ASSESSING STORMWATER RUNOFF WITH “SWAT” IN MIXED-USE DEVELOPMENTS: LEARNING FROM SOUTHLAKE TOWN SQUARE AND ADDISON CIRCLE IN NORTH TEXAS

by

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ABSTRACT

ASSESSING STORMWATER RUNOFF WITH “SWAT” IN MIXED-USE DEVELOPMENTS: LEARNING FROM SOUTHLAKE TOWN SQUARE AND ADDISON CIRCLE IN NORTH TEXAS

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Recognizing environmental problems associated with sprawl, North Texas communities are looking at options for future growth. Higher density mixed-used developments (MXDs) are being considered as an alternative to the continuation of current trends and adopted plans, yet little is known how they impact the region environmentally (Vision North Texas, 2008). More specifically, it is not clear how these developments perform in regard to stormwater runoff and water pollution.

This research evaluates the stormwater runoff and water pollution of two mixed-use developments (MXDs) in order to understand their environmental role in the future of North Texas. The research question in this study is two-fold. First, how the varying designs, planning and land management characteristics of two MXDs impact stormwater runoff and pollution. Second, is the Soil and Water Assessment Tool (SWAT) an effective tool to measure such an impact?

Two local mixed-use developments, Southlake Town Square and Addison Circle, are chosen based on urban form typology, common design elements and a similar mix of land uses

(Ozdil, et al.; 2009; New Urban News, 2003). The study utilizes Geographic Information Systems (GIS), site reconnaissance, and the Soil and Water Assessment Tool (SWAT) to evaluate stormwater runoff and pollution and its relation to land use density and the imperviousness of exterior design elements. Orthophotographic interpretation, using GIS, is used primarily to inventory, categorize and calculate design element areas and permeability. The inventory is followed by site inspection to: (1) assess the mitigation potential of exterior design elements, and (2) clarify ambiguities resulting from orthophotograph interpretation. Results of the hydrologic modeling are evaluated in relation to land use density and the imperviousness of exterior design elements. They are further validated through a comparison of observed data reported in regional and national stormwater runoff studies.

Based on the level of imperviousness, the land management scenarios and the site design, results of the two cases studies indicate higher concentrations of nitrate (NO3) in the surface runoff compared to commercial, industrial and residential land uses reported in other urban stormwater studies. Yearly average organic nitrogen (N) and soluble phosphorus (P) concentrations varied when compared to tested event mean concentrations of different land uses, but were lower than residential sites tested. This suggests that higher density urban areas, with significant levels of imperviousness, can produce lower amounts of pollutants in stormwater runoff than lower density residential developments.

Findings from the two case studies covered in this research lead to the conclusion that design, land-use density, and land management practices all affect the stormwater runoff performance in mixed-use developments. Careful planning and design combined with stormwater best management practices can help to improve the water quality and quantity of stormwater runoff. This research also illustrates that the Soil and Water Assessment Tool (SWAT) provided a reasonable assessment for stormwater runoff performance in higher density urban areas. With further research, SWAT can be a valuable tool for landscape architects in the pre-construction planning and design phases of development.

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CHAPTER 1

INTRODUCTION

1.1 Background

North Central Texas is a sixteen county region containing the Dallas/Fort Worth metropolitan area (Figure 1.1). Over the years, rapid development in the area has increased the amount of imperviousness directly effecting the environment. Although there are efforts to reduce this, research have shown that the continuation of current development patterns will continue to expand into low density, unincorporated areas (Vision North Texas, 2008). The resulting sprawl negatively affects important social, economic and environmental characteristics that help to define the Dallas/Fort Worth metropolitan area. Additionally, increased transportation infrastructure connected to outward growth is a key factor in creating impervious surface areas; producing air and water quality environmental problems.

Understanding water as a vital resource, communities in the region have become concerned about sprawl and its effects upon watersheds, natural drainage systems, and storm water runoff (North Central Texas Council of Governments, 2009). Recognition of the problem has produced a change in growth patterns, causing development in the region to expand vertically rather than horizontally (Kirk, 2008). As a result, North Texas has seen an increase in the construction of mixed-use developments. Based on future projections of population, resources and available land, it is suggested that this planning method can be a significant alternative for future growth (Vision North Texas, 2008).

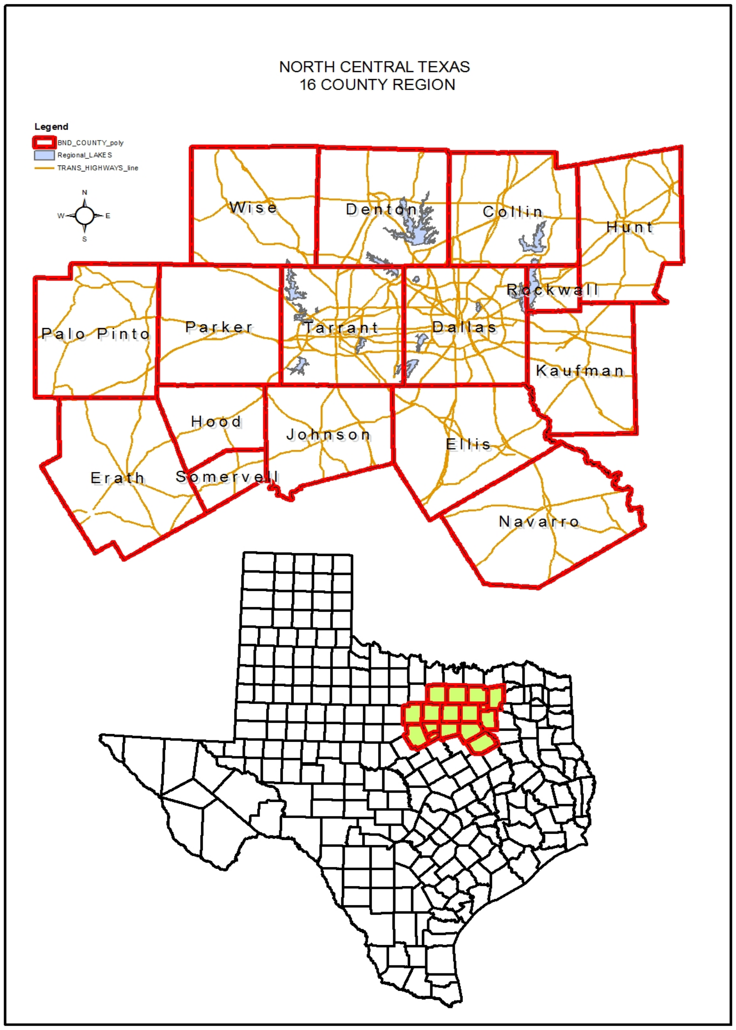

Figure 1.1: North Central Texas 16 County Region (adapted from NCTCOG, 2009)

Mixed-use development, in both urban form and function, can provide communities an alternative to planning approaches associated with sprawl. From an environmental standpoint, the combination of high density and mixed land uses can help limit the need for the automobile by taking advantage of necessary infill development, inner city revitalization and increased investment on public transportation modes. Regionally, the reduction of transportation infrastructure directly contributes to improved air and water quality.

In addition to the reduction of sprawl, application of mitigation strategies and design techniques, such as *integrated* Stormwater Management (iSWM) and Low Impact Development (LID), can significantly improve stormwater runoff quantity and quality. Considering current trends of development, through urban form and design, mixed-use developments have the potential to positively impact the environment in North Texas. However, to date, very little empirical knowledge has been generated concerning stormwater runoff and water pollution in high density/mixed-use urban environments. If this planning approach is being considered as a preferred method of growth for the future, then a better understanding is needed to ascertain how these developments can impact the environment.

Over the last few decades, sophisticated hydrological modeling tools, such as the Agricultural Policy/Environmental eXtender (APEX) and the Soil and Water Assessment Tool (SWAT), have been developed to assist in water resource assessment; and a significant amount of research has been done to validate their capabilities and limitations in regard to water and land management practices. The Soil and Water Assessment Tool, SWAT, through years of model incorporation upgrades and modifications, has gained a substantial review in the literature for its ability to accurately quantify natural and land management practices over large, complex watersheds (Gassman, et al.; 2007). Proven as a valuable tool for rural and agricultural studies, little research has been done to evaluate its capabilities to simulate, at a site level, hydrological and land management processes associated with high density urban developments. Testing the model in such a setting is important as it can add to the body of knowledge; providing software developers and users with an improved understanding of SWAT versatility.

1.2 Purpose of Study

Mixed-use developments, as a planning and design approach, are seen as a significant opportunity to help the region’s ability to improve sustainability, health and economic vitality

(Vision North Texas, 2008). In order for those in leadership roles to make well informed decisions relevant to the future of the region, a comprehensive understanding of such development is needed. As a way to assess the environmental imprint of mixed-use developments, this study focuses on the evaluation of stormwater runoff and water pollution in relation to land use density and the imperviousness of exterior design elements. The primary tools used to perform the analysis are Geographic Information Systems and the Soil and Water Assessment Tool (SWAT). Although a capable and proven tool for quantifying land management practices in large watersheds, SWAT has not been used extensively in an urban context; therefore, as a secondary research purpose, this study evaluates SWAT capabilities to simulate natural and operational processes in smaller scale, high density urban scenarios.

1.3 Research Questions

The primary questions addressed by this study are:

1. What is the environmental performance of mixed-use developments in North Texas in regard to stormwater runoff and water pollution?
2. How do land use density, design and land management practices affect that performance?
3. Can the Soil and Water Assessment Tool (SWAT) be used effectively to evaluate stormwater runoff water pollution in high density urban scenarios?

Although it is not as explicit, it is also intended of this research to address SWAT applicability to the profession of landscape architecture.

1.4 Methodology

As a performance assessment of stormwater runoff in mixed-use developments, this research relies primarily upon applied research and quantitative methods using Geographic Information Systems (GIS), and the Soil and Water Assessment Tool (SWAT). Criteria for site selections are based upon two locations with similar typologies. For each case, a standard process is applied and can be categorized into five staged of implementation:

1. Data Acquisition
2. Inventory and Analysis
3. Site Observation
4. Soil and Water Assessment Tool Modeling
5. Reporting of Results

A significant portion of the data required for the GIS and SWAT modeling is secondary data; and is obtained from various public and private resources. This data includes, but not limited to, project and development information, ground surface data (topography), orthophotography, current land use, and soil and weather data. Inventory and analysis, using GIS, is used to assess site geographic and hydrologic conditions, as well as the primary process used to measure land use density and permeability of exterior design elements. Site observations follow the initial GIS inventory and analysis to: (1) evaluate possible stormwater mitigation potential, and (2) clarify ambiguities from orthophotograph interpretation. Once all the necessary data has been acquired, a series of SWAT scenarios are run; (1) a default, 3 year simulation to gauge the validity of secondary data applied, and (2) a 5 year, monthly simulation with a basic yearly operational schedule applicable to permeable open space design elements. Results of the SWAT modeling and measurements of land use density are displayed in a series of charts; the findings are compared to historical data obtained from various urban stormwater runoff and pollution reports.

1.5 Significance and Limitations

Recognizing problems with current development trends, communities are looking at mixed-use development as an option for future growth; yet to date, little research has been done to assess the environmental impacts of this planning approach upon regional watersheds using the research methods and tools in this study. This thesis aims at generating empirical knowledge and review of methodological techniques relevant to the evaluation of environmental performance in two mixed-use developments. Information from the study can help the decision making processes for communities regarding future development, planning and land use. Implications for landscape architects, as seen in the results, show that the Soil and Water Assessment Tool (SWAT) can be valuable for site analysis, pre-construction planning, and design evaluation. The empirical knowledge generated will add to the body of knowledge pertaining to the use of SWAT in high density urban areas thereby helping the SWAT developers and users gain a better understanding of software capabilities and constraints.

The major constraints to this study include the urban form of mixed-use developments, a limited experience using the Soil and Water Assessment Tool (SWAT) in an urban context, and the relatively small amount of research produced regarding SWAT modeling specifically related to high density clusters. Two cases studies are used as the research population, and results are generalized through methodological application and use of the same sources for secondary data. Due to limitations in accessing specific data required for detailed modeling, this study utilized baseline data and simulators incorporated into the SWAT interface; primarily soils and weather data. A significant portion of the research utilizes publicly available secondary data, primarily in the GIS inventory and analysis, and SWAT modeling. This data is created by other organizations and may not have been thoroughly validated; this quality may not affect the reliability of the study.

1.6 Definition of Terms

The following list contains some terms frequently used in this thesis. Definitions and acronyms (when applicable) are applied in relation to the subject of this research.

Agricultural Policy/Environmental eXtender (APEX) - A modeling tool developed for use in whole farm/small watershed management to evaluate various land management strategies considering sustainability, erosion, economics, water supply and quality, soil quality, plant competition, weather and pests (Texas Water Resource Institute, 2009).

Best Management Practice (BMP) - Activities or structural improvements that help reduce the quantity and improve the quality of storm water runoff (North Central Texas Council of Governments, 2009).

Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) - A field-scale model for non-point source pollution evaluation.

Digital Elevation Contours (DEC) - Digital elevation lines derived from Light Detection and Ranging methods of surface analysis (North Central Texas Council of Governments, 2009).

Digital Elevation Model (DEM) - A cell based grid based upon x, y and z coordinates of points that represent a surface based upon Light Detection and Ranging methods (North Central Texas Council of Governments, 2009).

Erosion Productivity Impact Calculator (EPIC) - A model used to assess the effects of soil erosion productivity and predicts the effects of management decisions on soil, water, nutrient, and pesticide movements and their combined impact on soil loss, water quality and crop yields for areas with homogenous soils and management (Environmental Protection Agency, 2009).

Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) - A mathematical model developed for field-size areas to evaluate the effects of agricultural managements systems on movement of agricultural chemicals within and through the plant root zone (Leonard, et al.; 1987).

Hydrologic Response Unit (HRU) - Portions of a subbasin that have unique land use, soil, slope and land management characteristics (Neitsch, et al.; 2005)

*i*ntegrated Stormwater Management (iSWM) - Cooperative storm water management plan used to assist cities and counties in achieving their goals of water quality protection, stream bank protection, and flood control (North Central Texas Council of Governments, 2009).

Low Impact Development (LID)- An approach to land development (or re-development) that works to manage stormwater as close to its source as possible (Environmental Protection Agency, 2009).

Mixed-use Development (MXD) - A development with three or more significant revenue generating uses that have a significant functional and physical integration of project components; a relatively close-knit and intensive use of land; uninterrupted pedestrian connections; and development in conformance with a coherent plan that frequently stipulates the type and scale of uses, permitted densities, and related items (Ozdil, et al.; 2009).

Simulator for Water Resources in Rural Basins (SWRRB) - A model developed for simulating hydrologic and related processes in rural basins (Arnold and Williams, 1987).

Soil and Water Assessment Tool (SWAT) - A modeling tool used to quantify land management practices in large, complex watersheds (Texas A&M University, 2009).

1.7 Study Overview

The primary objective of this research is to evaluate the environmental performance of mixed-use development using Geographic Information Systems (GIS) and the Soil and Water Assessment Tool (SWAT). More specifically, an analysis of stormwater runoff and water pollution in relation to land use density and the imperviousness of exterior design elements. A secondary objective of the study is to assess SWAT capabilities for hydrologic modeling in high density urban areas. The format of this thesis is organized into five major sections: (1)

introduction, (2) literature review, (3) research methodology, (4) case studies and (5) analysis of results and conclusions.

The first section, Chapters 1-3, explores the issues leading to the prominence of mixed-use development as an alternative planning approach; the importance of understanding mixed-use development from an environmental standpoint; what other related studies have shown; and research methods utilized to reach the primary objective. The second section of this research, Chapter 4, focuses on the case studies; the objectives of which are to answer three questions: (1) what is the land use density, (2) what is the percentage of imperviousness of exterior design elements, and (3) what is the environmental performance of stormwater runoff for each case. The final section, Chapter 5 discusses the significance of the study, how it relates to the profession of landscape architecture, and possible inquiries for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review begins with an understanding of mixed-use development (MXD) as an urban form through definition, historical perspective, and factors leading to the advancement of this type of planning approach. As design of exterior streetscape elements in MXDs are relevant to environmental performance, a portion of the chapter describes how these elements can contribute to improved stormwater runoff mitigation. Further review focuses on stormwater runoff, pollution and water quality in North Texas and its relationship to land use density; with emphasis on mitigation strategies and devices that are available either through design or stormwater management. Concluding the chapter is a discussion on environmental point and non-point source modeling tools; with an emphasis on the Soil and Water Assessment Tool (SWAT), research involving SWAT used in different planning scenarios, and the value of further research into SWAT capabilities and limitations.

2.2 Mixed-Use Development

The Urban Land Institute (ULI) describes the difficulties associated with defining mixed-use developments (MXDs), understanding they can differ significantly in purpose, size, mix of uses, physical character, setting and design. Instead, the ULI established a concept describing this type of urban form as having three or more revenue producing land uses, significant functional and physical integration, and developed in accordance to a coherent plan; helping to differentiate MXDs from other multi-use projects that are less intensive in land use and not functionally integrated into the urban environment (Schwanke, 2003; Urban Land Institute, 1987). For purposes of this study, MXD is defined as a development with three or more significant revenue generating uses that have a significant functional and physical integration of project components; a relatively close-knit and intensive use of land; uninterrupted pedestrian connections; and development in conformance with a coherent plan that frequently stipulates the type and scale of uses, permitted densities, and related items (Ozdil, et al.; 2009).

While the term “mixed-use development” does imply a physical land use mix, it is important to understand that the planning and design process extends beyond that, incorporating social, economic and environmental values. Thus, when understanding mixed-use development, it is important to acknowledge planning and design processes which integrate:

- Social mix- income, housing tenure, demography, visitors, lifestyles;
- Economic mix- activity, industry, scales (micro to large), consumption and production;
- Physical land-use mix- planning use class, vertical and horizontal, amenity/open space;
- Temporal mix (of items 1-3) – 24-hour economy, shared use of premises/space, e.g. street markets, entertainment, live work (Evans and Foord, 2007).

Urban form typologies of mixed-use developments (MXDs) vary, and reflect development purpose, site location and context of the surrounding urban environment. Infill and revitalization mixed-use development efforts are most often built vertically; representing the desire or need to increase density and improve transit accessibility, or vertical integration into the surrounding urban environment (Urban Land Institute, 1987). The architecture of these developments are often three or more stories, with a mix of retail, office and residential.

Greenfield MXDs are typically associated with regional or town centers. These are vehicle oriented where development is not restricted by the density of the local urban environment and the architecture tends to be two stories or less, with an abundance of surface and street parking. Larger tracts of land and form typologies surrounding the site can limit the need to build vertically. In North Texas, the majority of mixed-use developments are vehicle oriented and research suggests that “although these developments offer special qualities of interest to users, they may not always promote solutions for increasing density and reducing auto dependency” (Ozdil, et al.; 2009; Vision North Texas, 2009, p.40).

