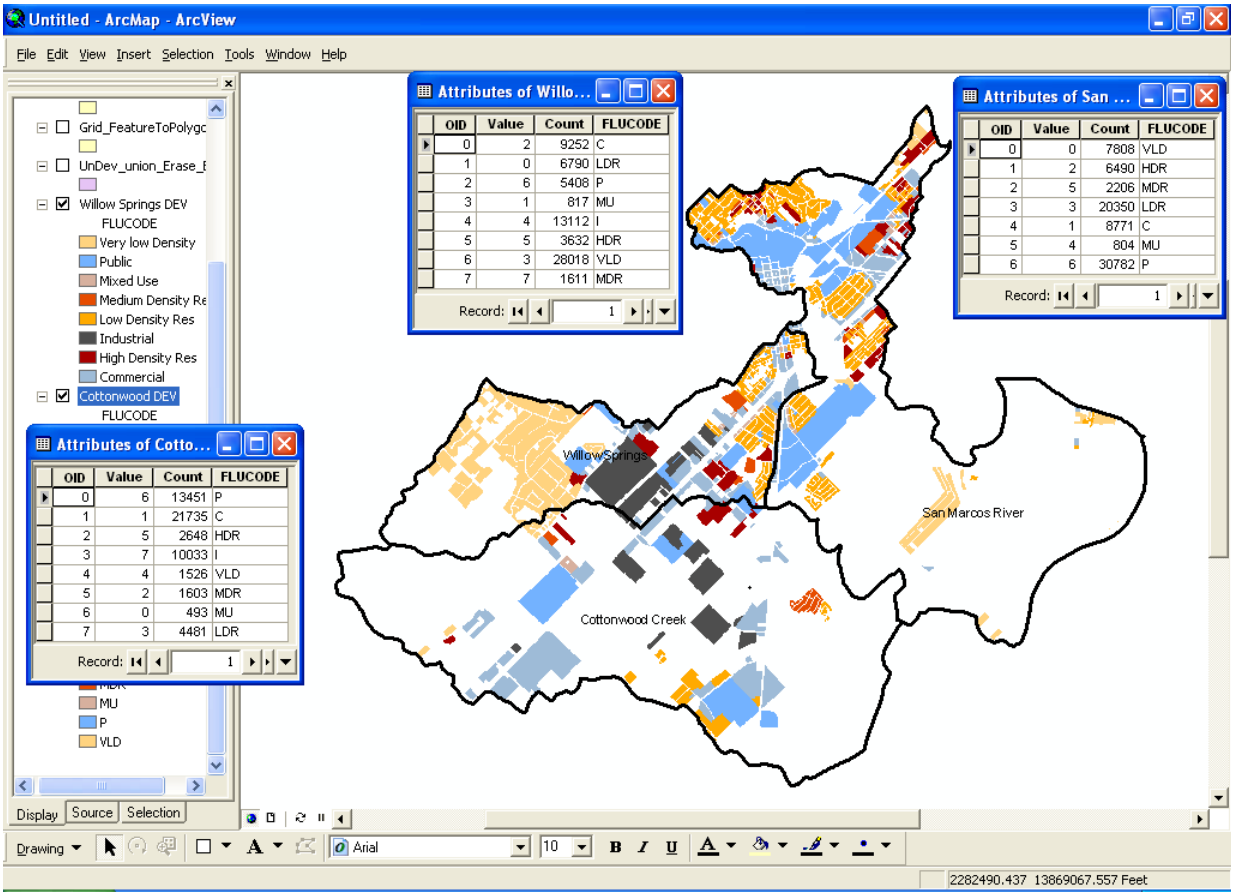
The map is made up of individual cells. The cell size was set to 30 feet in this study. In the attribute tables for each watershed there is a column labeled "count"; this refers to the number of cells in each land-usecategory. Each cell is 30 feet by 30 feet or 900 square feet. Thus the area in acres for each land-use category is calculated with the following equation: $A_{lu} = (900 * C_{lu}) * .00002$

Where:

A_{lu} = Acres by land-use type

C_{lu}= Count by land-use type

Figure 4.8 Explanation of how Area is Determined



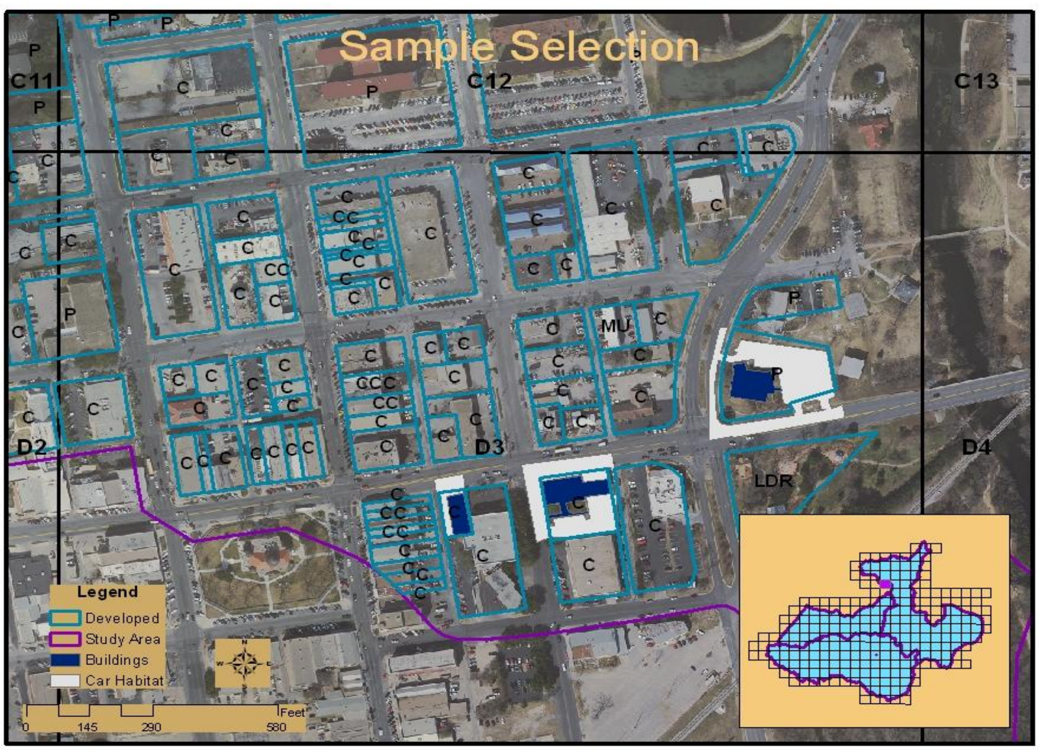
Source: see Description of Data (Appendix A)

Step 5: Determine impervious cover coefficients by land-use category

Methods for calculation of existing impervious cover vary in complexity, timespent, and accuracy (Bird 2000). Four general techniques are used to estimate impervious cover: direct measure, land use, road density, and population. Each technique varies in accuracy, effort, utility for forecasting, and utility to address different policies. While there have been many different methodologies used to estimate impervious cover, for the purpose of this report, coefficients for impervious cover are based on land use(Center for Watershed Protection 2000; Sleavin 2002; Capiella 2005). This technique was chosen because of its utility in forecasting and policy analysis. The accuracy and effort involved in using this technique are both moderate in comparison to some of the other techniques. The coefficients were derived for this specific area through a determination of impervious cover in a predetermined number of different sample areas in each land-use category (Bird 2000).

To derive impervious cover coefficients, a sample of individual parcels has to be taken. The method displayed in Figure 4.9, for choosing a sample was to use the same 2,000 by 2,000 square foot grid and select a roughly representative sample of land uses from each individual cell in the grid. This method was chosen so that the sample would be geographically distributed throughout the study area. The first law of geography says that objects closer to each other are more alike (Tobler 1970); thus a sample that is geographically dispersed is more representative.

Figure 4.9 Example of Sample Selection

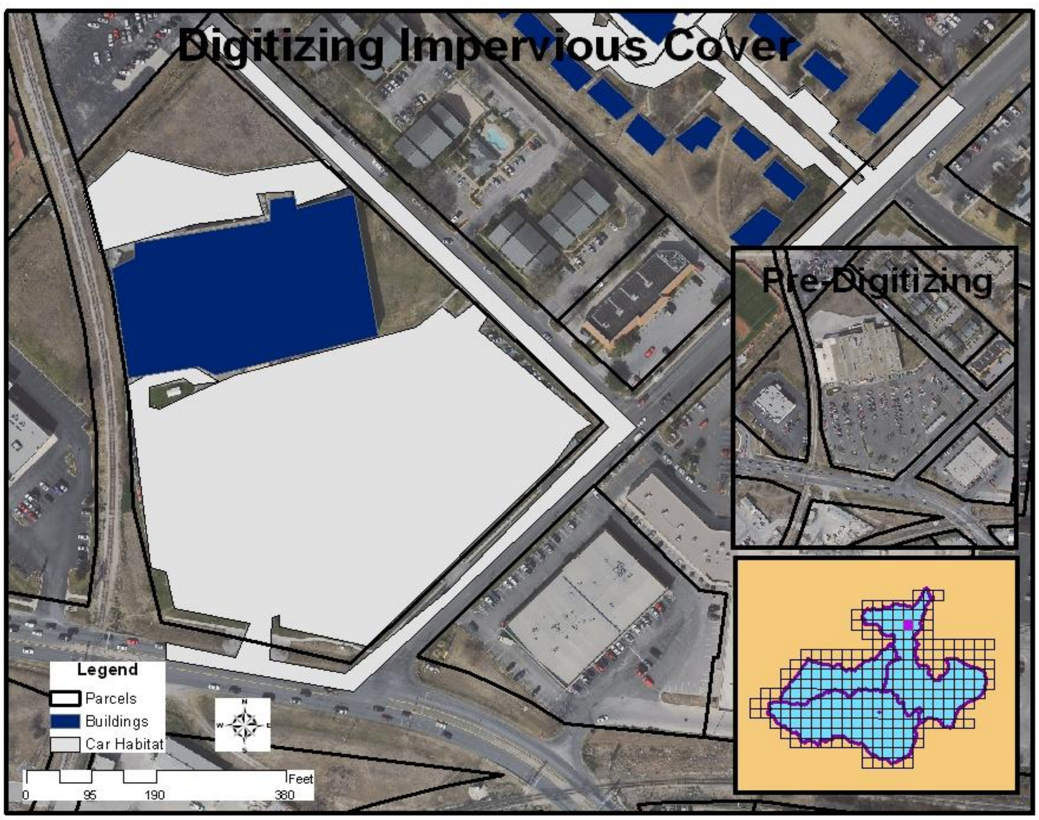


Source: See Description of Data (Appendix A)

Figure 4.9 depicts grid cell D3. This cell, which is in the Willow Creek watershed, contains mostly commercial land parcels. A selection of two commercial parcels and one public parcel were chosen as samples. The two commercial parcels were chosen because cell D3 is predominantly commercial. The public land-use category was chosen because the public land use designation is infrequent within the study area, but must be considered.

After the parcels were selected impervious cover including roofs, walkways, and patios were digitized into one layer. Impervious cover including roads, driveways, and parking lots were digitized in another layer. An example of this is shown in figure 4.10.

Figure 4.10 Digitizing Example



Source: See Description of Data (Appendix A)

When parcels are developed on both sides of a street, the car habitat of the sample includes half of the street that serves that parcel. This method enables the impervious cover coefficient to account for the road network that serves developed parcels. Because the impervious area of these samples included land that is outside of the parcel boundary, the total area was measured separately for each sample. Separating the two types of impervious cover allows an analysis of the percentage of impervious cover dedicated to car habitat. The formula used to calculate the mean impervious cover for each land-use type based on the samples taken was: Tia/n = IC

Where:

T_{ia} = Total impervious area

n = sample size

IC = Impervious cover coefficient or Mean impervious cover

Table 4-2Impervious Cover Coefficients by Land Use Category

Land Use	Sample Number	Mean Impervious Cover + (S.E)	Notes
Commercial	21	76.2%± 3.0	
High Density Residential	15	61.0%± 3.2	
Industrial	10	59.3%± 6.6	
Low Density Residential	23	39.0%± 2.7	Parcels from 4.5 to 1 dwelling unit per acre
Medium Density Residential	15	49.4%± 2.9	Includes mobile home parks, town homes and duplexes
Mixed Use	10	45.5%± 4.7	
Very Low Density Residential	16	23.9%± 3.0	Parcels greater than two acres
Public / Institutional	10	48.5%± 6.1	Includes schools, churches, government buildings and the University
Total	120	N/A	

Source: See Description of Data (Appendix A)

Parcels with dense tree cover could not be used as sample parcels because impervious cover was not visible in the aerial photograph. Error can also be introduced in the digitizing process when parcels are large and the image is zoomed out further. When digitizing smaller parcels, the accuracy is better because the scale is larger. As shown in table 4.2 the low-density residential category has the lowest standard error. Standard error is low when the percentage of impervious cover for all parcels in a particular land-use category is consistent. Another area where accuracy may be compromised is in the public land-use category; this is due to the presence of Texas State University. The entire university is one large parcel in the public land-use category. This parcel was different from other parcels in the land-use category, but because of its size digitizing the entire campus was outside of the scope of this project. Other parcels in the public land-use category include schools, churches, and government buildings. A few parcels from the university that were separate from campus were also able to be digitized for this category. Land-use categories that were geographically segregated, such as the industrial and commercial land uses, had more than a representative number of samples selected in densely populated grids so that there would be a large enough number of samples for analysis.

Step 6: Use the impervious cover coefficients to determine the percentage of impervious cover in each watershed assuming the three different scenarios.

This step was split into three different sections according to the three different working hypotheses. The method and evidence used to test the working hypotheses are summarized in three separate operationalization tables (tables 4.3, 4.4, and 4.5). The formulas and methodologies for each of the scenarios are then presented and discussed.

Working Hypothesis 1- Current policies

The following operationalizationtable (table 4.3)displaysworking hypothesis 1 and compares current conditions with hypothesized conditions at build out.