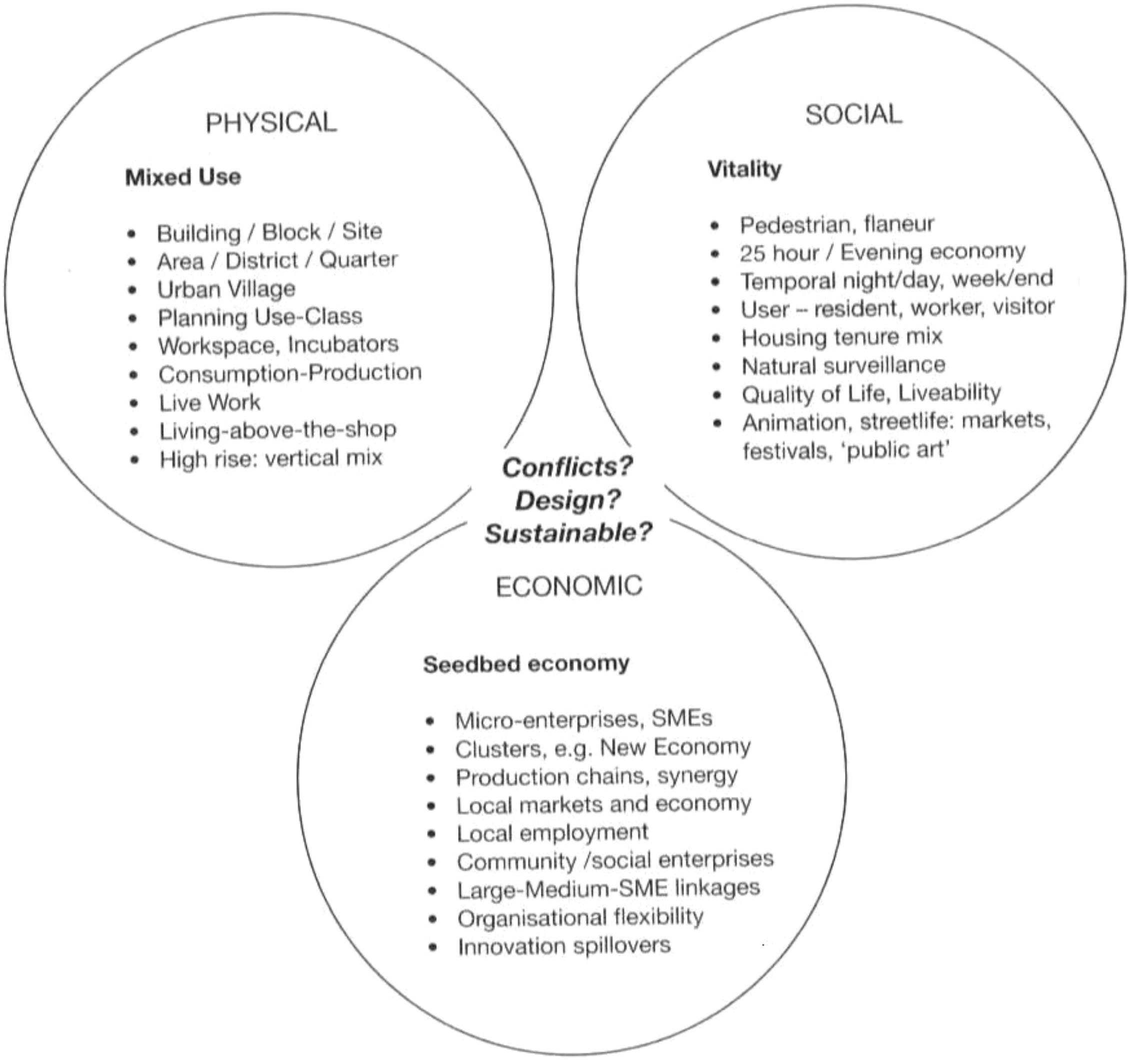

Figure 2.1: Mixed-Use Elements (Evans and Foord, 2007)

2.2.1. Historical Context

Mixed-use development is not a new development concept. Historically, it arose out of necessity rather than a planned effort. The need for protection, lack of space, predominantly pedestrian orientation and proximity to the greater population all contributed to the formation of highly dense, compact cities (Urban Land Institute, 1987). In more recent times, technological advances in transportation and engineering, coupled with a shift in planning trends based upon numbers instead of humanistic disciplines, reduced the American city into simplistic categories and quantities of sprawl (Duany, et al.; 2000). Economics became a primary motivation for development and little emphasis was placed upon future scenarios. The resulting sprawl led to rapid consumption of natural resources, and “the instinct to find more natural environments became the impulse that destroyed nature” (McHarg, 1971, p.154).

2.2.2. A Counter to Urban Sprawl

Recognizing adverse environmental impacts associated with sprawl, communities began looking for alternative methods of growth; leading toward a shift from modernist principles to newer compact developments incorporating some degree of sustainability (Thwaites, et al.; 2007).

In North Texas, changes in growth patterns started in the 1990’s as developers and planners directed growth inward, focusing on revitalization efforts in downtown central business districts and planning for the future with the development of light-rail transportation (Kirk, 2008). As of today there are 214 regionally recorded mixed-use developments, which fall into four broad categories:

- mixed-use tower,
- integrated multitower,
- mixed-use town centers/urban villages/districts,
- traditional/historical town centers (Ozdil, et al.; 2009; Schwanke, 2003)

2.2.3. Exterior Design Elements

A wide variety of conditions influence mixed-use development (MXD) planning and design. Purpose, need and want…as well as location, site and design, all contribute to the diversity of MXD project types. Despite this diversity; as an urban form and a design, MXDs contain the same principle elements:

- Physical and Structural Configuration
- Exterior Design
- Internal Design
- People-Oriented Spaces
- Parking Design (Schwanke, 2003; Urban Land Institute, 1987).

Important to this study are the exterior design elements, as they can directly influence environmental performance of stormwater runoff and pollution. As a design category, this component is quite broad; yet consistent when related to mixed-use development (MXD) design principles of walkability, connectivity, and density. Comprehensive research performed on landscape architecture and urban design literature, and the evaluation of design in pedestrian oriented urban spaces, has generated a list of common exterior design elements attributed to designer's perspectives of walkability and accessibility (Ozdil, 1996; Gupte, 2009). The design components specifically related to this study include: (1) curbs and ramps, (2) surface material, (3) vegetation and (4) water features. Careful planning and design of exterior design elements, using *integrated* Stormwater Management (*i*SWM) and Low Impact Development (LID) techniques, can minimize stormwater runoff (Carter and Burgess, Inc., 2004).

In addition to careful planning and design of exterior components, activities or structural features can be incorporated specifically to help mitigate quantity and quality of surface runoff (NCTCOG, 2009). These activities or structural features, called Best Management Practices (BMPs), are commonly used today in developments where some type of on-site stormwater management is necessary or required. Retention ponds, detentions ponds, infiltration trenches, bio-retentions, bio-filters, vegetated swales, permeable pavement and constructed wetlands are all examples of effective BMPs for runoff mitigation; and many of these structural BMPs double as open space or aesthetic amenities.

2.2.4. Land Use Density

A variety of land uses incorporated into one site can produce a high density urban form. Historic preservation, infill development, Brownfield redevelopment, revitalization, and to some degree adaptive use, are examples of high density mixed-use development (MXD) types. In North Texas, rapid growth and outward development has put a strain on available land and vital resources. Concerned about the situation, local communities are focusing their planning efforts inward; looking at high density MXDs to help relieve the impacts resulting from decades of sprawl.

From an environmental standpoint, there is a direct relation between mixed use development (MXD), land use density, stormwater runoff and water pollution. Land use density is measured by the amount of imperviousness in an area, and is representative of the level of pollution producing activities per acre (Marsh, 2005). Pollution producing activities are more numerous in dense areas, such as automobile traffic, spills, leakage, debris, and garbage; reflecting both the level of pollution loading and the efficiency of surface flushing by stormwater runoff, which is nearly 100 percent in heavily built-up areas (Marsh, 2005). Pollutant loading is the total amount of pollutants in stormwater runoff and is related to the amount and types of land use activity and the quantity of impervious materials (NCTCOG, 2008; Marsh, 2005). Although relatively high in areas with a high percentage of imperviousness, pollutant load does not reflect concentration or cause of pollution; nor does it reflect the relationship between population density and pollution, where the amount decreases per person in high density urban areas (Marsh, 2005).

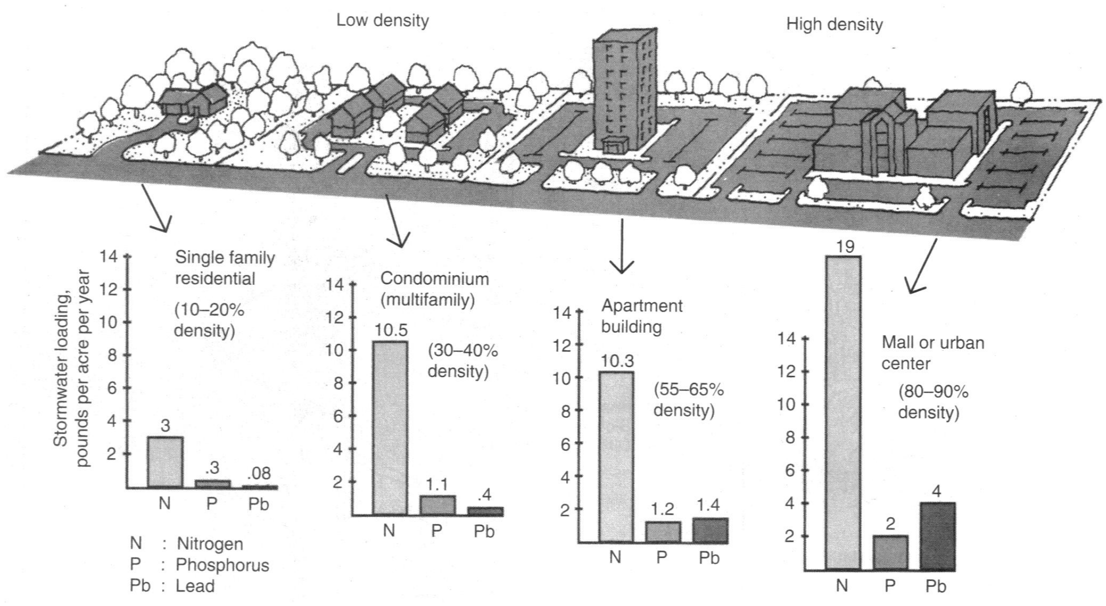

Figure 2.2: Relationship of Stormwater Pollution and Land Use Density (Marsh, 2005)

2.3 Stormwater Runoff and Pollution

Stormwater is essentially precipitation that accumulates in natural or constructed systems during and after a storm event (NCTCOG, 2009). Aside from certain conditions such as surface composition, topography, underlying soil structures, evaporation and vegetation, accumulated stormwater will primarily discharge, infiltrate or pond. The discharge of stormwater over the ground surface, or surface flow, is stormwater runoff (NCTCOG, 2009).

From a historical standpoint, the need to accommodate the automobile, rapid growth and planning methods associated with sprawl contributed to increased imperviousness. This resulted in and increase in surface flow velocity and discharge quantity of stormwater runoff. As a way to manage this problem, stormwater systems were engineered to divert runoff away from the surface as quickly as possible. Most often the discharge was directed toward a natural water feature such as a stream, river or lake; often conveyed in underground stormwater pipes. Additionally, runoff flows over impervious surfaces accumulated debris, chemicals, sediment or other pollutants; contaminating vital water resources (EPA, 2009).

Awareness of the situation at all levels, federal, state and local, led to a change in stormwater management. The federal Clean Water Act of 1977 was introduced to address water quality and pollution and how we manage runoff. The National Pollution Discharge Elimination System (NPDES), under Section 402 of the Clean Water Act, regulates at the federal and state level discharges of pollutants from point sources to natural waters of the United States (EPA, 2009). Additionally, state and local permitting became required for all new development; emphasizing the use of point source pollution mitigation strategies and Best Management Practices (BMPs) for improved stormwater management.

In North Texas, the collaboration between local governments has developed an improved program to manage stormwater quality issues affecting the region (NCTCOG, 2009). The *integrated* Storm Water Management project (*i*SWM) was designed to help mitigate stormwater runoff impacts by providing guidance and suggestions to local communities; helping them to achieve their goals of water quality protection (NCTCOG, 2009).

Some municipalities have incorporated post construction monitoring ordinances into their stormwater management plans; arguably as a result of previous data supporting problematic areas needing special attention, such as industrial sites located on or near water bodies. Today, regulations are in place to limit adverse effects of stormwater runoff in new development projects including post construction evaluation; yet due to cost and ambiguities in compliance, little emphasis is placed on long term post construction monitoring. As a result, it is not so clear how some of these developments perform environmentally.

2.3.1. Urban Runoff and Non-Point Pollution

The primary source of urban stormwater runoff and water pollution is non-point pollution. Surface flow of runoff picks up and carries away natural and man-made pollutants (Environmental Protection Agency). Depending on conveyance or mitigation strategies, these pollutants can end up in bodies of water such as rivers, lakes or streams. Nonpoint source pollution includes the following pollutants:

- Excess fertilizers, herbicides and insecticides from agricultural and residential areas
- Oil, grease and toxic chemicals from urban runoff
- Sediment from construction sites, crop and forest, and eroding stream banks
- Salt from irrigation
- Bacteria and nutrients from livestock
- Atmospheric deposition and hydrmodification (Environmental Protection Agency)

In 1983, the Nationwide Characterization of Urban Runoff (NURP) report was established to study event mean concentrations of pollutants associated with urban runoff (Novotny and Olem, 1994; EPA, 1983). Due to the complexities of the study, it was reported: "regardless of the analytical approach take, we are forced to conclude that, if land use category effects are present, they are eclipsed by the storm to storm variability and that, therefore, land use category is of little general use to aid in predicting urban runoff quality at unmonitored sites or in explaining site to site differences where monitoring data exists" (Novotny and Olem, 1994; EPA, 1983).

Despite the difficulties surrounding the NURP study, the Environmental Protection Agency, through the NURP study, was able to ascertain general event mean concentrations of pollutants found in urban runoff. These results were based on statistical analysis of sampled sites throughout the United States.

2.3.2. Water Resources Investigations Report 98-4158

In 1992 and 1993, a joint effort by the United States Geological Survey and North Central Texas Council of Governments produced a study detailing urban stormwater quality, event-mean concentrations (EMCs) and estimates of pollutant loads in the Dallas-Fort Worth area. The purpose of the study was to provide information pertaining to: (1) characterization of stormwater quality with respect to 188 properties and constituents; (2) event-mean concentrations for 12 properties and constituents for three separate land uses; (3) computed pollutant loads for the 12 properties and constituents for the three land uses; and (4) estimated annual pollutant loads for the 12 properties and constituents for 26 gauged basins in the study area (Baldys, et al.; 1993).

The three separate land uses evaluated in the study were industrial, commercial and residential. Sampling of stormwater quality for selected sites representing each land use showed that residential land use had the highest median concentrations of bacteria, nitrogen, ammonia, pesticides, phosphorus, chemical oxygen demand (COD) pollution and arsenic (Baldys, et al.; 1993). Median concentrations of suspended and soluble solids, metals, and Base/Neutral and Acid-Extractable Semi-volatile Organic Compounds (BNAs) were highest in industrial land use sites (Baldys, et. al, 1993).

The pollutant load, the total amount of pollutants in stormwater runoff, was measured on the basis of seven sampled storms at each site (Baldys, et al.; 1993). Pollutant loads per square mile for trace element pollutants was greatest in the industrial land use sites; loads per square mile of diazinon was greatest in residential land use sites; loads per square mile for nitrogen were dissimilar among all three types of land use sites (Baldys, et al.;1993).

Considering density and imperviousness, the commercial land use in the study is arguably similar to that of mixed-use developments. The results of the Water Resources Investigations Report 98-4158 concluded that pollutant load and mean concentrations are less substantial in commercial areas. The residential land uses studied, containing lower density and lower ratio of imperviousness, was a major contributor to stormwater runoff and water pollution (Figure 2.3).

Nutrient	No. of samples	Maximum	Minimum	Mean	95th percentile	75th percentile	Median 50th percentile	25th percentile	5th percentile
Nitrogen, total[1] ammonia plus organic[2]									
Residential	77	7.8	0.60	1.45	3.60	1.75	1.1	0.80	0.60
Commercial	42	4.2	.30	.96	2.14	1.05	.80	.60	.40
Industrial	63	2.0	.30	.86	1.66	1.00	.80	.60	.40
Nitrogen, total[1] nitrate									
Residential	42	.15	.02	.06	.12	.07	.05	.03	.02
Commercial	20	.12	.02	.06	.12	.08	.06	.03	.02
Industrial	47	.26	.02	.06	.15	.08	.05	.03	.02
Nitrogen, total[1] nitrite plus nitrate[2]									
Residential	77	1.70	.27	.64	1.20	.80	.58	.42	.31
Commercial	42	1.50	.23	.58	1.28	.73	.52	.39	.24
Industrial	63	2.70	.26	.69	1.18	.79	.63	.49	.30
Phosphorus, total[1, 2]									
Residential	77	1.0	.16	.38	.81	.48	.33	.24	.17
Commercial	42	.74	.05	.18	.53	.28	.14	.09	.05
Industrial	63	.92	.05	.28	.71	.38	.21	.16	.06
Phosphorus, dissolved[2, 3]									
Residential	77	.84	.04	.25	.48	.34	.21	.17	.08
Commercial	42	.47	.01	.09	.30	.11	.06	.04	.01
Industrial	63	.45	.03	.14	.39	.20	.09	.06	.04
Carbon, total[1] organic									
Residential	77	370	8.2	25.5	51.9	25.0	18.0	12.0	9.08
Commercial	42	48.0	5.8	16.0	45.8	18.2	12.0	9.3	6.56
Industrial	63	58.0	6.9	19.9	44.2	26.0	18.0	13.0	8.00

[1] “Total” is the total amount of a given constituent in a representative water sample regardless of the physical or chemical form of the constituent
[2] Constituent mandated by U.S. Environmental Protection Agency (1992).
[3] “Dissolved” refers to that material in a representative water sample that passes through a 0.45-millimeter membrane filter.

Figure 2.3: Nutrient Pollutant Runoff (Baldys, et al.; 1993)

2.4 Stormwater Runoff Mitigation Strategies and Devices

There are number of regulations that ensure environmental responsibility of development. Over the last few decades stormwater runoff and water pollution has become a concern, and construction today is highly regulated at federal, state and local levels. Improvements in management, planning and design now incorporate mitigation strategies and devices to limit the impact of stormwater runoff.