Table 4.3Operationalization of Hypothesis 1

Hypothesis 1: Existing San Marcos development regulations implemented over the long term will result in water quality that is not consistent with community expectations.		
Sub hypotheses	**Current Conditions**	**Hypothesized Build-out Conditions**
Working Sub hypotheses 1a (Willow Springs): If existing development regulations are implemented over the long term the Willow Springs watershed will move from a fair level (yellow, 11%-25% impervious) of stream quality to a degraded level (red, >25% impervious).	Impervious cover: 22% Stream quality: Fair (yellow)	Impervious cover: increases by 4% + Stream quality: Degraded (red)
Working Sub hypotheses 1b (San Marcos): If existing development regulations are implemented over the long term, the San Marcos watershed will remain at the same fair level (11% - 25%) of imperviousness.	Impervious cover: 13% Stream quality: Fair (yellow)	Impervious cover: increases by <13% Stream quality: Fair (yellow)
Working Sub hypotheses 1c (Cottonwood Creek): If existing development regulations are implemented over the long term the Cottonwood Creek watershed will move from a fair level (yellow, 11%-25% impervious) of stream quality to a degraded level (red, >25% impervious).	Impervious cover: 11% Stream quality: Fair (yellow)	Impervious cover: increases by 14%+ Stream quality: Degraded (red)

A build-out map is a map that represents what a community will look like when all of its buildable land has been converted according to its current land-use policies and zoning regulations (Arendt 1999). There are several assumptions made when constructing a build-out map, including:

- Full buildout of the watershed occurs based on allowable zoning (e.g., no rezoning)
- Current land cover on developed land remains the same in future build-out scenario unless specific land cover changes are identified in the watershed protection scenario (e.g., reforestation, removal of impervious cover)
- Protected land remains the same in future build-out scenario

- Buildable land will be converted to impervious cover as dictated by current land use regulations(Center for Watershed Protection 2000).

Land use based impervious cover coefficients derived in step 5 allow a simple calculation of future impervious cover levels by watershed. The formulas used to obtain estimates of future impervious cover are: $A_{blu}*ICC_{lu} = A_{IC}$

Where:

A_{blu}= Area of buildable square feet in land-use category

ICC_{lu} = Impervious cover coefficient by land-use category

A_{IClu} = Area of impervious cover in that land-use category

After the area of impervious cover is generated for each category the imperviousness of the watershed is calculated with the following formula:

$(T_{IA}/T_{WA})*100 = IC\%$

Where:

T_{IA} = Total area of buildable impervious cover + current impervious cover

T_{WA} = Total watershed area

IC = Impervious cover percentage

The impervious cover percentage in a watershed is the indicator of stream quality: 0%-10% is good (green), 11%-25% is fair (yellow), >25% is degraded (red).

Working Hypothesis 2 – Conservation Developments

Criteria used to explore the consequences of hypothetical conservation development policies on San Marcos' impervious cover and stream quality are summarized in table 4.4. In working hypotheses two and three all assumptions remain the same except the last assumption, which states that "Buildable land will be converted to impervious cover as dictated by current land use regulations" (Center for Watershed Protection 2000).

Table 4-4Operationalization of Hypothesis 2

Working Hypothesis 2: Conservation development ordinances will result in stream quality that is more consistent with community expectations.		
Sub hypotheses	**Conditions under Working Hypothesis 1 at build-out**	**Hypothesized Conditions under a Conservation Development Ordinance**
Working Sub hypotheses 2a (Willow Springs): The Willow Springs watershed will experience some improvement in the level of imperviousness when a conservation development ordinance is in place; as compared to working hypothesis 1a(see Table 4-3) where current policies persist.	Stream quality: Degraded	Stream quality: Fair
Working Sub hypotheses 2b (San Marcos): The San Marcos watershed will experience some improvement in the level of imperviousness when a conservation development ordinance is in place; as compared to working hypothesis 1b(see Table 4-3) where current policies persist..	Stream quality: Fair	Stream quality: Fair
Working Sub hypotheses 2c (Cottonwood Creek): The Cottonwood Creek watershed will experience some improvement in the level of imperviousness when a conservation development ordinance is in place; as compared to working hypothesis 1c(see Table 4-3) where current policies persist..	Stream quality: Degraded	Stream quality: Fair

The Center for Watershed Protection studies (1995) showed that well-designed conservation development policies decrease the amount of car habitat in a development by up to 50%. The possible 50% reduction is based on two assumptions made in this study: new conservation developments will have efficiently designed street networks that focus on minimizing the amount of impervious cover due to car habitat, and the lots are large enough to accommodate a significant amount of savings in impervious cover. The method used to accommodate the second assumption is to select parcels from the very low density residential category. This method is used because conservation developments are most commonly utilized in scenarios involving large lot zoning. Further considerations include the exclusions of very low density residential parcels that are smaller than ten acres.

The formula used to calculate the impact of a conservation development ordinance on percent impervious cover is: $T_{IAb} - [(A_{vld} * IC_c)/2] = T_{IAc}$

Where:

T_{IAb} = Total impervious area at build-out

A_{vld} = Area of very low density applicable to policy

IC_c = Impervious cover coefficient from car habitat

T_{IAc} = Total impervious area under a conservation development policy

The total impervious area in the watershed is then divided by the total area of the watershed equaling the percentage of impervious cover of the watershed described by the formula: $(T_{IAc}/T_{WA}) * 100 = IC_{\%}$.

Where:

T_{IAc} = Total impervious area under a conservation development policy

T_{WA} = Total watershed area

IC =Percentage of impervious cover of the watershed

The impervious cover percentage in a watershed is the indicator of stream quality: 0%-10% is good (green), 11%-25% is fair (yellow), >25% is degraded (red).

Working Hypothesis 3- Prohibition on Floodplain Development

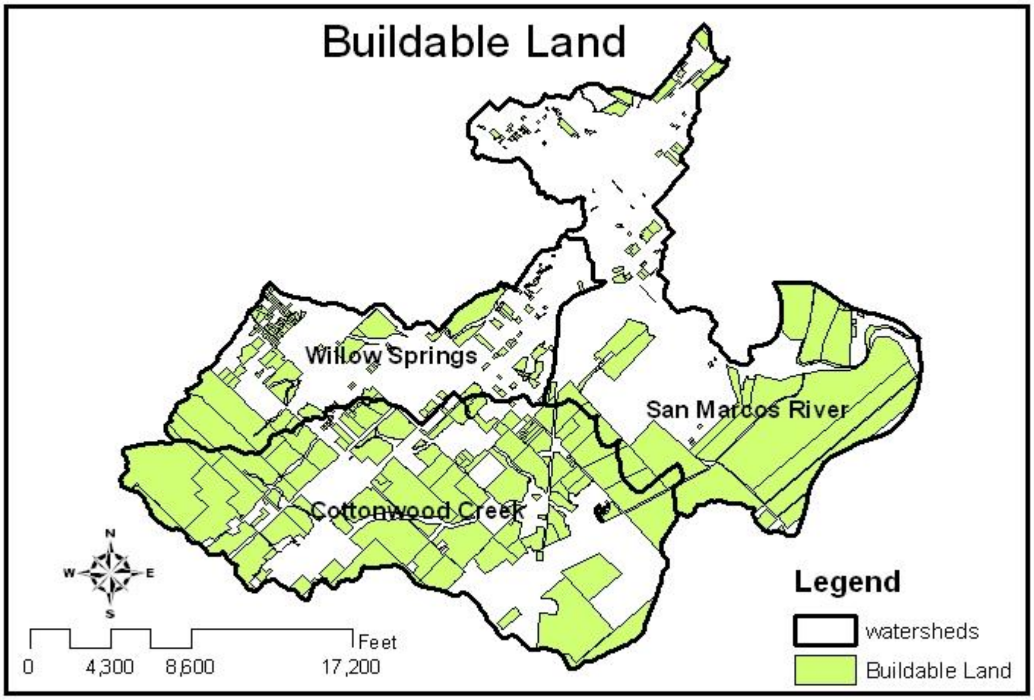
The third policy analyzed was a prohibition on development in the floodplain. Prohibiting new development in the floodplain effectively conserves land from development. The effectiveness of a prohibition on development in the floodplain is contingent on how much of the area is conserved as part of the floodplain.