In North Texas, a proactive collaboration between local governments has produced a regional stormwater management guidance program called *integrated* Storm Water

Management (*i*SWM) (NCTCOG, 2009). The purpose of the program is to assist cities and counties in achieving their goals of water quality protection, stream bank protection, and flood control as well as meeting construction and post-construction obligations required by state and federal permitting (NCTCOG, 2009). From a stormwater management standpoint, mitigation is done primarily though education, regulation and incorporation of Best Management Practices (BMPs). BMPs are activities or structural improvements that can help mitigate quantity and quality of stormwater runoff; and include treatment requirements, operating procedures, and practices to help control runoff, spillage or leaks, waste disposal or drainage from raw material storage (NCTCOG, 2009). Some examples of structural BMPs are filter berms, filtration basins, vegetated buffers and holding basins (Marsh, 2005).

Recently, Low Impact Development (LID) design techniques have been incorporated into projects specifically to help mitigate problems associated with stormwater runoff. LID is a design approach to site development and stormwater management that aims to mitigate impacts to water and air through integration and conservation of natural systems and hydrologic functions of a site (Carter and Burgess, Inc., 2004). The combination of stormwater management best management practices (BMPs) and LID work together to manage stormwater runoff in a way that reduces impacts of the built environment, and promotes the natural movement of water within a watershed (EPA, 2009). Broadly applied, LID and BMPs combined can help to maintain or restore a watershed’s hydrologic performance (EPA, 2009). LID is categorized into passive and active techniques for mitigation of stormwater. Passive techniques use natural, gravity-driven processes to slow and filter water; they include micro-basins, French drains, swales, rain gardens, vegetated rooftops, infiltration devices and permeable pavements (Carter and Burgess, Inc., 2004). Active techniques go beyond gravity-driven processes and usually include mechanical systems like pumps for rainwater capturing and distribution of non-potable water (Carter and Burgess, Inc., 2004).

2.5 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a water resource modeling tool developed to evaluate impacts of natural processes and land management practices in large, complex watersheds over significant periods of time (Neitsch, et al.; 2005). SWAT is the culmination of thirty years of development; originally based on several ARS modified hydrologic models such as:

- Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS)
- Simulator for Water Resources in Rural Basins (SWRRB)
- Groundwater Loading Effects on Agricultural Management Systems (GLEAMS)
- Erosion-Productivity Impact Calculator (EPIC) (Neitsch, et al.; 2005).

Initially, these models were created for hydrologic simulations and related processes in rural and agricultural basins; and through significant testing, research has shown these tools to be effective for the planning and design of water resources projects (Arnold, 1987).

The Soil and Water Assessment Tool (SWAT) functionality and simulation output is heavily dependent on input data and parameters representative of numerous processes that can occur in a watershed, basin or subbasin; and calculated based upon the following equation categories:

- Climate
- Hydrology
- Nutrients/Pesticides
- Erosion
- Land Cover/Plant
- Management Practices
- Main Channel Processes
- Water Bodies (Neitsch, et al.; 2005)

The Soil and Water Assessment Tool (SWAT) is a very detailed and dynamic modeling tool capable of evaluating long term impacts with daily, monthly and yearly time-steps. It is physically based and computationally efficient (Neitsch, et al.; 2002). The ArcSWAT ArcGIS extension was developed to be used with ESRI ArcGIS platform, as a way to combine features from both applications. ArcSWAT is the interface that is used in this study.

The basic modeling can be separated into four comprehensive categories, or steps; and progression is limited until processes in each category are completed. Following a successful simulation, Sensitivity Analysis and Model Calibration are used to validate model output in relation to observed data. The Watershed Delineation process uses a digital surface model to calculate accumulation, flow, designation of the drainage network, establishment of monitoring points within the network, and division of basin into subbasins, or watersheds. Hydrologic Response Unit (HRUs) analysis incorporates land use, soils and topographic input data to define and delineate areas within a subbasin containing unique combinations of land use, management and soil properties (Neitsch, et al.; 2005). HRUs assemble a variety of complex landscape properties within a subbasin into one unit; helping to simplify SWAT processing by avoiding simulations at a field scale level and increasing the prediction accuracy of loadings from the subbasin (Neitsch, et al.; 2005). Editing SWAT Input data is the final step before running a simulation which allows the user to edit primary SWAT databases as well as parameter changes at the subbasin and watershed level. The SWAT output can be generated as a text format file easily interchangeable into spreadsheet or table format.

Despite continuous upgrades to adapt to different key agricultural processes, it has been noted that there are some significant gaps in its ability to perform at a smaller scale (Gassman, et al., 2009). As the SWAT model has been primarily used in an agricultural context, little literature exists about its performance with smaller scale, urban environments.

2.5.1. Case Study of Stormwater in The Woodlands, Texas

In 2008 and 2009, a federally funded study using the Soil and Water Assessment Tool (SWAT) was completed; *Using SWAT to Compare Planning Methods for Neighborhoods: Case Study of Stormwater in The Woodlands, Texas*. The purpose of the study was to evaluate how different planning approaches compare in relation to stormwater runoff based upon Ian McHarg's planning and design of The Woodlands in Texas. Three hypothetical planning scenarios were created using SWAT: (1) conventional, low density residential, (2) the same scenario with the incorporation of stormwater Best Management Practices (BMPs) and (3) a New Urbanist, high density mixed-use development (Yang, et al.; 2009).

Using the Soil and Water Assessment Tool (SWAT) and publicly available secondary data, the study modeled each land use scenario to evaluate quality and quantity of stormwater runoff. The results showed that the high density land use scenario generated the least amount of runoff and sediments; while the conventional low density residential without Best Management Practices (BMPs) generated the most (Yang, et al.; 2009). Additionally, the study showed that with proper education, training and support, SWAT can effectively simulate land management practices and hydrology in urban environments.

2.5.2. Agricultural Policy/Environmental eXtender

The Agricultural Policy/Environmental eXtender (APEX) is an environmental modeling tool effective at simulating management and land use impacts at a farm and small watershed scale (Gassman, et al.; 2009). APEX was developed in response to limitations of Soil and Water Assessment Tool (SWAT) that became evident concluding the research in *Livestock and the Environment: A National Pilot Project* (Gassman, et al.; 2009). Over the years, through enhancements, additions and upgrades, APEX has evolved into "essentially a multi-field version of the predecessor EPIC model and can be executed for single fields similar to EPIC as well as for a whole farm or watershed this is subdivided based on fields, soil types, landscape positions, or subwatersheds” (Gassman, et al.; 2009).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This portion of the research focuses on methodology. The chapter begins with research design; which describes briefly the study population in relation to research objectives, required data, and methodological approach. In addition to some of the considerations mentioned above, the following sections include: a framework for this research to organize and display of relevant case information and results; data acquisition and processing of information using Geographic Information Systems (GIS) and the Soil and Water Assessment Tool (SWAT); and the scope and limitations of the study.

3.2 Research Design

In order to assess the stormwater runoff and pollution performance of mixed-use developments in relation to land use density and permeability of exterior design elements, a population is needed. In this study two mixed-use developments are chosen to represent the study population, primarily as a way to limit an otherwise exhaustive sampling. Criteria for site selection are based upon the following:

- Urban form typologies: horizontal and vertical
- Similarities in a mix of land uses: office, retail and residential with all other land uses being secondary;
- Common exterior design elements: structural, vehicle and pedestrian circulation, surface parking and open space.
- Applicability to Soil and Water Assessment Tool modeling.

The data needed for the study are separated into two categories based on the research objectives; (1) the evaluation of stormwater runoff and pollution in mixed-used developments, and (2) the relationship between stormwater runoff and pollution, land use density, and the imperviousness of exterior design elements.

The Soil and Water Assessement Tool (SWAT) is the primary platform used in the stormwater runoff and pollution analysis. Data type needed for SWAT varies depending on what is being modeled and desired outcome. In many studies, observational data is often used to increase accuracy of results and includes information from weather stations, stream gauges, water quality sampling, or validated results from previous studies; however, it is not always required. The most basic data categories necessary for SWAT modeling are elevation, climate, hydrology, land use, soils, water features and land cover. This type of information is generally available to the public in digital or Geographic Information Systems (GIS) format.

GIS is used for site inventory and analysis, resulting in the measurement of land use density, and imperviousness of exterior design elements. This information is needed to achieve the study objectives, yet it can not be acquired from outside sources; rather it is created manually, in digital format, based on interpretation of secondary data.

A methodological approach is developed to address the volume of data gathered and how it is to be used; the process of which is based primarily on the comprehension of Geographic Information Systems (GIS) and Soil and Water Assessment Tool (SWAT) functionality in relation to study objectives. The developed methods, or procedures, are applied to both cases; acting as a control to help generalize results and limit outside influences. The general method, or procedure, used in this study is as follows:

- Acquire necessary data
- Inventory and analysis of the site
- Site observation
- Calculate land use density and exterior design element permeability

- Set up the SWAT simulation
- Configure and modify data/ parameters in relation to land use density
- Develop and incorporate land management operations schedule
- Run the simulation for a 5 year period at monthly intervals
- Display the results

3.3 Case Study Design

Case studies are used in research as a way to collect, present and analyze data fairly (Yin, 2009). In the design profession, they often illustrate or analyze a project or process and can be organized based upon type of project, a problem, geographic region or designer (Francis, 1998). Case studies vary in format and detail depending on scope and subject matter of research goals. In this research, two case studies are used following an abstract format providing basic project information, and site location; with the body of the study focusing on land use density, permeability of exterior design elements and site characteristics relevant to the Soil and Water Assessment Tool (SWAT) modeling. The primary purpose of each case study is to organize, analyze and display information; the objective of which is to answer three questions: (1) what is the land use density, (2) what is the measurement of imperviousness of design elements, and (3) what is the water quality of stormwater surface runoff.

3.4 Data Acquisition

The first phase of this study concentrates on the acquisition of secondary data through applied research. The majority of this data will be used as a base for the GIS inventory and analysis. As a way to minimize the complexity associated with numerous data resources, this study utilizes resources where data is publically available. Additionally, using these sources may help to normalize results of the stormwater runoff assessment.

North Central Texas Council of Governments (NCTCOG) is used as the primary resource for local Geographic Information Systems (GIS) data. The GIS data includes, but not limited to, transportation, aerial photography, land use, ground surface, water features, soils, and political boundaries. User data is created using the information obtained to produce a detailed inventory and analysis of land use density and a measurement of surface area permeability of exterior design elements. Additionally, relevant information was obtained from Cooper and Stebbins, City of Southlake and the City of Addison, and The University of Texas at Arlington.

Table 3.1: Secondary Data Sources

	NCTCOG	**NHD**	**USGS**	**USDA**	**UTA**	**TNRIS**	**City of Southlake**	**City of Addison**	**Cooper and Stebbins**
Roads	x					x			
Water Features	x	x							
Watersheds		x							
Soils	x		x						
Digital Elevation Model						x			
Digital Elevation Contour	x								
City Boundaries	x					x			
County Boundaries	x					x			
Land Use	x						x	x	
Aerials	x			x					
Project Information								x	x
Building Footprint					x				

- NCTCOG- North Central Texas Council of Governments
- NHD- National Hydrography Dataset
- USGS- United States Geological Survey
- USDA- United Stated Department of Agriculture
- UTA- The University of Texas at Arlington
- TNRIS- Texas Natural Resources Information System

3.5 GIS Component

Although used throughout the study, the primary function of Geographic Information Systems (GIS) is for the site inventory and analysis. The method involves using secondary information to create user data resulting in a spatial, quantitative database of land use density and surface area permeability. Since the majority of the GIS information acquired was obtained from North Central Texas Council of Governments (NCTCOG), all user and Soil and Water Assessment Tool (SWAT) information was re-projected to match the spatial attributes of the NCTCOG data.

To set up the site inventory and analysis, shapefiles obtained from NCTCOG are used as a base and spatial reference: 2 foot resolution orthophotography, transportation networks, political boundaries and water features. Initially, a feature class file is created to delineate the site boundaries and calculate the total land area. Separate line feature class files are created for each design element:

- Circulation: Vehicle and Pedestrian
- Public Space
- Parks
- Parking Lot Islands
- Foundation Landscape
- Streetscape
- Structural
- Water Features

For the purpose of this research surface parking, pedestrian walkways and vehicular circulation are combined into one category (circulation). The Streetscape category combines frontage and any permeable surface areas accessible to pedestrians. Tree wells are not included in this study due to the complexities associated with methodology.

The method used to delineate each design feature is based primarily upon interpretation of the 2 foot resolution orthophotographs. The process of delineation is not automated and the digitization is labor intensive. Due to uncertainty related to the orthophotograph interpretation, a cross reference between different orthophotgraph sources is utilized to help clarify ambiguities. Basic geo-processing is done to convert the line feature class into an area.

The results of the inventory and analysis are entered into a table and displayed to show calculations of area and surface category (Table 3.2). This method and process is the same for all case studies.

Table 3.2: Exterior Design Elements Inventory

DESIGN ELEMENTS:	Area ft2	Impermeable	Permeable
Circulation			
Public Space			
Parks			
Parking Lot Islands			
Foundation Landscape			
Streetscape			
Structural			
Water Features			

3.6 SWAT Component

The Soil and Water Assessment Tool (SWAT) is used for the hydrologic modeling, the output of which provides detailed data related to surface runoff and water quality. Specific data is required by SWAT in order to set up a simulation; the most basic of which is elevation, soils, weather, and land use. For purposes of this study, soil and weather data used in the simulations are incorporated into the SWAT interface, and can readily be inserted into the setup. Digital Elevation Models (DEM) at 30 meter resolution, used for large scale topographical analysis, is obtained from Texas National Resources Information System

(TNRIS). For specific site elevation, 2 foot Digital Elevation Contours (DEC) are acquired from North Central Texas Council of Governments (NCTCOG). The land use data used in this study is a modified combination of NCTCOG 2005 Land Use, City of Southlake current land use, and user defined land use based upon inventory and analysis of impervious and permeable surfaces. The primary categories of the user modified land use are: urban high density residential (URHD), urban medium density residential (URMD), commercial (UCOM), transportation (UTRN), institutional (UINS), open space Bermuda (BERM), undeveloped Hardwood forest (FRSD), and water (WATR). The urban land information incorporated into the Soil and Water Assessment Tool database is derived from other inventoried watersheds with similar land types and thus the density of residential categories used in this study are defined as follows:

- Residential-High Density- >8 unit/acre or unit/2.5 hectare
- Residential-Medium Density- 1-4 unit/acre or unit/2.5 hectare (Neitsch et al.; 2004)

Hydrologic response units (HRUs) are produced from land use, soils and elevation data inputs. HRUs are portions of a subbasin that have unique land use, soil, slope and land management characteristics. They are used most often to simplify a simulation by combining all similar soil and land use areas into a single response unit (Neitsch, et al.; 2002).

Input tables are written and incorporated into the simulation, most often unmodified to set up a default run. This allows the user to notice anything unusual in the output before a significant amount of time is spent modifying input parameters. There are thirty input files, or variables, of which fifteen are required (Appendix A), and are categorized by watershed level, subbasin level, HRU level, reservoir and point source. During the editing process, the Soil and Water Assessment Tool (SWAT) has a feature in the interface that allows the user to incorporate data from the Agricultural Policy/Environmental eXtender (APEX).

A detailed and extensive calibration and sensitivity analysis can be performed on a simulation to validate output in relation to observed data; and is most successful for advanced users. The process is generally divided into several steps depending on observed data and desired calibration goals: water balance and stream flow, sediments and nutrients (Neitsch, et al.; 2002). The lack of observed data made sensitivity analyses and model calibrations impractical for this study.

3.7 Delimitations

Understanding the environmental performance of mixed-use developments (MXDs) in North Texas as the broader issue, this study evaluates stormwater runoff of MXDs using a combination of Geographic Information Systems (GIS) and the Soil and Water Assessment Tool (SWAT). More specifically, it is focused on the nutrient pollution of stormwater runoff in relation to land use density and the imperviousness of design elements. Other important factors such as velocity, flow, flooding, downstream channel erosion, and offsite influences are not within the scope of this study.

3.8 Limitations

The Soil and Water Assessment Tool (SWAT) modeling approach was primarily developed to evaluate various natural processes and land management practices in large scale watersheds. Parameters associated with mixed-use developments as an urban form do not readily convert to modeling parameters of SWAT. Literature suggests that environmental models such as the Agricultural Policy/Environmental eXtender (APEX) and SWAPP are designed to run simulations at a smaller scale, or field level; representing a different approach to hydrologic modeling. SWAPP is software that was developed to convert SWAT files to and from APEX formats to model simultaneously (Saleh and Gallego, 2006). Historically, SWAT has been used in agricultural and rural settings, and not specifically in high density urban scenarios. As a result there is not a significant amount of literature, experience or technical knowledge to use as a guide for this research. This study is the first to use SWAT for a post construction evaluation of stormwater runoff and water pollution in high density cluster development.

A significant portion of the research utilizes publicly available secondary data, primarily in the GIS inventory and analysis, and SWAT modeling. This data is created by others, and has not been validated for this study. Quality Assurance/Quality Control (QA/QC) procedures can be performed to review the data and identify major errors such as attribution of GIS features or topology. However, in this study, a significant amount of time is not allocated for secondary data review. An assumption was made that a substantial QA/QC was performed on the data by the developers prior to distribution.

CHAPTER 4

ANALYSIS AND FINDINGS

4.1 Introduction

Included in this chapter is the Soil and Water Assessment Tool (SWAT) analysis of the two case studies, Southlake Town Square and Addison Circle. The primary purpose of each case study is to organize, evaluate, report and display information; the objective of which is to answer three questions: (1) what is the land use density, (2) what is the measurement of imperviousness of streetscape elements, and (3) what is the water quality of stormwater surface runoff?

Each case study begins with an introduction containing basic project history and information as well as the site location. Following the introduction is detailed information regarding site characteristics related to Soil and Water Assessment Tool (SWAT) modeling data input; such as topography, hydrology, weather, soils, land use and land management practices. A portion of the site characteristics section includes the inventory and analysis process of measuring land use density and permeable surface areas. The third section of the case study describes SWAT input data, modifications, and modeling process (steps) of the simulation. Concluding the case study is the reporting and display of SWAT modeling results of stormwater runoff and pollution performance in relation to land use density and the imperviousness of exterior design elements.

4.2 Case Study: Southlake Town Square

4.2.1. Project Information and Scenario

Southlake Town Square is a 125 acre master planned mixed-use development, located within the corporate limits of the city of Southlake, Tarrant County in North Texas. It is bound to the north by State Highway 114, to the south by Southlake Boulevard, and to the west by Carroll Avenue (Figure 4.1). The primary mixes of uses are commercial, retail, office, residential and institutional. Like many town squares in Texas, Southlake Town Square is home to Southlake City Hall. The development of Southlake Town Square began in 1998, though the collaboration between developer Cooper and Stebbins, designers David M. Schwarz Architects and Mesa Design Group, and the City of Southlake. Phase I construction began in 1998, incorporating 235,000 square feet of office, retail and institutional uses; with another 48,000 square feet of retail space added over several years. The first residential component, in Phase II, began in 2004 and was completed in 2005. Future construction will add more commercial, retail and residential uses with an ultimate build out potential of 2 million square feet (Figure 4.2) (Southlake Economic Development, 2006).