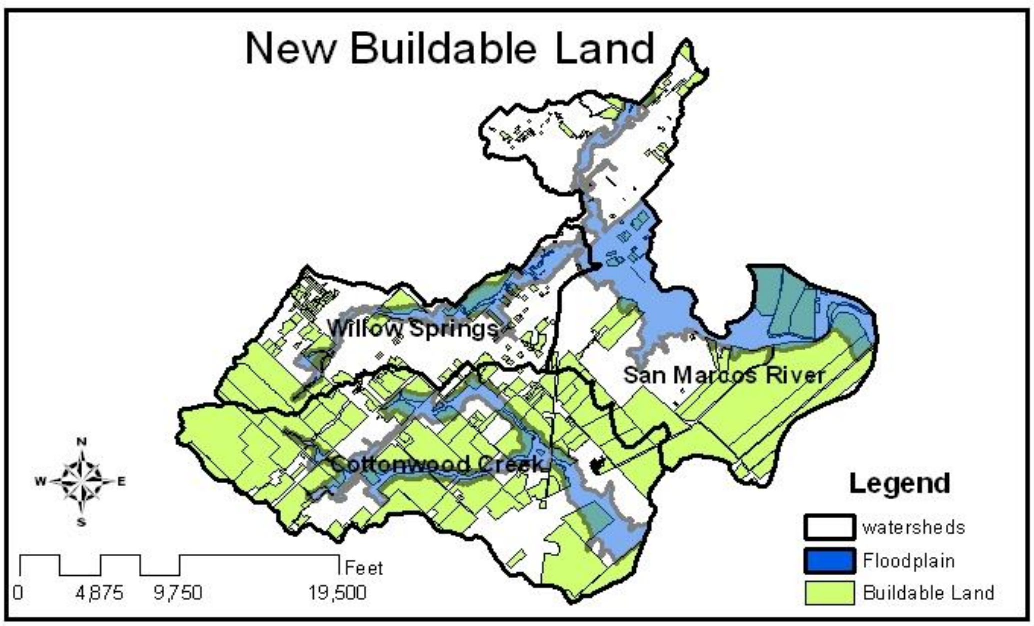
Table 4-5Operationalization of Hypothesis 3

Working Hypothesis 3: Restricting floodplain development will result in water quality that is more consistent with community expectations.		
Sub hypotheses	**Conditions under Working Hypothesis 1 at build-out**	**Conditions under a Policy Prohibiting Development in the 100 year Floodplain**
Working Sub hypotheses 3a. (Willow Springs): The Willow Springs watershed will experience some improvement if development is prohibited in the floodplain	Stream Quality: Degraded	Stream Quality: Fair
Working Sub hypotheses 3b. (San Marcos): The San Marcos watershed will experience some improvement if development is prohibited in the floodplain	Stream Quality: Fair	Stream Quality: Fair
Working Sub hypotheses 3c. (Cottonwood Creek): The Cottonwood Creek watershed will experience significant improvement if development is prohibited in the floodplain	Stream Quality: Degraded	Stream Quality: Fair

Calculating the effectiveness of this policy involves recalculating the amount of undeveloped land that can be classified as buildable. Figure 4.11 shows the process of removing the floodplain from the buildable land map. This creates a new buildable land map from which to create a build-out map. The new buildable land map, classified by land-use category is displayed in Figure 4.12.

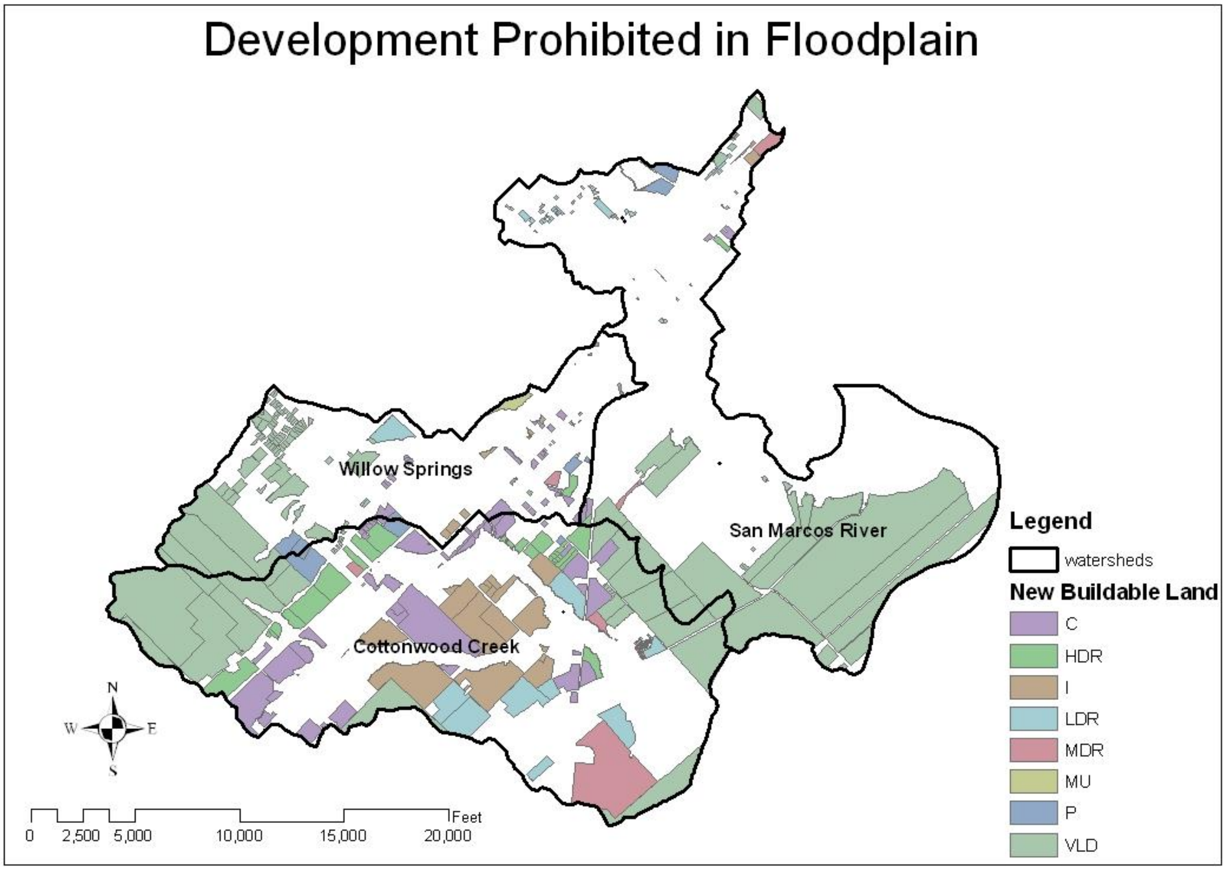
Figure 4.11 Process of Removing the 100-year Floodplain from the Buildable Land Map





Source: See Description of Data (Appendix A)

Figure 4.12New Buildable Land Classified by Land-Use Category



Source: see Description of Data (Appendix A)

Once the new buildable land layer is calculated, the same formulas as used in hypothesis 1 were used in hypothesis 3 to calculate the percentage of impervious cover of each watershed. The formulas used to determine estimates of future impervious cover are: $A_{blu}*ICC_{lu} = A_{IC}$

Where:

A_{blu}= Area of buildable square feet in land-use category

ICC_{lu} = Impervious cover coefficient by land-use category

A_{IClu} = Area of impervious cover in that land-use category

After the area of impervious cover is generated, the imperviousness of the watershed is calculated with the following formula:

$(T_{IA}/T_{WA})*100 = IC\%$

Where:

T_{IA} = Total area of buildable impervious cover + current impervious cover

T_{WA} = Total watershed area

IC = Impervious cover percentage

The impervious cover percentage in a watershed is the indicator of stream quality: 0%-10% is good (green), 11%-25% is fair (yellow), >25% is degraded (red).