The hydrologic scenario used in this case study is to evaluate the water quality of stormwater runoff *surface flow*; based on a modified land use, measurement of imperviousness, surface drainage from site elevations, soil content, weather and land management operations designed for land cover maintenance. It is important to note that the actual conveyance of stormwater is directed underground through engineered stormwater systems, and deposited into a series of retention and detention basins. Ultimately, the stormwater runoff is primarily managed on site, with little runoff draining into stream networks.

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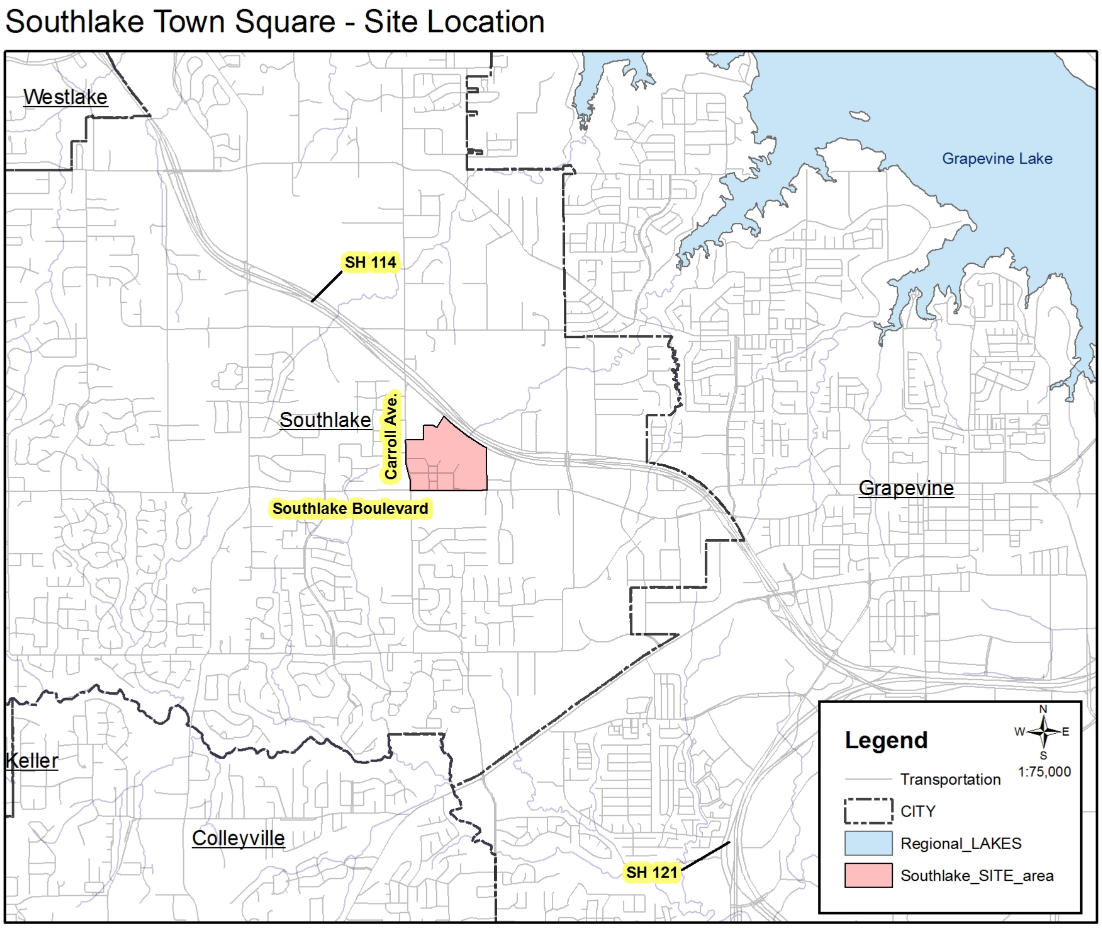
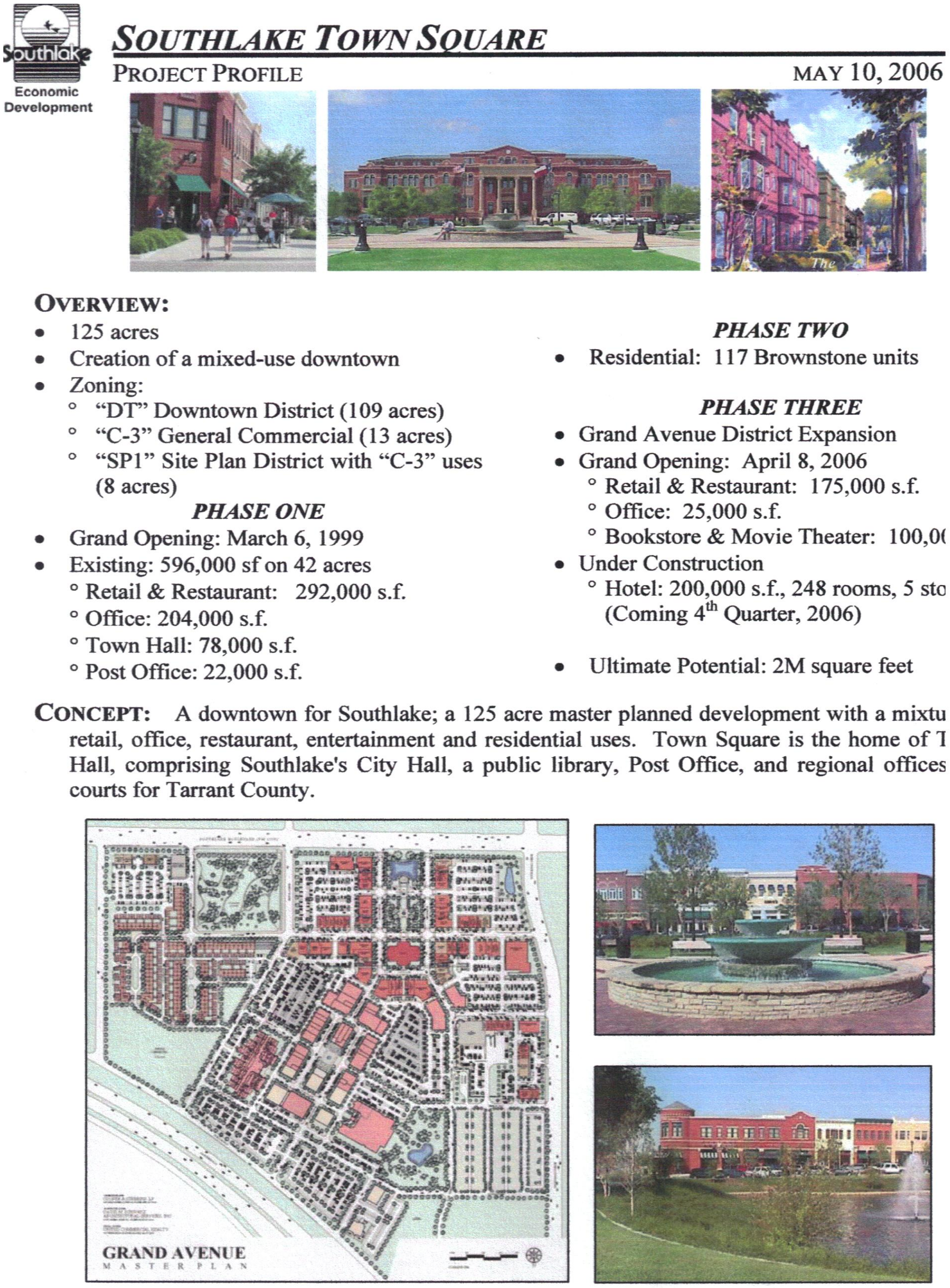


Figure 4.1: Southlake Town Square Location (adapted from NCTCOG, 2009)

actual conveyance of stormwater is directed underground through engineered stormwater systems, and deposited into a series of retention and detention basins. Ultimately, the stormwater runoff is primarily managed on site, with little runoff draining into stream networks.



Southlake
Economic
Development

SOUTHLAKE TOWN SQUARE

PROJECT PROFILE

MAY 10, 2006

OVERVIEW:
- 125 acres
- Creation of a mixed-use downtown
- Zoning:
  - "DT" Downtown District (109 acres)
  - "C-3" General Commercial (13 acres)
  - "SP1" Site Plan District with "C-3" uses (8 acres)

PHASE ONE
- Grand Opening: March 6, 1999
- Existing: 596,000 sf on 42 acres
  - Retail & Restaurant: 292,000 s.f.
  - Office: 204,000 s.f.
  - Town Hall: 78,000 s.f.
  - Post Office: 22,000 s.f.

PHASE TWO
- Residential: 117 Brownstone units

PHASE THREE
- Grand Avenue District Expansion
- Grand Opening: April 8, 2006
  - Retail & Restaurant: 175,000 s.f.
  - Office: 25,000 s.f.
  - Bookstore & Movie Theater: 100,0
- Under Construction
  - Hotel: 200,000 s.f., 248 rooms, 5 sto (Coming 4th Quarter, 2006)
- Ultimate Potential: 2M square feet

CONCEPT: A downtown for Southlake; a 125 acre master planned development with a mixtu retail, office, restaurant, entertainment and residential uses. Town Square is the home of T Hall, comprising Southlake's City Hall, a public library, Post Office, and regional offices courts for Tarrant County.

Figure 4.2: Southlake Town Square Project Profile (Southlake Economic Development, 2006)

4.2.2 Site Characteristics

4.2.2.1. Topography

Large scale ground surface analysis was done prior to Soil and Water Assessment Tool (SWAT) set-up and modeling. United States Geological Survey (USGS) Digital Elevation Models (DEMs) at 30 meter resolution were downloaded from Texas Natural Resources Information System (TNRIS) for the Colleyville and Grapevine quadrangles. DEM 30 meter resolution is the cell size for the grid, meaning each cell is 30 meters by 30 meters. Review of this data provided a regional topographic assessment of elevation variations in the corresponding watersheds, possible flow directions and collecting water features (Figure 4.3).

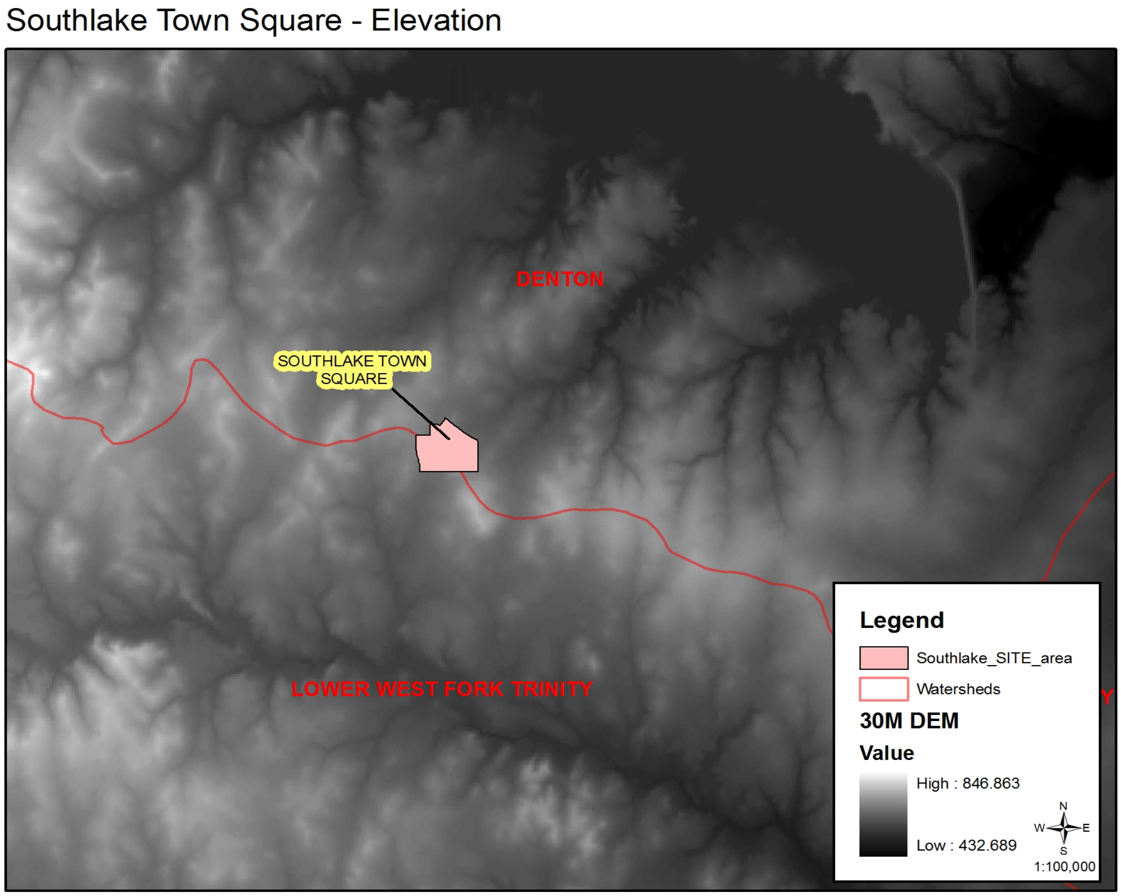


Figure 4.3: Southlake Town Square Regional DEM (adapted from TNRIS, 2009)

Slope analysis in the vicinity of Southlake Town Square showed several areas with significant grade changes. Within the site, the lowest slope percentages are in the southwest and northern sections; indicating natural areas for drainage (Figure 4.4).

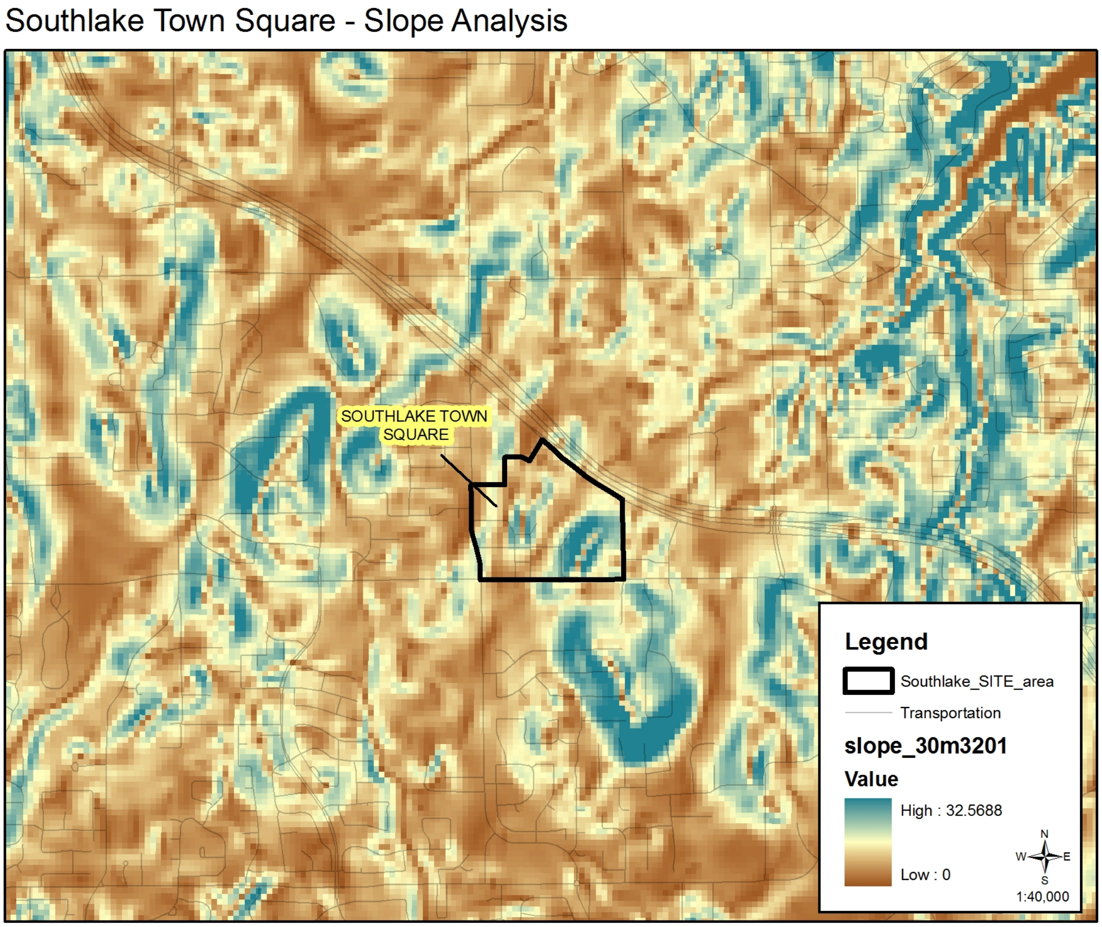


Figure 4.4: Southlake Town Square Slope Analysis (adapted from TNRIS, 2009)

Realizing the 30 meter Digital Elevation Models (DEMs) don’t always reflect changes in topography resulting from new development, this study utilized 2007 updated Digital Elevation Contours (DECs) acquired from North Central Texas Council of Governments (NCTCOG) for the actual Soil and Water Assessment Tool (SWAT) modeling (Figure 4.5). The 2 foot interval contours were converted to raster, or grid format, as required by SWAT. In order to rasterize and model small areas in SWAT, such as parking lot islands, the grid cell size was changed to 1,1; whereas each cell is 1’ x 1’.


Southlake Town Square - 2007 2' Digital Elevation Contours

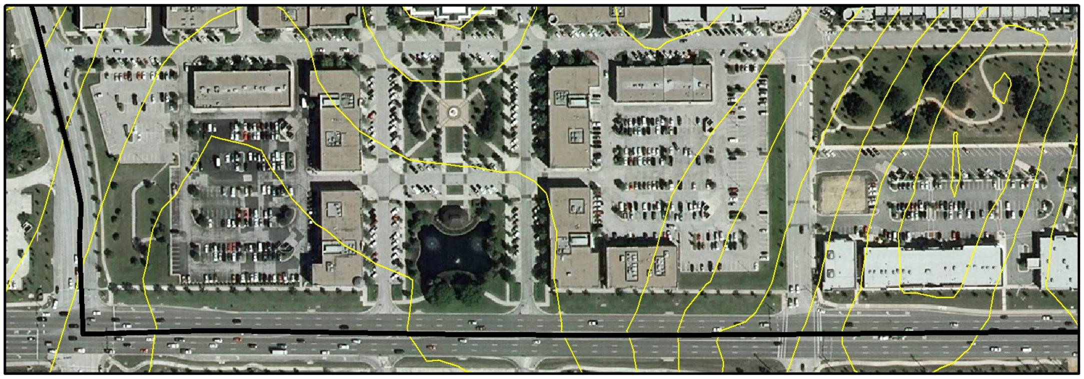

Southlake Town Square - 30m DEM 5' contours

Figure 4.5: Southlake Town Square DEC and DEM Contours (adapted from NCTCOG, 2009)

Results of the topographic analysis show that based on the United States Geological Survey (USGS) Digital Elevation Models (DEMs), the natural drainage at Southlake Town Square is to the northeast and southwest. The 2’ interval Digital Elevation Contours (DECs) combined with grid and 3D model, further show drainage in Southlake Town Square is to the northeast and southwest. Historical and new topographic data both have the same site outlets for drainage; and from a design standpoint, this shows us that developers, planners and designers we careful to mimic the natural drainage.

4.2.2.2. Hydrology

Southlake Town Square is perhaps unique from a Soil and Water Assessment Tool (SWAT) modeling standpoint. The development is located on a ridge, or area of high ground, and is essentially a starting point in two drainage networks; bordering the Denton and Lower West Fork Trinity watersheds (Figure 4.6). The natural surface runoff is to the northeast into Grapevine Lake, and southwest into Big Bear Creek. The topographic and slope analysis from the previous section shows that developers, planners and designer were careful to mimic as best as possible natural drainage conditions; and stormwater runoff is managed primarily on site through a series of structural Best Management Practices (BMPs). Identifiable onsite BMPs

Southlake Town Square - Watersheds

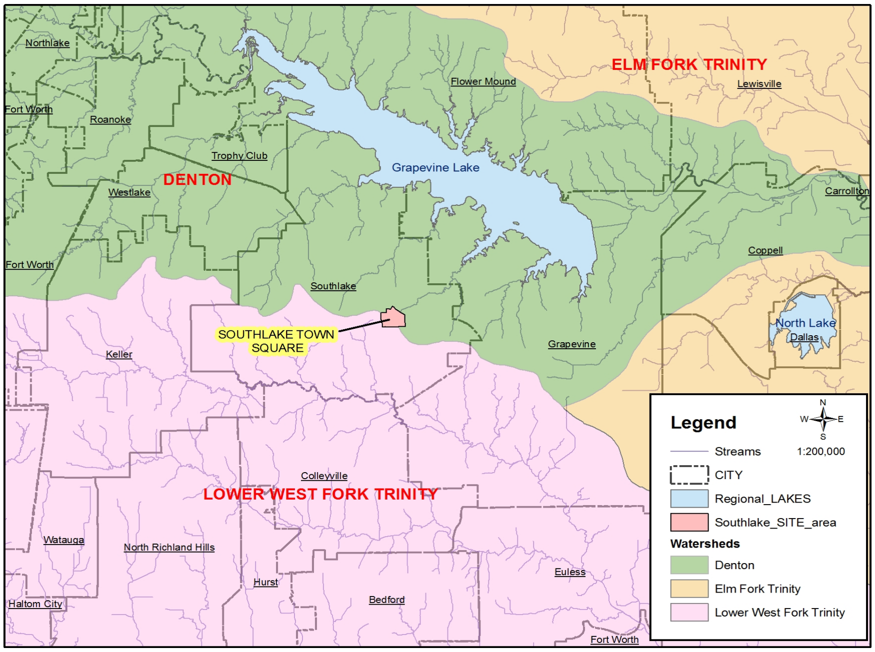


Figure 4.6: Southlake Town Square Regional Watersheds (adapted from NCTCOG)

include detention and retention basins that double as open space amenities (Figure 4.7).

Figure 4.7: Southlake Town Square Retention and Detention Basins

For Soil and Water Assessment Tool (SWAT) modeling, the Digital Elevation Contours (DECs) in grid format was loaded into the SWAT project to set up the foundation for watershed delineation. In this study, the DEC grid was used as the primary source to calculate accumulation and flow based on areas of 5 hectares. This helps to reduce the detail of stream networks, inlets, and ultimately, the number of subbasins within the watershed. Stream network, longest reach and outlets were derived from the accumulation and flow calculation, and three manually added outlets were inserted at the major drainage points; two at the northern edge of the site, and one at the southwestern edge. The basin was divided into 9 subbasins, or watersheds, based on Digital Elevation Contour (DEC) grid processing, stream networks, and manually added outlets (Figure 4.8).

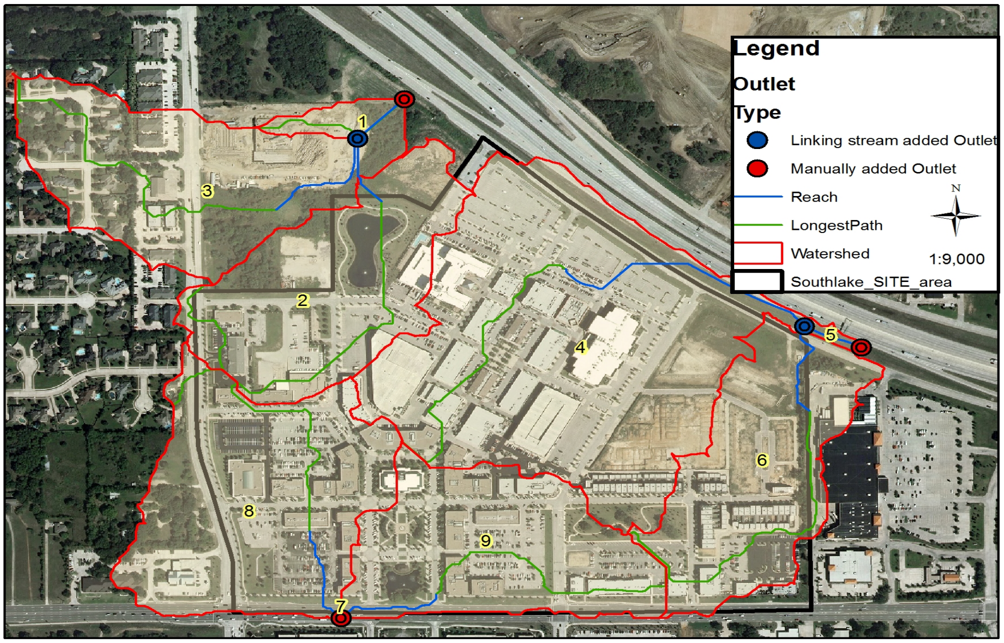


Figure 4.8: Southlake Town Square Hydrology

4.2.2.3. Soils and Weather

The soils information used in this study, State Soil Geographic Database (STATSG0), is from the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service

(NRCS) and is available through the Soil and Water Assessment Tool (SWAT) interface. Southlake Town Square and surrounding areas have Callisburg type soils, and are characteristic of the Cross Timbers region of North Texas. The soils have been formed on a dissected, rolling landscape with low to moderate topography dissected by numerous streams (Risinger, 2007). The Callisburg series are deep, well drained, moderately slowly permeable soils with slow to medium runoff typically formed in beds of clay and clay shale. Use is primarily agricultural for pasture and grain crops, with native vegetation consisting of post oak and blackjack oak with bluestem and other rangeland grasses as an understory (National Cooperative Soil Survey, 2010) (Figure 4.9). No soil parameters were changed in this study.

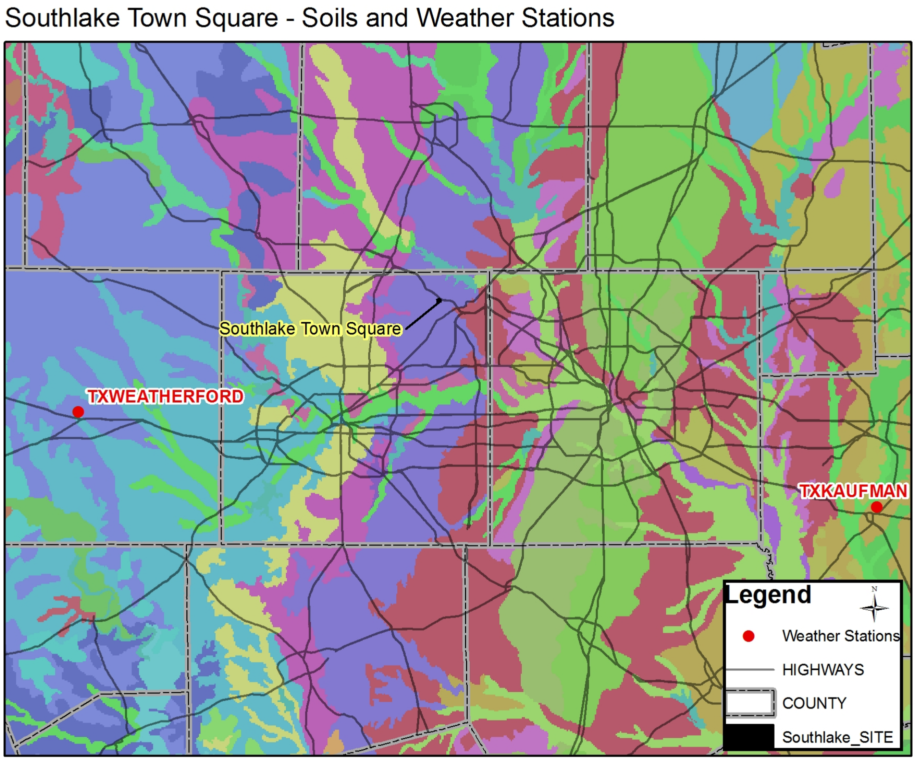


Figure 4.9: Regional Soils and Weather Stations (adapted from STATSG0, 2009)

Weather data used in this study is from the Soil and Water Assessment Tool (SWAT) weather geo-database that comes with the interface. Data from the weather generator contains weather data from 1,041 weather stations from around the United States and is based on a model developed by Nicks in 1971, whereas daily values are generated from average monthly values (Neitsch, et al.; 2005). SWAT does have the option, however, to incorporate weather data from other sources. When using the SWAT weather data, the software locates geographically the closest weather station to the study area. In this case, the closest weather station is in Weatherford, Texas (Figure 4.9). No weather parameters were changed in this study.

4.2.2.4. Land Use

The land use data used in this case study is a combination of data obtained from North Central Texas Council of Governments (NCTCOG) and the City of Southlake. The current mix of uses onsite are Commercial, Office, Retail, Hotel, High Density Residential, Institutional and Public Park. For purposes of this study, Retail, Office and Hotel land use categories were combined into Commercial.

Impermeable surface areas (surface parking, rooftops and pedestrian circulation) were combined with their corresponding land use, and the FIMP (fraction of total impervious area in urban land type) and FCIMP (fraction directly connected to impervious area in urban land type) parameters for Urban Commercial, Institutional and High Density Residential were changed to better reflect actual imperviousness. Additionally, SCS Runoff Curve parameters for the urban area land use types of Commercial, Institutional, and High Density Residential were changed based on surface condition of runoff; in this case, hard surface, which reflects the level of imperviousness.

Permeable open space areas, parks and parking lot islands were classified as a separate land use, BERM (Bermuda grass). BERM is categorized as a land cover/plant growth crop. No crop or hydrological parameters were changed for this category with the exception of indicating it as a fertilized crop. Identifiable onsite vehicle circulation was incorporated into a separate urban land use: Transportation. FIMP (fraction of total impervious area in urban land type) and FCIMP (fraction directly connected to impervious area in urban land type) urban area parameters were increased and the hydrological SCS Runoff Curve numbers were changed to reflect surface condition of runoff. Pedestrian walkways and surface parking were incorporated into this group as well.

Due to the modifications in the land use data, a user look-up table was created based upon the urban land use codes and values integrated into the SWAT interface. The following is a list of land use categories within the basin (Figure 4.10).

- URHD- Urban High Density Residential (>8 unit/acre)
- URMD- Urban Medium Density Residential (1-4 unit/acre)
- UCOM- Urban Commercial
- UTRN- Urban Transportation (circulation)
- UINS- Urban Institutional
- BERM- Bermuda Grass (open space, parks and parking lot islands)
- FRSD- Hardwood Forest (undeveloped, native Cross Timbers)
- WATR- Water (Neitsch et al.; 2004)

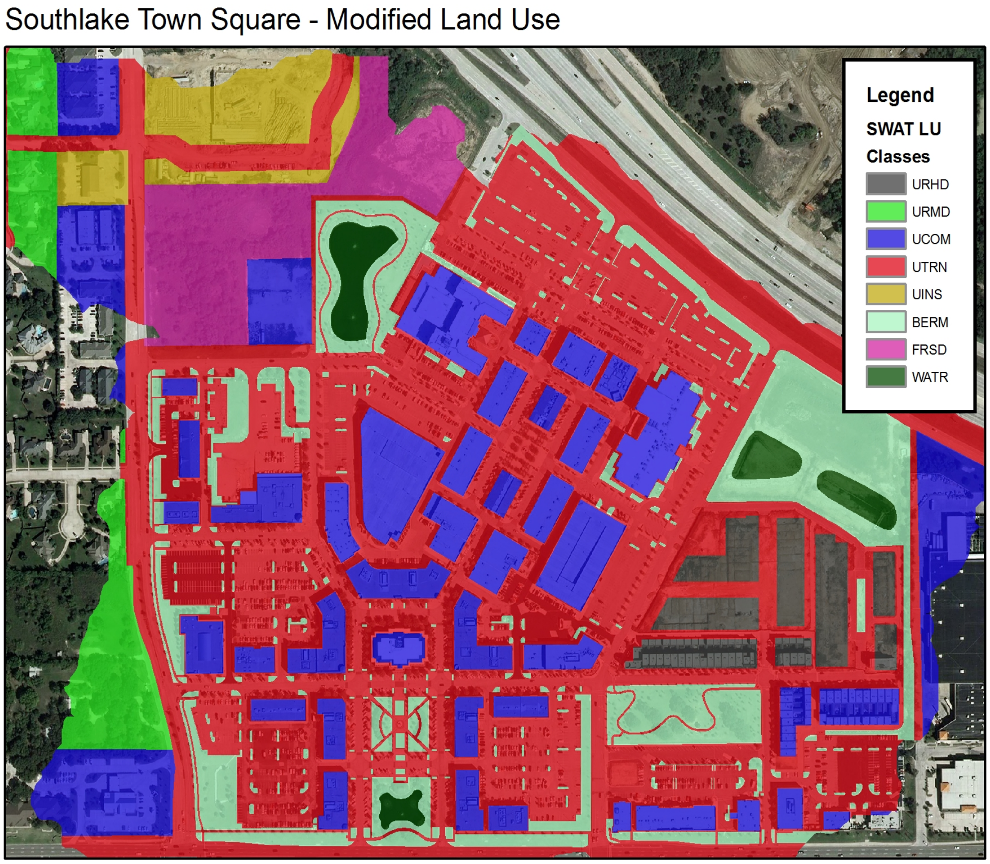


Figure 4.10: Southlake Town Square Land Use (adapted from City of Southlake, NCTCOG, 2009)

4.2.2.5. Land Management

An important function of the Soil and Water Assessment Tool (SWAT) modeling is the quantification of land management practices and natural processes in watersheds or river basins. Land management practices used in this study were assigned to permeable surface areas; these areas include open spaces, parks and streetscape elements such as parking lot islands. As a way to manage the health and appearance of turf grass areas, a very basic fertilizer operations schedule was developed.

For turf grass fertilization, a high nitrogen fertilizer was used, 24-6-00, at a rate of .5 pounds of Nitrogen per 1000 square feet. This rate is low for Bermuda grass maintenance, with higher rates generally applied to active turf grass areas such as sports fields and golf courses. The applications started in April, and continued every six weeks until the end of the growing season in November. For this study, fertilizer amount used for 24-6-0 was 101.5 kilograms per hectare. No fertilizer related parameters were changed.

4.2.2.6. Land Use Density

Land use density is a measurement of imperviousness. For this study, Geographic Information Systems (GIS) is used to measure the land use density based upon interpretation of 2 foot resolution orthophotographs obtained from North Central Texas Council of Governments (NCTCOG). The NCTCOG images were cross referenced with publically available Google Earth aerial photography to help clarify areas obscured by shadow or tree canopies. All discernible exterior design elements were digitized, and areas calculated; tree wells were not included. The exterior design element categories are: (1) Circulation-vehicle and pedestrian, (2) Public Space, (3) Parks, (4) Parking Lot Islands, (5) Foundation Landscape, (6) Streetscape-frontages, (7) Water Features. The total area of the site is 5,371,004 square feet, or roughly 124 acres. Impervious surface areas covered 75.6% of the site, containing 4,065,029 square feet, or roughly 93 acres (Figure 4.12). Permeable surface areas of exterior design and open space elements are measured at 1,305,975 square feet, or roughly 30 acres. Bodies of water in this study were incorporated into the permeable surface area measurements. Calculations of area, in square feet, can be seen in Table 4.1 and acre conversions in Figure 4.11.