Calculating the percentage of impervious cover for each watershed under different hypothetical policy scenarios allows a community to more effectively plan for their future. Chapter 5 presents the results from this analysis.

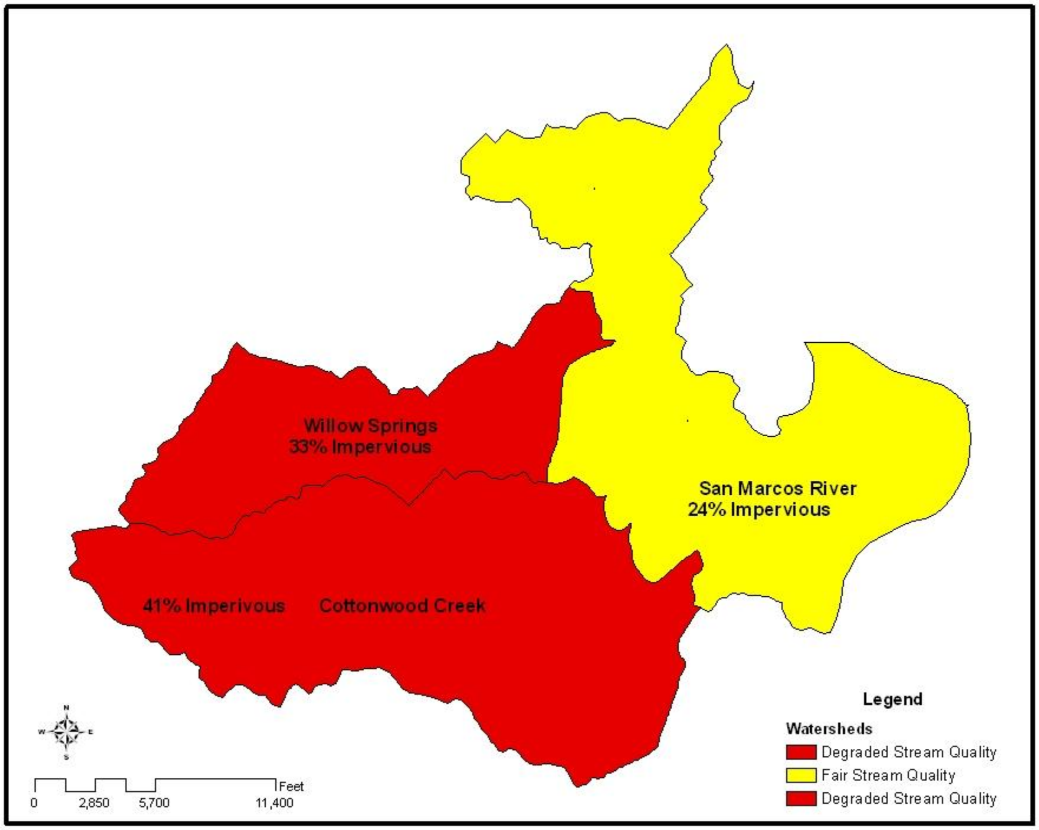
Chapter 5. Results

The results of this study are presented in the form of build-out maps. Figures 5.1, 5.2, and 5.3 depict the level of impervious cover and stream quality at build-out if (1) current land use policies persist; (2) a conservation development ordinance is applied; and (3) a prohibition on development in the 100-year floodplain is implemented. The evidence from the first build-out map depicting San Marcos under current development regulations (figure 5.1) gives the community an idea of how well its current policies address the goals of the community. The second two maps provide evidence of how well two stream quality protection ordinances address community goals.

Current Policies at Build out

Figure 5.1 is a graphic representation of the first scenario where current policies are extrapolated into the future.

Figure 5.1 Stream Quality and Impervious Cover Calculations for Build out under Current Policies



Source: see Description of Data (Appendix A)

Figure 5.1 shows that while all watersheds experienced an increase in the percentage of impervious cover, the Cottonwood Creek and Willow Springs watersheds surpassed 25% impervious cover; moving these watersheds into a degraded state of stream quality. Because community goals in San Marcos seek to retain the current level of stream quality, the increase in the percentage of impervious cover in the Cottonwood Creek and Willow Springs watersheds are not consistent with community expectations. The rise in the percentage of impervious cover in the San Marcos watershed was similar to the rise in the Willow Creek watershed. However, the difference in the current conditions of these watersheds allowed the San Marcos watershed to retain its fair level of water quality. The resulting stream quality of the San Marcos watershed is consistent with community expectations. These results are summarized in table 5.1.

Table 5-1Summary of the Effects of Current Policies on Build-out Conditions

Sub-Hypotheses	**Current Conditions**	**Hypothesized Build-out Conditions**	**Actual Build-out Conditions**	**Hypotheses Supported**
Working Sub hypothesis 1a. (Willow Springs): If existing development regulations are implemented over the long term the Willow Springs watershed will move from fair to degraded stream quality.	Impervious cover: 22% Stream quality: Fair (yellow)	Impervious cover: increases by 4% + Stream quality: Degraded (red)	Impervious cover: 32% Stream quality: Degraded (red)	Yes
Working Sub hypothesis 1b. (San Marcos): If existing development regulations are implemented over the long term the San Marcos watershed's stream quality will remain fair.	Impervious cover: 13% Stream quality: Fair (yellow)	Impervious cover: increases by < 13% Stream quality: Fair (yellow)	Impervious cover: 24% Stream quality: Fair (yellow)	Yes
Working Sub hypothesis 1c. (Cottonwood Creek): If existing development regulations are implemented over the long term the Cottonwood Creek watershed will move from fair to degraded stream quality.	Impervious cover: 11% Stream quality: Fair (yellow)	Impervious cover: increases by 14%+ Stream quality: Degraded (red)	Impervious cover: 41% Stream quality: Degraded (red)	Yes

Table 5-1 shows that the San Marcos and Willow Springs watersheds experienced a similar increase in the percentage of impervious cover, while the Cottonwood Creek watershed showed an exceptionally larger increase. These results indicate that the Cottonwood Creek watershed is set to experience a significant amount of growth in the future. This watershed, while currently undeveloped, is zoned to receive a large amount of San Marcos' future growth.

Implications

The buildable land map allows a city to visualize which watersheds will receive the largest percentage of growth and what that growth will look like in terms of land use and impervious cover. A watershed with a larger percentage of its land dedicated to high intensity land uses (e.g., commercial or industrial uses) will have a greater impact on the future water quality. Table 5.2 shows the total number of buildable acres in each watershed as well as how many acres of the total buildable land are dedicated to each of the land-use categories.