Table 4.1: Southlake Town Square Land Use Density Calculations

DESIGN ELEMENTS:	IMPERMEABLE (SQ.FT.)	PERMEABLE (SQ.FT.)
Circulation	2,910, 016	
Public Space		45,141
Parks		440,855
Parking		47,770
Foundation Landscape		80,420
Streetscape		574,107
Structural	1,155,013	
Water Features		117,682
TOTAL	**4,065,029**	**1,305,975**

Figure 4.11: Southlake Town Square Design Element Area Measurement

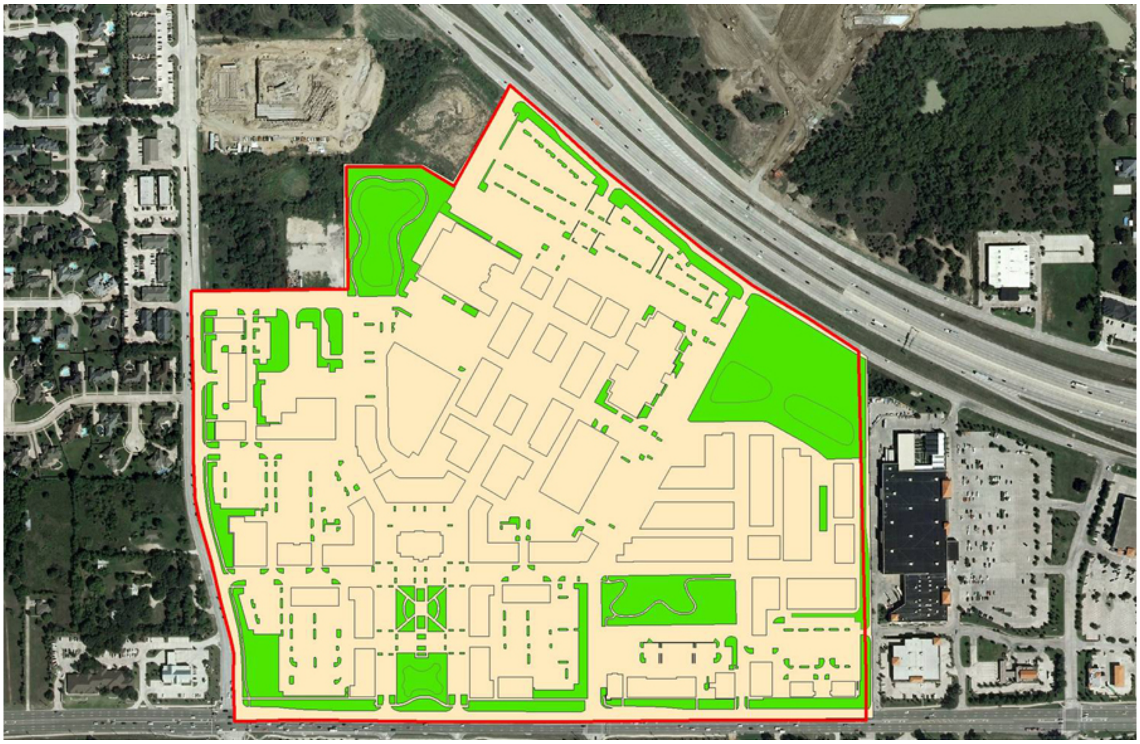


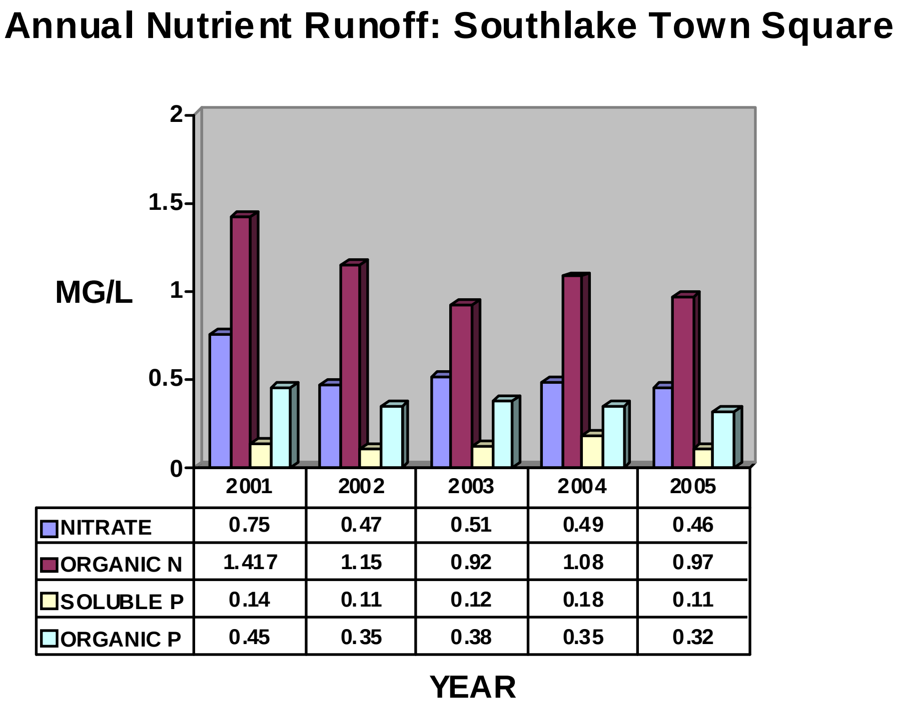
Figure 4.12: Southlake Town Square Land Use Density

4.2.3. Soil and Water Assessment Tool Modeling Results

To assess stormwater runoff and pollution in Southlake Town Square, two separate simulations were run through the Soil and Water Assessment Tool (SWAT). The first simulation is used primarily to gauge model input and was run for three years. This is similar to a default run whereas input data was not modified and operation schedules were not included. Review of default model output allows the researcher to check for any significant problems associated with primary data used in the model set up. The second simulation included a five year run at monthly intervals, with parameter changes made to reflect actual site conditions, and the incorporation of a basic maintenance operation for turf grass health and appearance.

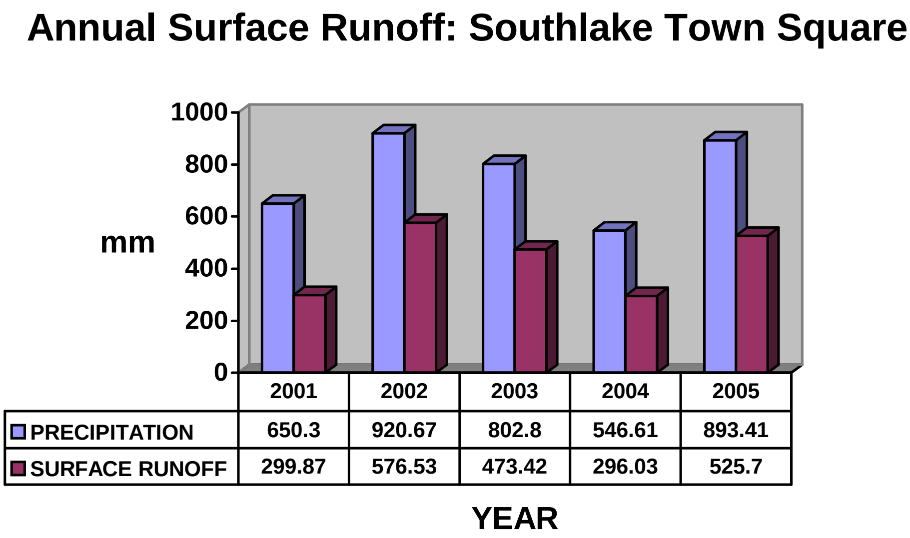
The results for the five year scenario are taken from the generalized output file, and displayed in Figure 4.13 and 4.14 for yearly averages of precipitation, surface runoff, and nutrient runoff. Precipitation and surface runoff are measured in millimeters; nutrient runoff is measure in kilograms/hectare, and converted into milligrams/liter. The following is a brief description and definitions of terms used in the output:

- UNIT TIME- This is broken into number of months for the simulation in a specific year
- PREC- Precipitation in mm
- SURQ- Surface runoff in mm
- NO3SURQ- Amount of Nitrate in the surface runoff in kg/ha
- NORGANIC- Amount of organic nitrogen in the surface runoff kg/ha
- PSOLUBLE- Amount of soluble phosphorus in the surface runoff hg/ha
- PORGANIC- Amount of organic phosphorus in the surface runoff kg/ha



	2001	2002	2003	2004	2005
NITRATE	0.75	0.47	0.51	0.49	0.46
ORGANIC N	1.417	1.15	0.92	1.08	0.97
SOLUBLE P	0.14	0.11	0.12	0.18	0.11
ORGANIC P	0.45	0.35	0.38	0.35	0.32

Figure 4.13: Southlake Town Square Annual Nutrient Runoff



	2001	2002	2003	2004	2005
🟦 PRECIPITATION	650.3	920.67	802.8	546.61	893.41
🟥 SURFACE RUNOFF	299.87	576.53	473.42	296.03	525.7

Figure 4.14: Southlake Town Square Annual Surface Runoff

4.3 Case Study: Addison Circle

4.3.1. Project Information and Scenario

Addison Circle is a vertical, moderately high density neighborhood center with mixed-use buildings located in Addison, Texas (New Urban News, 2003). It is bound on the east side by the Dallas North Tollway, Arapaho Road to the south and Addison Road to the west and Airport Parkway to the north (Figure 4.15). In 1992, the idea for Addison Circle came to fruition through the futures planning done by the Addison 2020 Committee; by 1998, a collaboration between the City of Addison and developers worked to create of set of codes and ordinances to govern the new community, a model which was based on multi-use districts in European communities as well as Boston's Back Bay and Chicago's Lincoln Park (The City of Addison, 2010). The site contains 124 acres with a primary mix of residential, institutional, commercial (office and retail) and public use; nearly 5 million square feet of residential with 4800 units, and 6 million square feet of mixed commercial (Whitehead and Rutherford, 2004). The development partners for Phases 1-3 consist of Columbus Realty Trust, Post Properties and Champion Partners Gaylord Properties; Phase 4, Amicus Partners; and the involvement of the Town of Addison in all phases (Whitehead and Rutherford, 2004). RTKL Associates, Inc. is the urban designer (New Urban News, 2003; Whitehead and Rutherford, 2004).

The hydrologic scenario used in this case study is similar to that of the scenario used in the Southlake Town Square; whereas the purpose is to assess the water quality of stormwater runoff *surface flow* using a modified land use, level of imperviousness, surface drainage based on elevation, soil structures, weather and land management operations used for basic land cover maintenance. A brief site inspection was performed to analyze actual site stormwater management. Taking into consideration site slope, it appears that the stormwater is conveyed underground to the east toward the natural drainage networks connected to White Rock Creek.

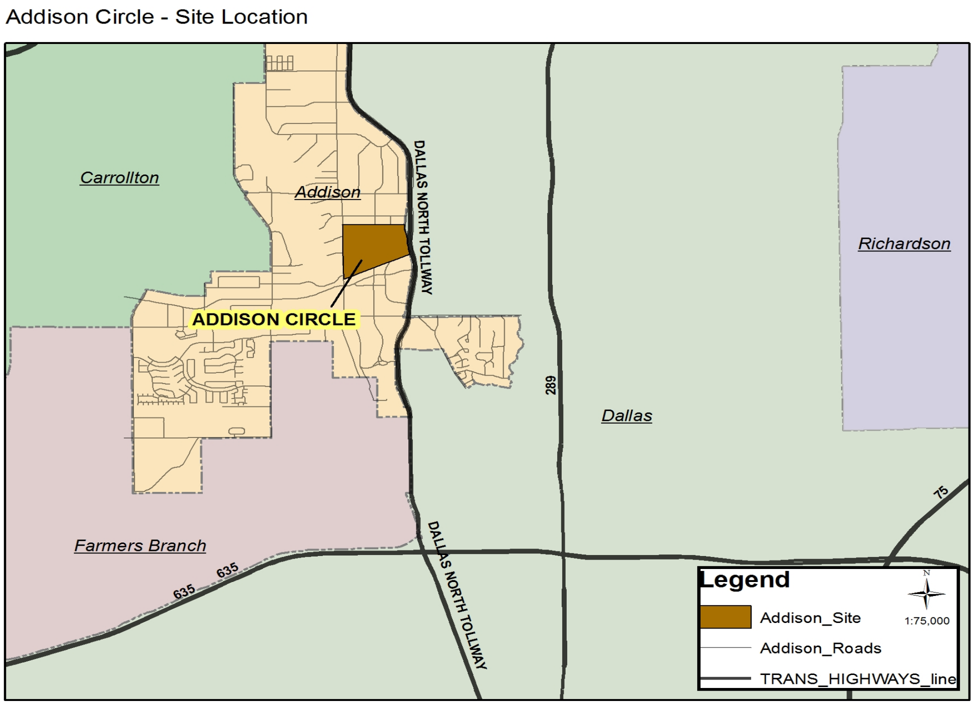


Figure 4.15: Addison Circle Site Location (adapted from NCTCOG, 2009)

4.3.2. Site Characteristics

4.3.2.1. Topography

A regional evaluation of elevation is performed based upon 30 meter resolution Digital Elevation Models (DEM) taken from the United States Geological Survey (USGS) Addison Quadrangle; resulting in a topographic assessment of the surrounding areas in relation to watersheds and drainage networks (Figure 4.16).

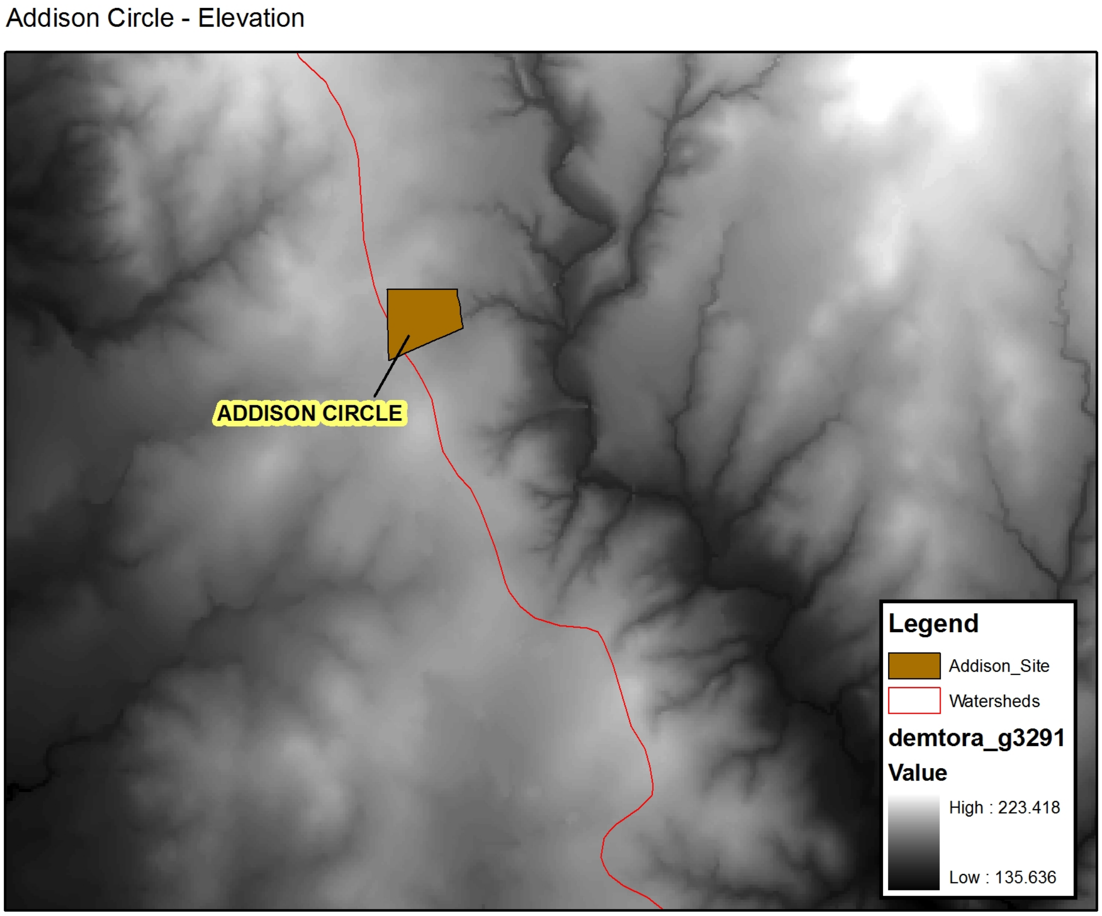


Figure 4.16: Addison Circle Regional DEM (adapted from TNRIS, 2009)

Slope analysis is conducted in Geographic Information Systems to identify significant changes in elevation. The slope analysis revealed that the area surrounding Addison Circle, and the site itself, is very flat. Slopes ranged from 0% to 4% with the higher ranges near or at natural drainage channels and stream banks (Figure 4.17).

A comparison is performed on two different elevation sources, 30 meter Digital Elevation Model (DEM), and 2’ interval Digital Elevation Contours (DEC) derived from Light and Detection and Ranging x, y and z points. The comparison shows that the 2’ interval DEC contours are more accurate that the 2’ contours derived from the USGS 30 meter DEM (Figure 4.18). The 2 foot interval contours are converted to raster, or grid format, as required by SWAT and the grid cell size was changed to 1, 1; whereas each cell is 1’ x 1’.

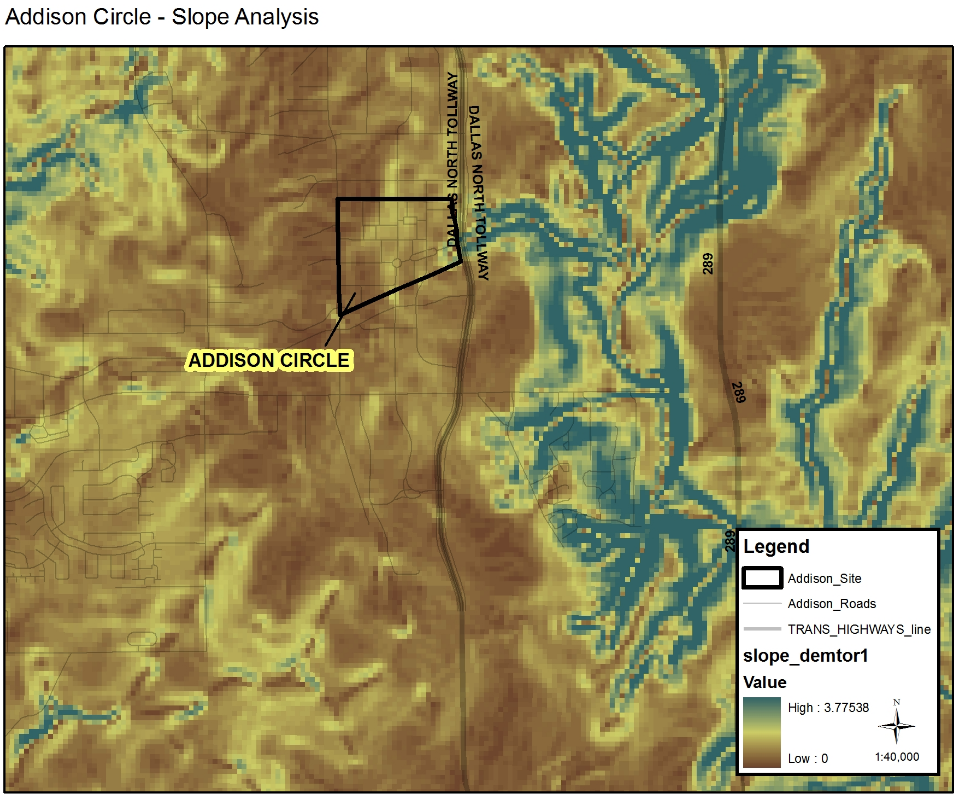
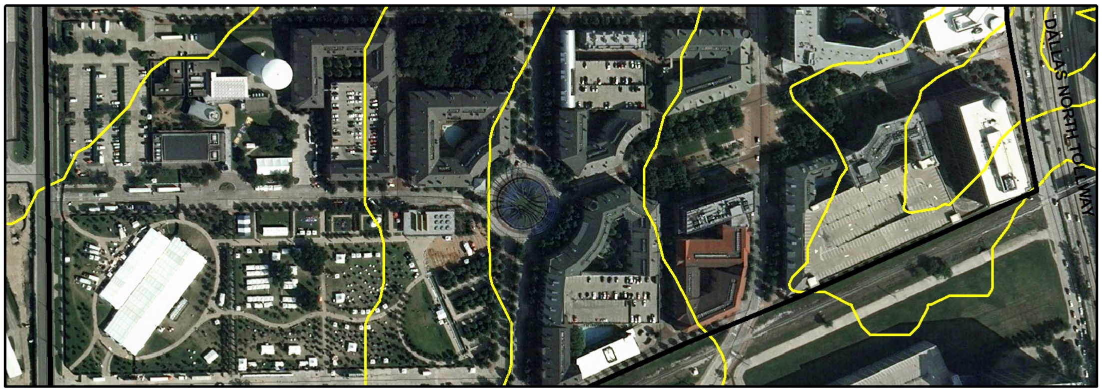


Figure 4.17: Addison Circle Slope Analysis (adapted from TNRIS, 2009)


Addison Circle - 30 meter Digital Elevation Models 2' contours

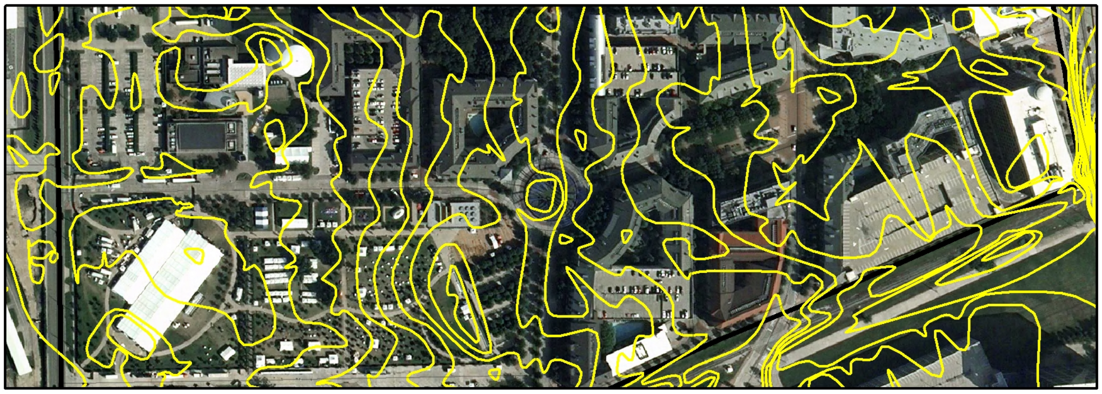

Addison Circle - 2007 2' Digital Elevation Contours

Figure 4.18: DEM and DEC Comparison (adapted from NCTCOG, 2009)

4.3.2.2. Hydrology

Addison Circle is located in a flat area, bordering two separate watersheds: Elm Fork Trinity to the west and Upper Trinity to the east (Figure 4.19). Different from Southlake Town Square, Addison Circle is not situated at a highpoint between two watersheds with flow directed into both, but rather a low land area with the primary natural drainage moving east into the Upper Trinity watershed and ultimately, White Rock Creek. The topographic and slope analysis shows that post construction surface runoff is directed east, similar to that of the natural drainage; with Arapaho Road as a major conduit (this can be seen in Figure 4.18). During the site inspection, no identifiable structural Best Management Practices (BMPs) or other stormwater runoff mitigation devices were noticed.

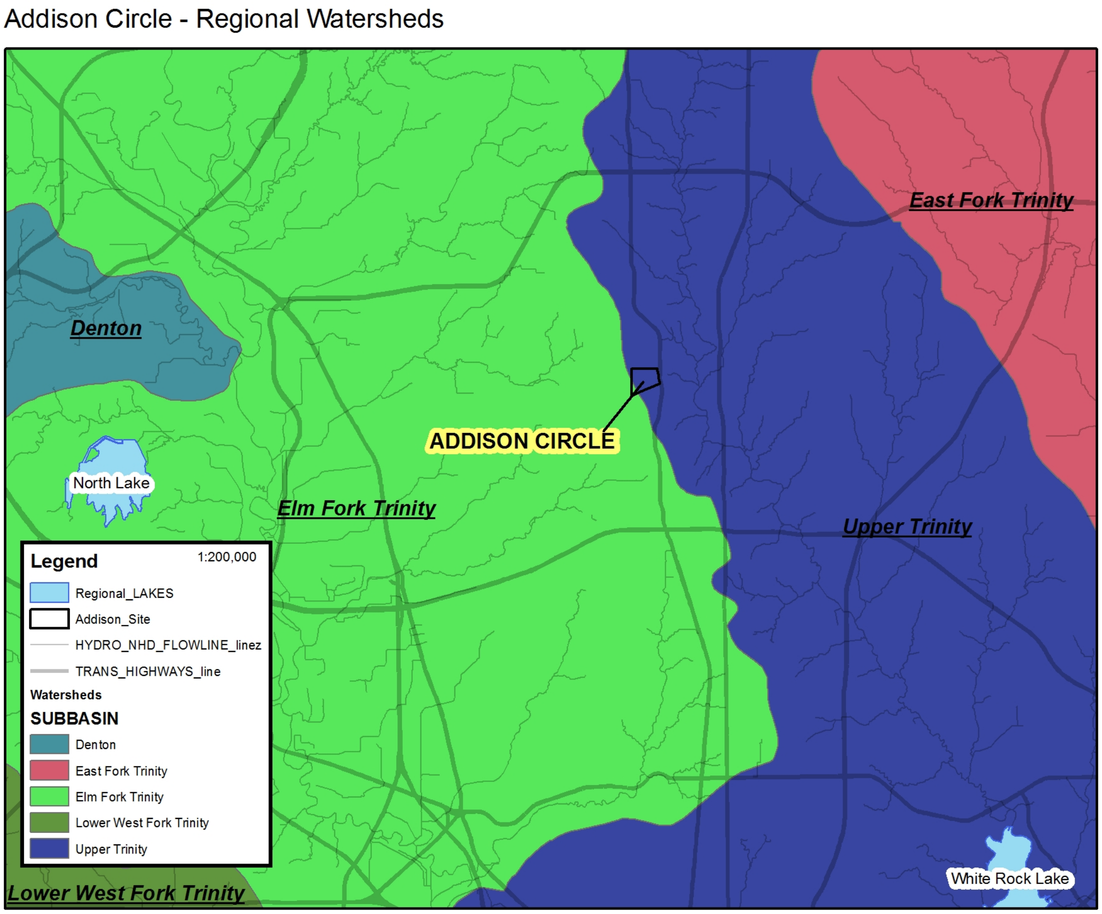


Figure 4.19: Addison Circle Regional Watersheds (adapted from NCTCOG, 2009)

The 2' Digital Elevation Contours (DEC) are converted into grid format, and used for the Soil and Water Assessment Tool (SWAT) modeling. Accumulation and flow calculations are based on an area of 5 hectares; and reaches and longest paths are created, with one watershed outlet added at the east end of the site where the reaches come together. The site is divided into 5 subbasins based on the DEC grid processing and watershed delineation process in SWAT (Figure 4.20).

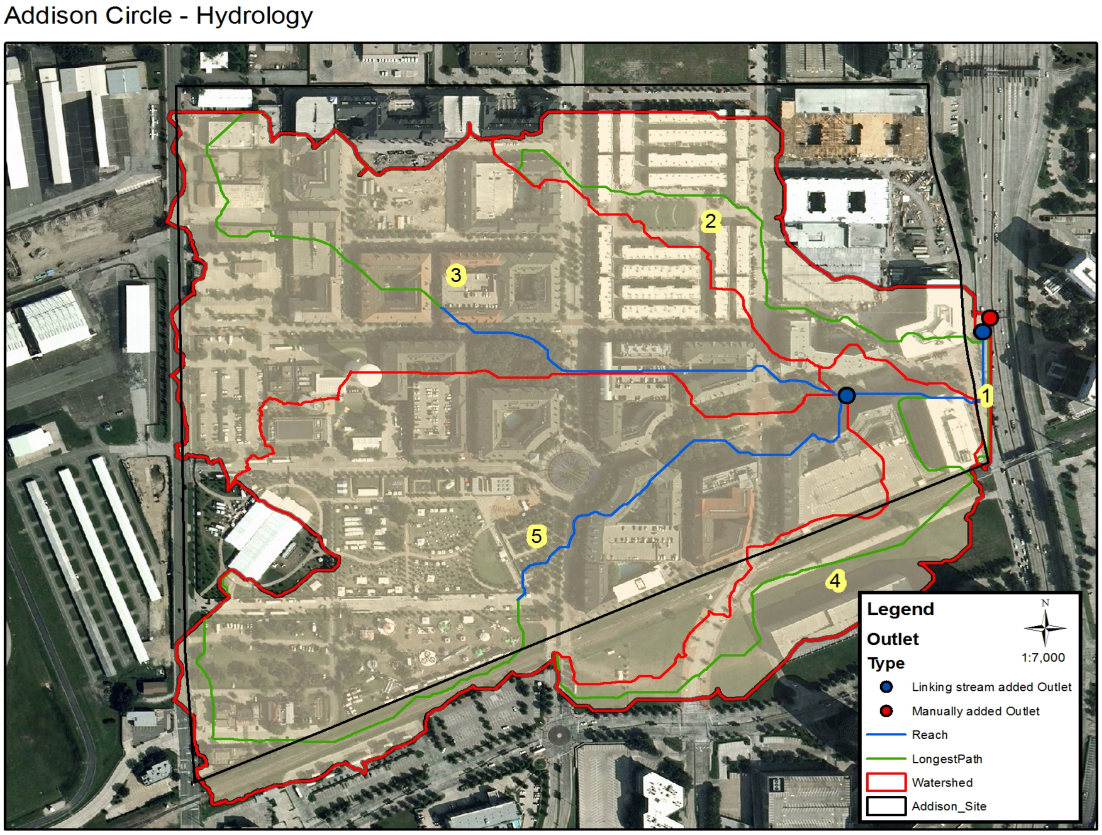


Figure 4.20: Addison Circle Hydrology

4.3.2.3. Soils and Weather

As with the Southlake Town Square case, the soils used for the Addison Circle study comes with the SWAT interface; the source for which is the United States Department of Agriculture (USDA), Natural Resources Conservation Service, State Soil Geographic Database (STATSG0). The soil in Addison Circle is grouped into Austin and Stephen series of Texas Blackland Prairie. These soils are formed on a flat, gently rolling plain, dissected by southeastward flowing streams such as White Rock Creek; the parent materials of which, over time, have generated a significant extent of clayey soils having high shrink-swell properties (United States Department of Agriculture, 2008). The Blackland Prairie is predominantly prairie vegetation with little bluestem, big bluestem, indiangrass, switchgrass and eastern gamagrass as the major species and savannah plant communities along riparian areas and streams (United States Department of Agriculture, 1981) (Figure 4.21).

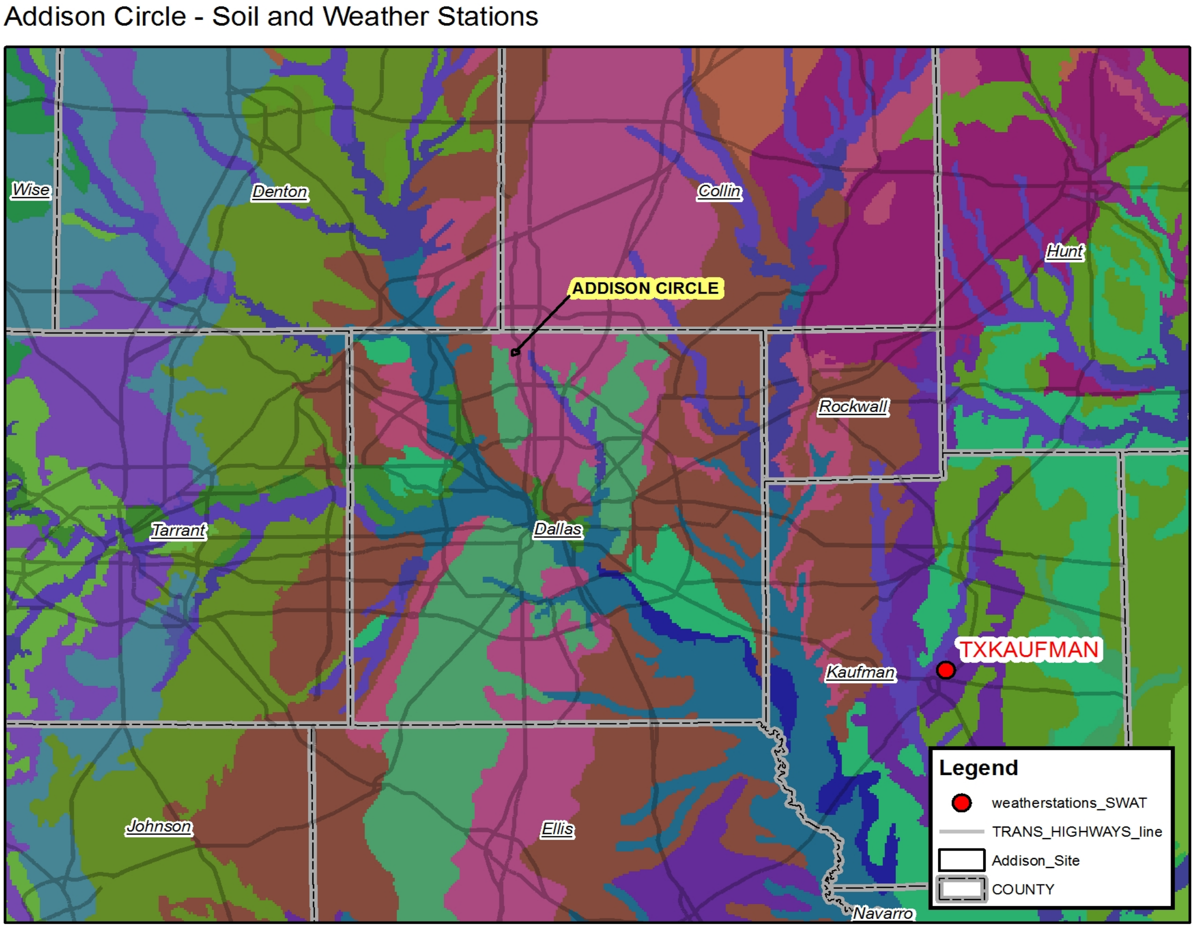


Figure 4.21: Regional Soils and Weather Stations (adapted from STATSG0, 2009)

Weather data used for the Addison Circle study is from the weather generator incorporated into the Soil and Water Assessment Tool (SWAT) interface. Addison Circle was modeled for 5 years, at monthly intervals, with daily precipitation values. The closest weather station within the SWAT database is in Kauffman, Texas (Figure 4.21). No weather parameters were changed in this case study.

4.3.2.4. Land Use

The same approach to land use modification in the Southlake Town Square case was performed for Addison Circle. The current mix of uses onsite contain Commercial, Retail, Office, High Density Residential (>8 unit/acre), Institutional, Industrial, and Public Space/Park. Retail and Office uses were incorporated into Commercial. These land uses are re-classified based upon SWAT Urban and Crop land use categories, inventory and analysis of land use density and exterior design elements (Figure 4.22).

As with Southlake Town Square, the FIMP (fraction of total impervious area in urban land type) and FCIMP (fraction directly connected to impervious area in urban land type) parameters for Urban Commercial, Institutional and High Density Residential were changed to better reflect actual imperviousness; and SCS Runoff Curve parameters were changed based on surface condition of runoff and the relation to the level of imperviousness. No other land use or urban parameters were changed.

The crop land use FRSD (hardwood forest) is representative of the forested park at the southwest corner of Quorum Drive and Morris Avenue. The following is a list of land use categories within the basin (Figure 4.22).

- URHD- Urban High Density Residential (>8 unit/acre)
- UIDU- Urban Industrial
- UCOM- Urban Commercial
- UTRN- Urban Transportation (circulation)
- UINS- Urban Institutional
- BERM- Bermuda Grass (open space, parks and parking lot islands)
- FRSD- Hardwood Forest (Neitsch et al.; 2004)

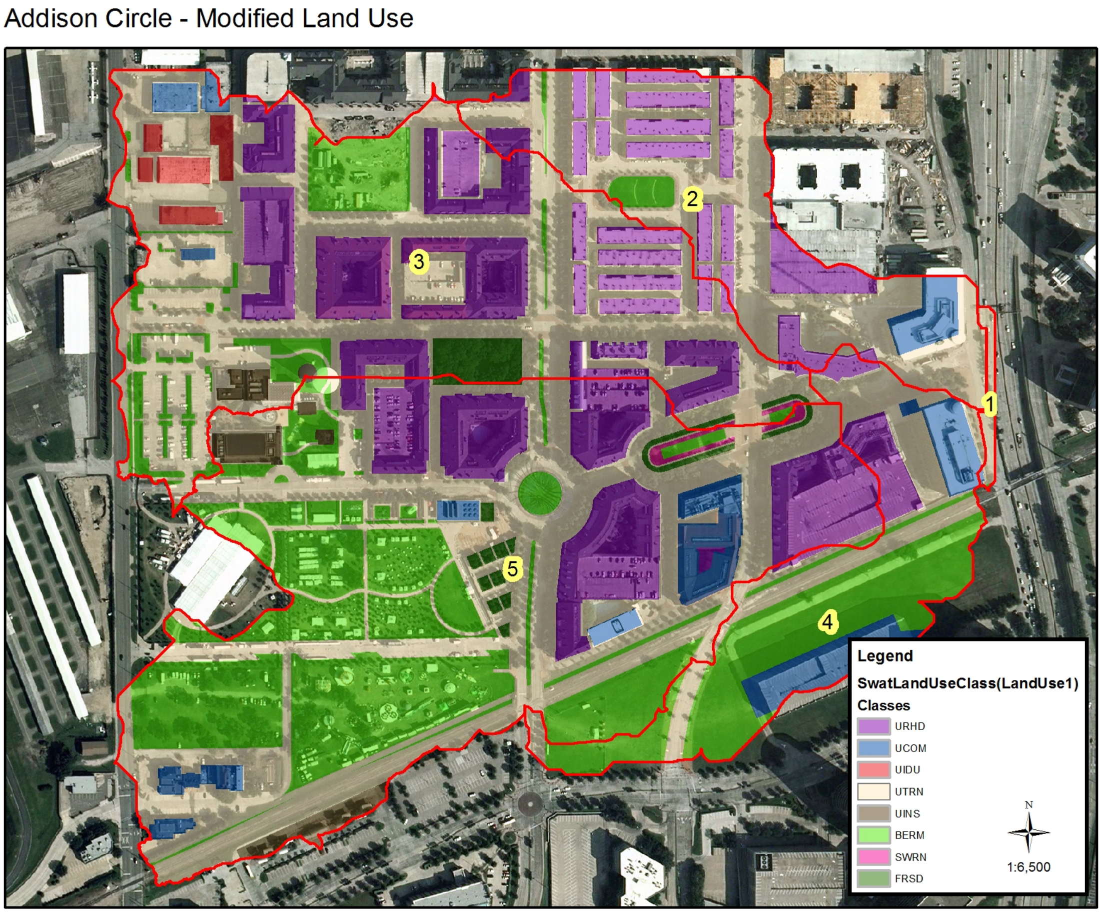


Figure 4.22: Addison Circle Modified Land Use (adapted from NCTCOG, 2009)

4.3.2.5. Land Management

The same operations schedule from Southlake Town Square was incorporated into the Addison Circle scenario to evaluate land management practices in maintaining basic Bermuda turfgrass needs for health and appearance. Likewise, the same high nitrogen fertilizer, 24-6-0, was used at the same application rates used in the Southlake Town Square case study.