Table 5.2 Buildable Acres by Watershed and Land Use

Future Land Use Code	San Marcos Acres	Willow Acres	Cottonwood Acres
C	25	70	641
I	0	33	622
MU	0	71	0
P	30	39	53
HDR	12	10	288
MDR	28	7	252
LDR	51	52	310
VLD	2006	534	1221
Total	**2152**	**815**	**3388**

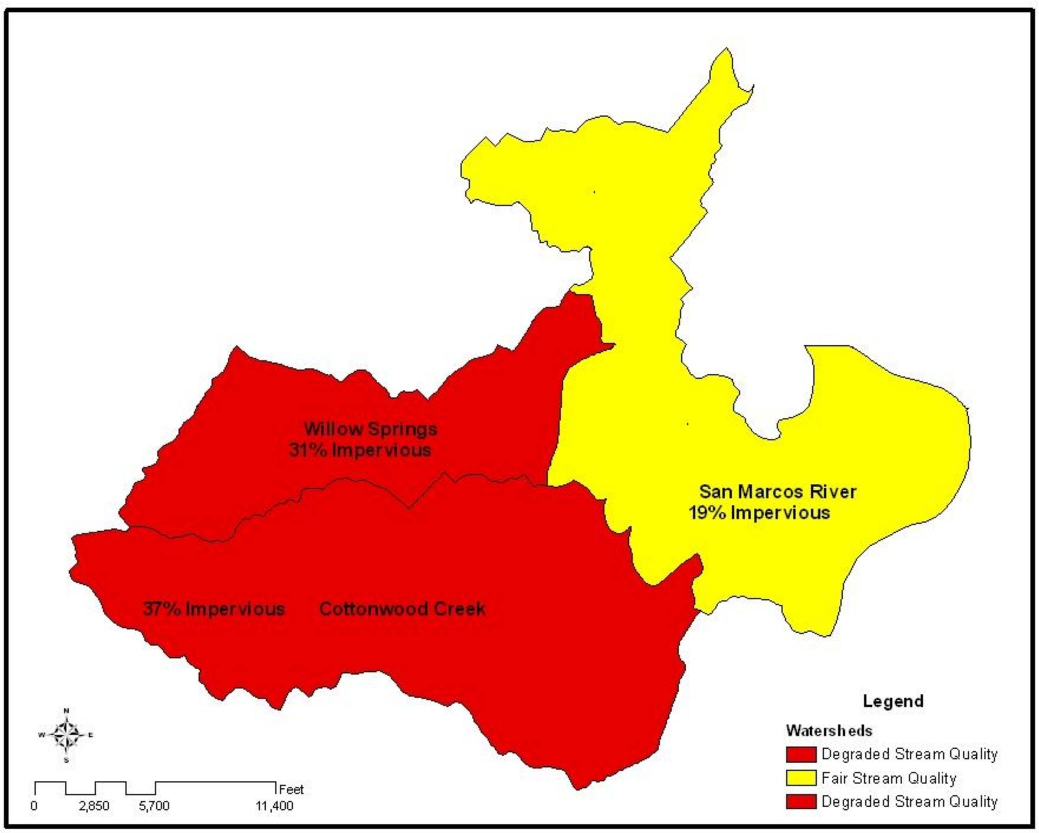
Source: See Description of Data (Appendix A)

The relatively small increase in the percentage of impervious cover in the Willow Creek watershed is related to the relatively small number of buildable acres. Buildable acres alone do not account for the dramatic increase in the percentage of impervious cover in the Cottonwood Creek watershed. Interstate Highway 35 runs through this watershed, influencing land-use choices along the corridor. The Cottonwood Creek watershed has the greatest percentage of high intensity land uses such as industrial, commercial, and high and medium density residential. Hence, the land-use category of buildable acres has a strong effect on the high percentage of impervious cover in the Cottonwood Creek watershed.

Conservation Development Policy

Figure 5.2 is a graphic representation of the impacts of a watershed protection policy that enforces conservation developments in the very low density land-use category. If conservation development ordinances achieved their purpose for this study, the stream quality in the Cottonwood Creek and Willow Springs watersheds would be fair.

Figure 5.2 Stream Quality and Impervious Cover Calculations for Build out under Conservation Development Policy



Source: See Description of Data (Appendix A)

A conservation development ordinance does not reduce impervious cover levels enough to change the stream quality designation in any of the three watersheds from their designation under current policies at build out. According to table 5.3, the Willow Springs watershed experiences a 1% decrease while the Cottonwood Creek and San Marcos watersheds both experience a 4% decrease in percent impervious cover.

Table 5-3Summary of the Effects of a Conservation Development Ordinance on Build-out Conditions

Sub hypotheses	**Actual Build-out Conditions**	**Hypothesized Build-out conditions with Conservation Development Ordinance**	**Actual Build-out conditions with Conservation Development Ordinance**	**Hypotheses Supported**
Working Sub hypotheses 2a (Willow Springs): The Willow Springs watershed will experience some improvement in the level of imperviousness when a conservation development ordinance is in place.	Impervious cover: 32% Stream quality: Degraded (red)	Impervious cover: Decrease by 8% Stream quality: Fair (yellow)	Impervious cover: 31% Stream quality: Degraded (red)	No
Working Sub hypotheses 2b (San Marcos): The San Marcos watershed will experience significant improvement in the level of imperviousness when a conservation development ordinance is in place.	Impervious cover: 24% Stream quality: Fair (yellow)	Impervious cover: no increase Stream quality: Fair (yellow)	Impervious cover: 19% Stream quality: Fair (yellow)	Yes
Working Sub hypotheses 2c (Cottonwood Creek): The Cottonwood Creek watershed will experience some improvement in the level of imperviousness when a conservation development ordinance is in place.	Impervious cover: 41% Stream quality: Degraded (red)	Impervious cover: Decrease by 17% Stream quality: Degraded (red)	Impervious cover: 37% Stream quality: Degraded (red)	No

Implications

The amount of land subject to conservation development ordinances impacts the effectiveness of this stream quality protection policy. Table 5.4 presents the number of acres of land subject to this policy in each of the three watersheds.

Table 5.4 Acres of Conservation Developments by Watershed

	San Marcos	Willow Springs	Cottonwood Creek
Land Subject to Conservation Developments (Acres)	1984	426	1992

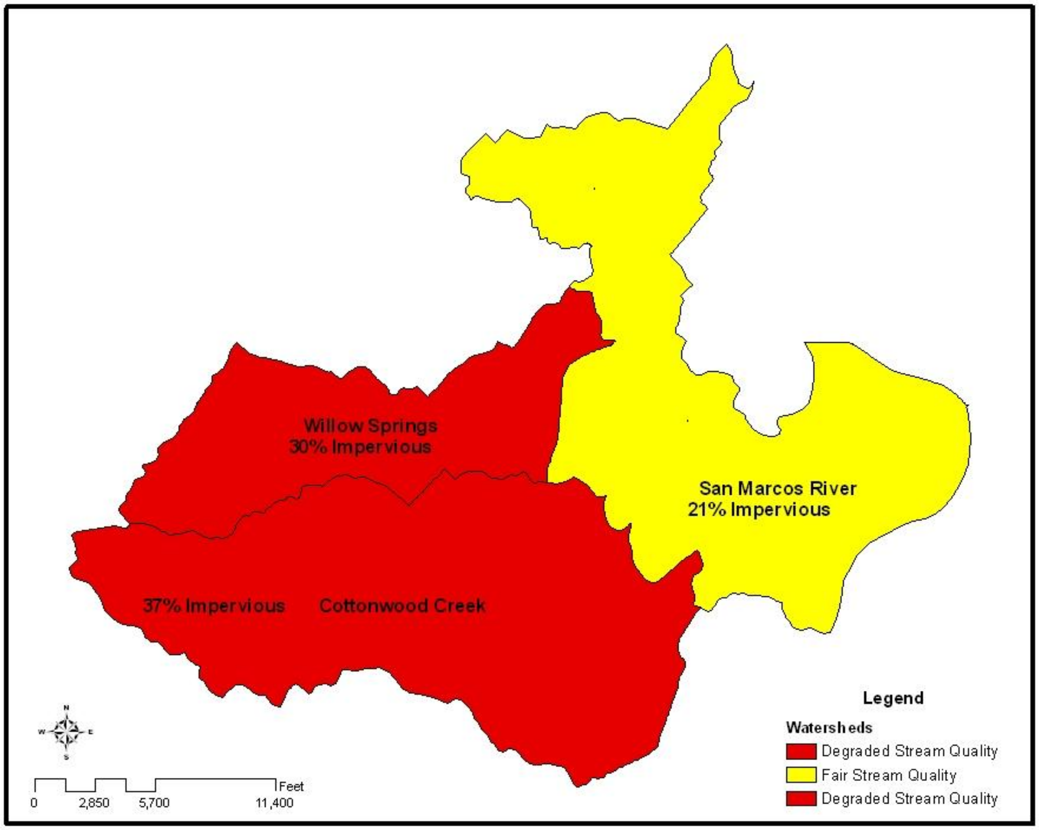
Source: See Description of Data (Appendix A)

The San Marcos and Cottonwood Springs watersheds have large quantities of land subject to the policy and thus are more greatly impacted by the policy. While the Willow Springs watershed does not see much improvement in the percentage of impervious cover due to a conservation development policy.

Policy Prohibiting Floodplain Development

Figure 5.3 is a graphic representation of the impacts of a watershed protection policy that prohibits development in the 100-year floodplain.

Figure 5.3Stream Quality and Impervious Cover Calculations for Build out under Floodplain Protection Policy



Source: see Description of Data (Appendix A)

Prohibiting development in the 100-year floodplain does not significantly impact the stream quality in any of the three watersheds.Stream quality at build out does not meet community expectations when a floodplain development policy is in place.

Table 5.5Summary of the Effects of Prohibiting Development in the 100 Year Floodplain on Build-out Conditions

Sub-Hypotheses	Actual Build-out Conditions	Hypothesized Build-out Conditions with Floodplain Policy	Actual Build-out Conditions with Floodplain Policy	Hypotheses Supported
Working Sub hypothesis 3a. (Willow Springs): The Willow Springs watershed will experience some improvement if development is prohibited in the floodplain	Impervious cover: 32% Stream quality: Degraded (red)	Impervious cover: Decrease by 8% Stream quality: Fair (yellow)	Impervious cover: 30% Stream quality: Degraded (red)	No
Working Sub hypothesis 3b. (San Marcos): The San Marcos watershed will experience some improvement if development is prohibited in the floodplain	Impervious cover: 24% Stream quality: Fair (yellow)	Impervious cover: no increase Stream quality: Fair (yellow)	Impervious cover: 21% Stream quality: Fair (yellow)	Yes
Working Sub hypothesis 3c. (Cottonwood Creek): The Cottonwood Creek watershed will experience significant improvement if development is prohibited in the floodplain	Impervious cover: 41% Stream quality: Degraded (red)	Impervious cover: Decrease by 17% Stream quality: Degraded (red)	Impervious cover: 37% Stream quality: Degraded (red)	No

Implications

The effects of a watershed protection policy that prohibits development in the floodplain are more dramatic in watersheds where development has not already occurred in the floodplain, and where a larger percentage of the watershed is contained in the 100-year floodplain. Table 5.6 shows how many acres are removed from buildable land in each of the three watersheds in this scenario. The impact of this policy is greatest in the Cottonwood Creek watershed because the least amount of development has already occurred in this watershed.

Table 5-6 Factors in Stream Buffer Policy

	San Marcos	Willow Creek	Cottonwood Springs
Number of Acres Removed from Buildable Land	474	135	974
Percentage of Watershed Removed from Buildable Land	22%	17%	29%

Source: see Description of Data (Appendix A)

Economic Implications

The economic implications of this policy are impossible to ignore. Prohibiting development renders a parcel which is completely within the floodplain useless for economic gain. Thus implementing this policy would be considered a taking of those parcels, and the city would have to purchase any properties that are completely within the 100-year floodplain. Parcels that are only partially within the floodplain can be given density increases or transfers to make up for the land that is within the floodplain. This policy is beneficial when the benefits to stream quality are high, such as in the Cottonwood Creek watershed, and the number of properties affected is low.

Chapter 6. Conclusions and Recomendations

Local land-use policies dictate how a community will look and feel in the future. The development of these policies should represent the values of a wide array of community stakeholder groups. Community involvement, however, needs to go further than a statement of goals; land-use policies should be shaped and developed by the community. Community involvement is challenging when policies involve complex ecological principles and design that is difficult to communicate. GIStechnology is a valuable tool that can be used to facilitate the formulation of land-use policies.

This research focused on stream quality protection policies in San Marcos, Texas. Impervious cover was used as an indicator of stream quality. Three different working hypotheses,representing stream quality protection policies, were analyzed for adherence to community goals. Working hypothesis1 used the current land development rules, while working hypotheses2 and 3 analyzed two different water quality protection measures. The results of this analysis are displayed in table 6.1.

Table 6.1 Summary of the Results for the Three Working Hypotheses

Working Hypotheses	Supported
Working Hypothesis 1: Existing San Marcos development regulations implemented over the long term will result in water quality that is not consistent with community expectations.	Yes
Working Hypothesis 2: Conservation development ordinances will result in stream quality that is more consistent with community expectations.	No
Working Hypothesis 3: Restricting floodplain development will result in water quality that is more consistent with community expectations.	No

San Marcos has not specifically outlined its goals for stream quality, so this research made assumptions based on master planning documents, surveys, and the goals of proximate cities. The assumed water quality goals in San Marcos are that, while the percentage of impervious cover in the watershed will rise, the community wants to maintain its current level of stream quality. The watersheds should all remain in the fair (11% - 25%) range of stream quality. The San Marcos watershed remained at this level of stream quality after build out, but both the Cottonwood Creek and the Willow Springs watersheds moved to a degraded level of stream quality.

The most effective stream quality protection measures combine different policies based on their effectiveness in the situation. Table 6.2summarizes the change in percentage of impervious cover in each of the watersheds according to the policy in place. There is also an added scenario that incorporates both protection measures.

Table 6.2 Summary of Percentage of Impervious Cover for each Policy Scenario

Watershed	Current	Build-out	Conservation Developments	Floodplain	Both Conservation Techniques Employed
San Marcos	13%	24%	21%	21%	18%
Willow Springs	22%	32%	32%	30 %	29%
Cottonwood Creek	11%	41%	39%	37%	35%

Source: see Description of Data (Appendix A)

Analyzing the effectiveness of stream quality protection plans individually allows a community the opportunity to choose a plan or group of plans that work best for their location. Watershed based stream quality protection plans are another way to achieve the maximum amount of benefits without unnecessary economic impacts. For example, according to table 6.2

prohibiting development in the 100-year floodplain only lowers the percentage of impervious cover in the Willow Creek watershed by 2%. This decrease may not outweigh the economic impacts of such a policy. The Cottonwood Creek watershed, however, would experience a 4% reduction in the percentage of impervious cover. Depending on how many properties are affected by this policy, prohibiting floodplain development may be a very effective policy for this watershed. The flexibility to enact watershed based protection policies may prove very efficient for a jurisdiction.

Recommendations for Further Research

This research set out to show how GIS technology can be used as a tool in policy analysis. As reflected in Table 6.1, the water quality protection measures chosen for this study did not result in water quality that is consistent with the city's goals. The methodology used for this study can be duplicated for other more comprehensive stream quality protection policies. Possibilities for improvement in the model include:

- expanding the scope of the study to include more watersheds
- collecting more samples to improve the accuracy of impervious cover estimates
- a more in-depth analysis of current development policies and their effects on impervious cover

The research shows that San Marcos needs to begin working on water quality protection policies now so that the community does not find itself in a situation of degraded water quality and few policy options for improvement in the future. Models such as this one, using GIS technology, should be used in the initial and final stages of policy development.

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Appendix A: Description of Data

The data used to create the maps is described in Table A-1. All of this data was readily available from the local jurisdiction. Some smaller communities may have less data available while larger cities may have more specific impervious cover data available. If a community already has impervious cover data available this minimizes the amount of work involved in deriving impervious cover coefficients.

Table A-1 Description of Data

Data Source	Data Description
ESRI Data and Maps V9.2	Map Layer including county, city, road, state, and water data.
City of San Marcos	Parcel Data
City of San Marcos	Floodplain Data
City of San Marcos	Future Land Use Data
City of San Marcos	Stream and River Data
City of San Marcos	Street Data
City of San Marcos	Aerial Photographs

Appendix B: Table for Deriving Impervious Cover Coefficient

Table B-1 Deriving Impervious Cover Coefficients for the Commercial Land Use

FLU Code	Parcel ID	Buildings (sq. ft.)	Car habitat (sq. ft.)	total Area	Total Impervious	Impervious (%)	standard error	Car habitat (%)	Building (%)
C	R102012	5714	23835	43879	29548	67.3%		54.3%	13.0%
C	R10363	4137	13428	21060	17564	83.4%		63.8%	19.6%
C	R103996	3400	15730	29663	19130	64.5%		53.0%	11.5%
C	R10400	1188	5375	12615	6563	52.0%		42.6%	9.4%
C	R110075	7207	10112	38706	17319	44.7%		26.1%	18.6%
C	R12181	7479	37571	59899	45050	75.2%		62.7%	12.5%
C	R14459	8299	56671	101366	64970	64.1%		55.9%	8.2%
C	R23380	47524	207627	264107	255150	96.6%		78.6%	18.0%
C	R25562	10512	29043	51876	39555	76.2%		56.0%	20.3%
C	R27106	78274	295618	482266	373892	77.5%		61.3%	16.2%
C	R39367	4762	18192	26535	22954	86.5%		68.6%	17.9%
C	R40094	5569	9742	17058	15312	89.8%		57.1%	32.6%
C	R40377	3103	18698	27127	21802	80.4%		68.9%	11.4%
C	R41425	6887	14079	26819	20966	78.2%		52.5%	25.7%
C	R41460	9186	29793	43448	38979	89.7%		68.6%	21.1%
C	R41482	4434	6157	11269	10591	94.0%		54.6%	39.3%
C	R71116	5741	31550	44745	37291	83.3%		70.5%	12.8%
C	R71253	201099	311055	619861	512154	82.6%		50.2%	32.4%
C	R87577	3835	33874	49427	37710	76.3%		68.5%	7.8%
C	R97290	58342	33698	114162	92040	80.6%		29.5%	51.1%
C	R97512	17367	105214	215979	122581	56.8%		48.7%	8.0%
Total						1599.8%		1192.1%	407.7%
Average						76.2%	3.0%	56.8%	19.4%

Appendix C: Impervious Cover Calculationsin the Cottonwood Creek Watershed

Tables C-1 through C-4 are examples of how to derive the percent impervious cover of a watershed using impervious cover coefficients. This appendix includes the current situation plus the situation at build-out using each of the three working hypothesis.

Table C-1: Calculation of Current Impervious Cover for Cottonwood Creek Watershed

Future Land Use Code	Count	Square Feet	Acres	Impervious Coefficient	Impervious Cover(acres)
C	21735	19561500	391	0.762	298
I	10033	9029700	181	0.593	107
MU	493	443700	9	0.455	4
P	13451	12105900	242	0.485	117
HDR	2648	2383200	48	0.61	29
MDR	1603	1442700	29	0.494	14
LDR	4481	4032900	81	0.39	31
VLD	1526	1373400	27	0.239	7
Total					608
Watershed Area	298317	268485300	5370		5370
Percent Impervious Cover					11.3%

Table C-2 Calculation of Percent Impervious Cover of Cottonwood Creek at Build–out Using Working Hypothesis 1

Future Land Use Code	Count	Square Feet	Acres	Impervious Coefficient	Impervious Cover
C	35598	32038200	641	0.762	488
I	34537	31083300	622	0.593	369
MU	17	15300	0	0.455	0
P	2947	2652300	53	0.485	26
HDR	16014	14412600	288	0.61	176
MDR	14027	12624300	252	0.494	125
LDR	17227	15504300	310	0.39	121
VLD	67854	61068600	1221	0.239	292
Impervious Area of Buildable Land			3388		1596
Plus Current Development					608
Total Impervious Area					2204
Divided by Watershed Area					5370
Impervious Cover at Build-out					41.0%

Table C-3: Calculation of percent Impervious Cover at Build-out of Cottonwood Creek Using Working Hypothesis 2

VLD Parcels subject to Conservation Development ordinances	Count	Multiplied by cell size (Square Ft)		Acreage	Multiplied by Impervious cover coefficient from Car Habitat for VLD Land Use
R10490	2711	2439900		49	6
R10504	4629	4166100		83	10
R11728	1436	1292400		26	3
R85318	1521	1368900		27	3
R15897	1917	1725300		35	4
R13041	11057	9951300		199	23
R15900	7267	6540300		131	15
R12023	275	247500		5	1
Q1000	2716	2444400		49	6
R10209	653	587700		12	1
R10508	3039	2735100		55	6
CA27912	153	137700		3	0
GC70655	748	673200		13	2
GC56633	1574	1416600		28	3
CA27813	5271	4743900		95	11
R10487	4314	3882600		78	9
partial parcel	8854	7968600		159	19
R70337	31476	28328400		567	66
CA28233	4237	3813300		76	9
R15908	2208	1987200		40	5
partial parcel	786	707400		14	2
partial parcel	5672	5104800		102	12
partial parcel	8137	7323300		146	17
Impervious Cover from car habitat for large VLD parcels					233
Subtract 50% for conservation developments					117
Subtract from Total Impervious Area at Build-out					2088
Divided by Total Area of Watershed					5370
Percent impervious cover					39%

Table C-4: Calculation of percent Impervious Cover at Build-out of Cottonwood Creek Using Working Hypothesis 3

Future Land Use Code	Count	Square Feet	Acres	Impervious Coefficient	Impervious Cover
C	29067	26160300	523	0.762	399
I	26594	23934600	479	0.593	284
MU	17	15300	0	0.455	0
P	2947	2652300	53	0.485	26
HDR	14700	13230000	265	0.61	161
MDR	13044	11739600	235	0.494	116
LDR	13805	12424500	248	0.39	97
VLD	67285	60556500	1211	0.239	289
Impervious Area of Buildable Land minus Floodplain			3014		1372
Plus Current Development					608
Total Impervious Area					1980
Divided by Watershed Area					5370
Percent Impervious Cover					36.9%