4.3.2.6. Land Use Density

The process used to calculate the land use density in Addison Circle, or the measurement of imperviousness, is repeated from the Southlake Town Square case study. A combination of Geographic Information Systems (GIS), orthophotograph interpretation, and site inspection is utilized for inventory and analysis of exterior design elements and amount of imperviousness (Figure 4.23). Although the method is the same, the inventory and analysis was significantly more difficult with Addison Circle due to the nature of urban form and characteristics of the orthophotographs.

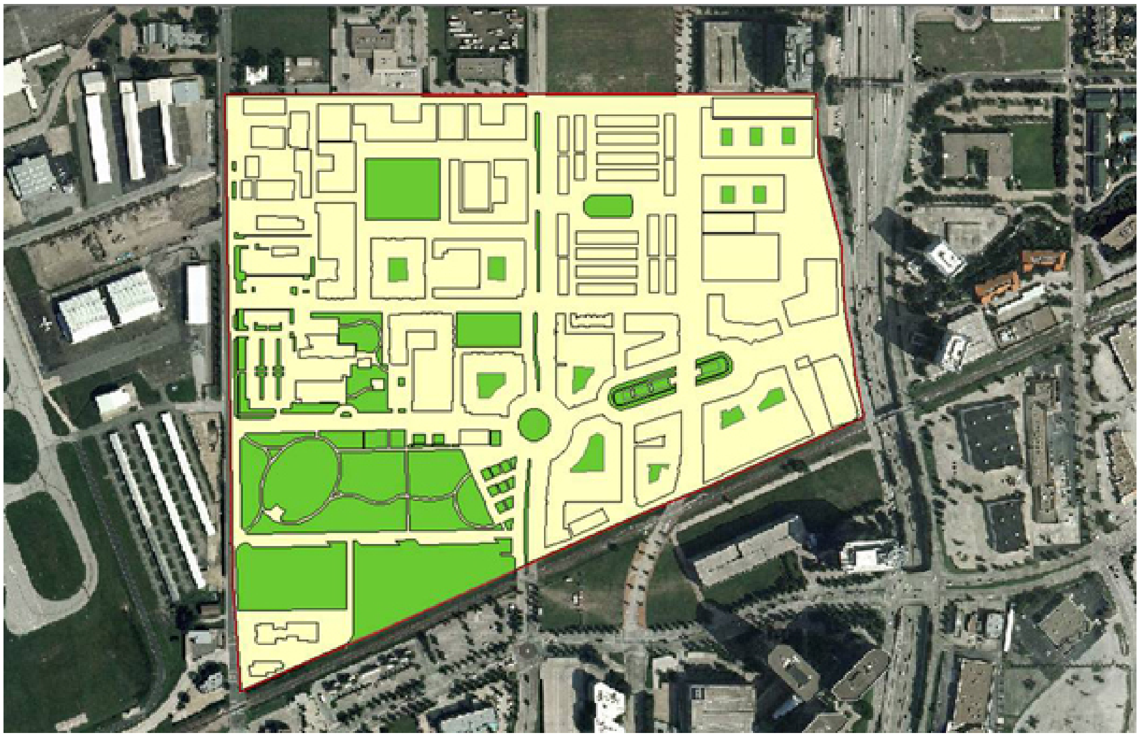


Figure 4.23: Addison Circle Land Use Density

Addison Circle is a highly dense mixed-use development on a relatively small site (124 acres). There are approximately 4800 residential units, with nearly 6 million square feet of commercial land use (Whitehead and Rutherford, 2004). Because of this, development is directed veritcally, rather than horizontally as seen in Southlake Town Square. The majority of structures in Addison Circle are three levels or more; with a common mix of commercial, office and residential. Stand alone residential untits are three levels or more as well. Building height is a significant factor when using orthophotographs for ground surface evaluation and inventory in high density urban areas.

The Addison Circle Study relied on two sets of orthophotographs used in measuring land use density and inventory of exterior design elements. Characteristics of both were similar with the exception of variance of angle, extent and year created. The deciduous tree canopies in the primary set of images, obtained from North Central Texas Council of Governments (NCTCOG), were bare; the angle and length of shadows indicate the images were taken most likely in winter, time of day late morning (Figure 4.23). The secondary source images have full deciduous tree canopies; the angle and length of shadows indicate the images were captured in the early morning (Figure 4.24).

Orthophotograph Primary Source

Orthophotograph Secondary Source

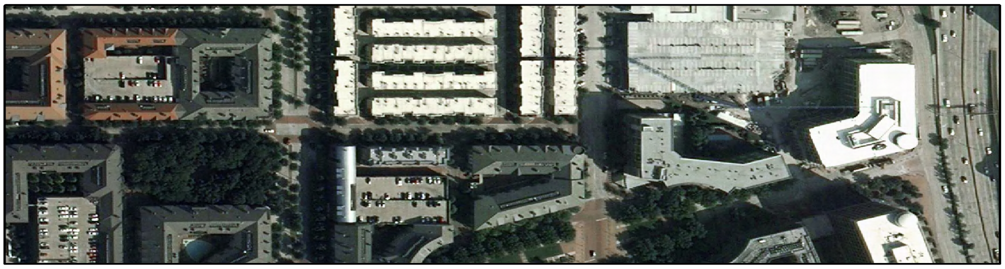


Figure 4.24: Comparison of Orthophotographs in Addison Circle (NCTCOG, 2009)

Due to the problems associated with orthophotograph interpretation and inventory methodology, exterior design elements north and east of structural components could not be captured. Site inspection revealed these elements to be primarily tree wells and private property lawns (Figure 4.25); yet because of time constraints, these components could not be accurately measured, plotted, and incorporated into the study. Additionally, accessibility to private courtyards was limited, and it is assumed these areas contain a mix of permeable and impervious surfaces. For the purpose of this study, these areas were classified as permeable Public Space exterior design elements.

Figure 4.25: Addison Circle Tree Wells and Private Property Lawns

The following is a list of exterior design element categories in Addison Circle.

- Circulation: vehicle and pedestrian
- Public Space
- Parks
- Parking Lot Islands
- Foundation Landscape
- Streetscape
- Structural

The total area of the site is 4,395,062 square feet. The impervious surface areas covered 78% of the site, containing 3,441,038 square feet as seen in Table 4.2 and Figure 4.26. Permeable surface areas of exterior design and open space elements are measured at 954,026 square feet.

Table 4.2: Addison Circle Land Use Density Calculations

DESIGN ELEMENTS:	IMPERMEABLE (SQ.FT.)	PERMEABLE (SQ.FT.)
Circulation	2,062,361	
Public Space		236,015
Parks		637,587
Parking Lot Islands		12,641
Foundation Landscape	NA	NA
Streetscape		67,781
Structural	1,378,676	
Water Features	NA	NA
TOTAL	**3,441,037**	**954,024**

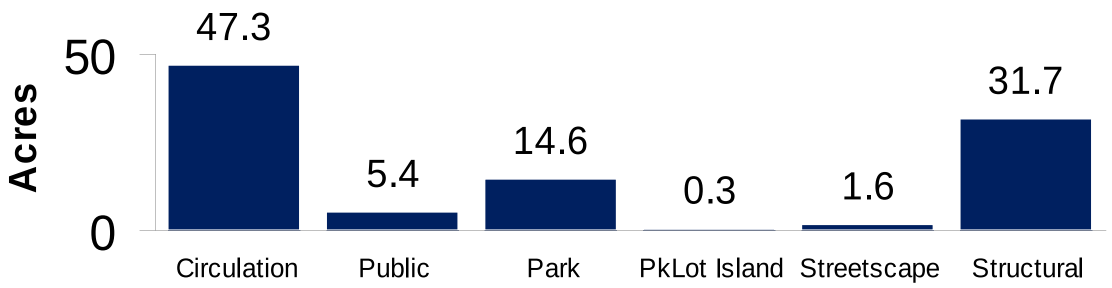


Figure 4.26: Addison Circle Design Elements Area Measurements

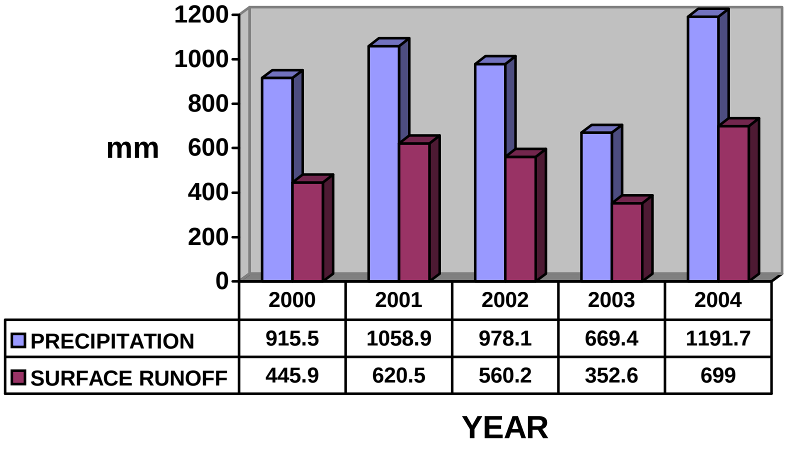
4.3.3. Soil and Water Assessment Tool Modeling Results

Similar to Southlake Town Square, two Soil and Water Assessment Tool (SWAT) simulations were run to assess stormwater runoff and pollution. The first simulation, with all values and parameters at default, is run to gauge model input. The default simulation resulted in a disproportionate amount of organic nitrogen; the soil chemical parameter of organic nitrogen was modified slightly to produce a more likely result. The primary simulation was run for five years, at monthly intervals and incorporates parameter changes and operational schedules as mentioned previously.

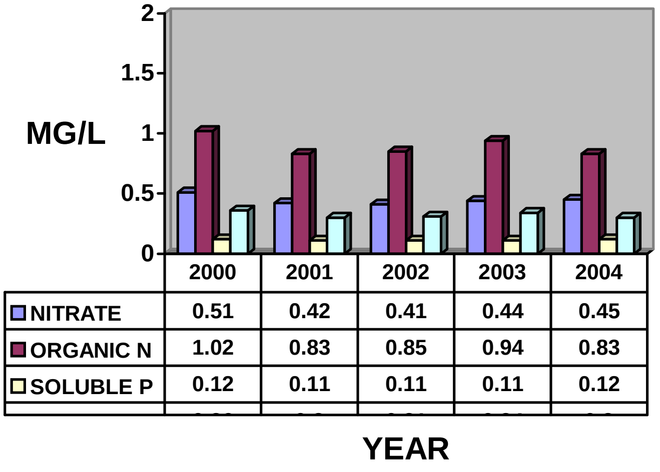
The results for the 5 year scenario general output are displayed in Figure 4.27 for yearly averages of precipitation, surface runoff, and nutrient runoff. Precipitation and surface runoff are measured in millimeters; nutrient runoff is measure in kilograms/hectare, and converted into milligrams/liter. The following is a brief description and definitions of terms used in the output (Appendix B and C).

- UNIT TIME- This is broken into number of months for the simulation in a specific
- PREC- Precipitation in mm
- SURQ- Surface runoff in mm

- NO3SURQ- Amount of Nitrate in the surface runoff in kg/ha
- NORGANIC- Amount of organic nitrogen in the surface runoff kg/ha
- PSOLUBLE- Amount of soluble phosphorus in the surface runoff hg/ha
- PORGANIC- Amount of organic phosphorus in the surface runoff kg/ha


Annual Surface Runoff: Addison Circle

	2000	2001	2002	2003	2004
🟦 PRECIPITATION	915.5	1058.9	978.1	669.4	1191.7
🟥 SURFACE RUNOFF	445.9	620.5	560.2	352.6	699


Annual Nutrient Runoff: Addison Circle

	2000	2001	2002	2003	2004
🟦 NITRATE	0.51	0.42	0.41	0.44	0.45
🟥 ORGANIC N	1.02	0.83	0.85	0.94	0.83
☐ SOLUBLE P	0.12	0.11	0.11	0.11	0.12

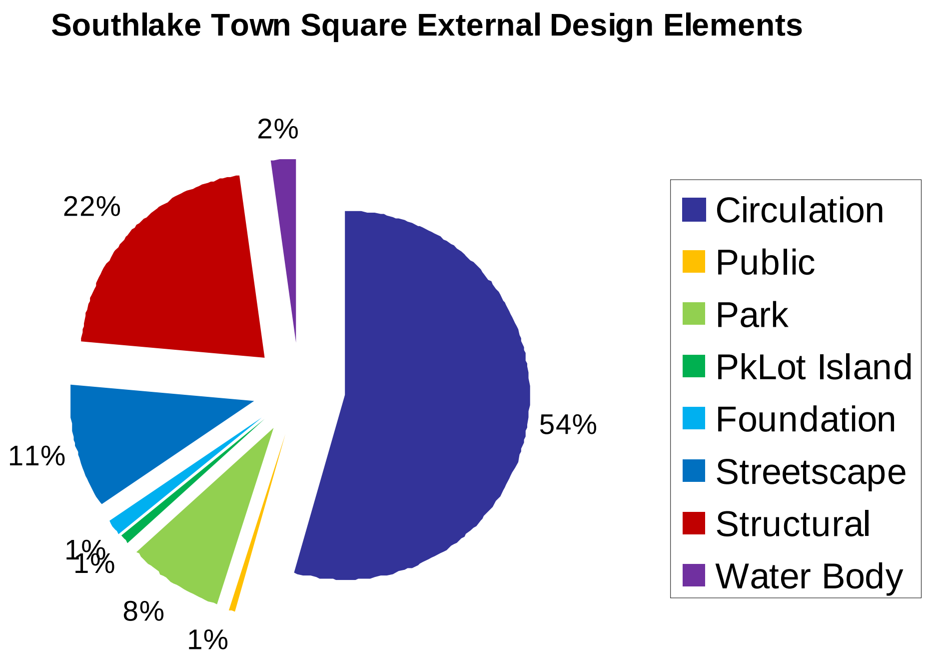
Figure 4.27: Addison Circle Annual Surface and Nutrient Runoff

4.4 Summary of Findings

The two cases studies in this research, Southlake Town Square and Addison Circle are both mixed-use developments in North Texas. They contain the same basic exterior design elements and a similar mix of uses; yet vary significantly in purpose, design, urban typologies, and context. An objective of the research is to understand how varying design and planning approaches in mixed-use developments may impact the environment through stormwater runoff and pollution analysis; and methods and procedures used in both cases were the same, with only slight variations in parameter changes resulting from site specific characteristics. Although comparing two different urban areas presents methodological limitations and concerns, looking at the results side by side may help to provide some insight related to the environmental performance of mixed-use developments.

4.4.1. Land Use Density and Exterior Design Elements

Looking at the land use density and exterior design elements of both Southlake Town Square and Addison Circle (Figure 4.28), a general trend can be seen in relation to circulation and structural exterior design components. Naturally, they are the largest contributors to imperviousness; 75.6% of site area in Southlake Town Square and 78% in Addison Circle. The Circulation element in Southlake Town Square is noticeably larger in proportion to site than in Addison Circle, and is directly related to site design, urban form typology and purpose. That is to say, the purpose of Southlake Town Square appears to be that of a regional hub primarily for commercial, public and government use, with residential use as a secondary inclusion; the design and urban form typologies, both horizontal and vehicle oriented, reflect that purpose.



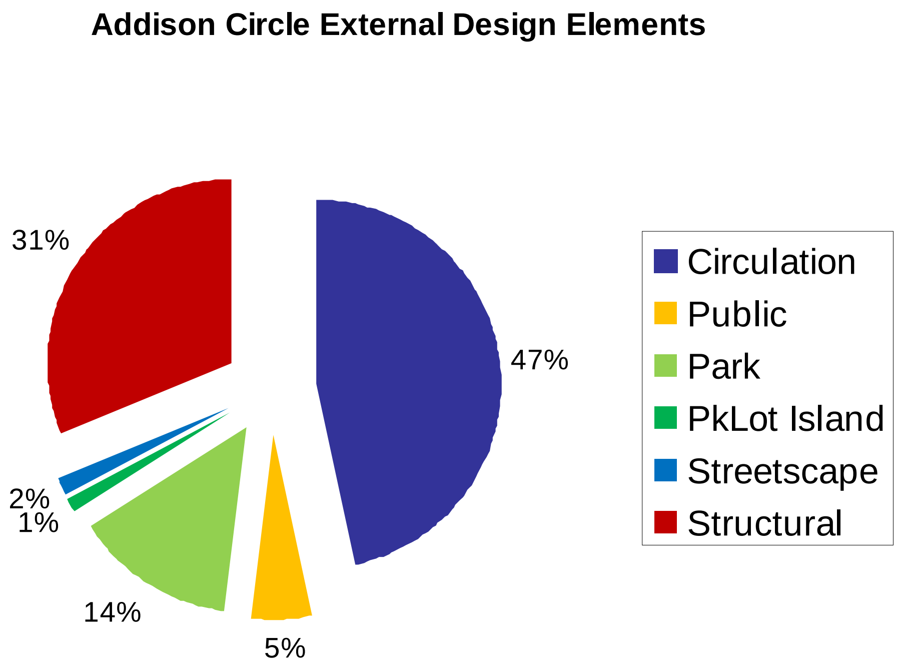


Figure 4.28: External Design Elements: Southlake Town Square and Addison Circle

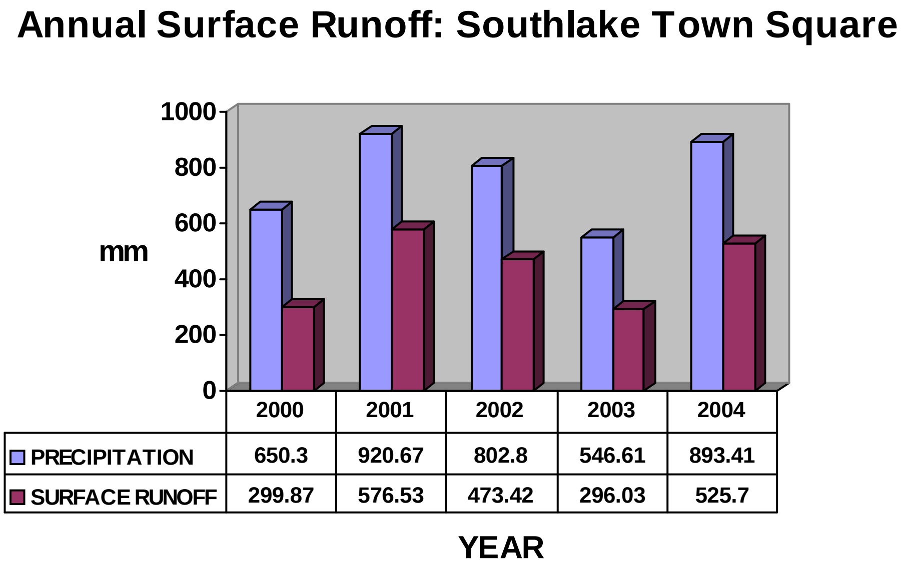
The streetscape elements in Southlake Town Square are more significant than in Addison Circle; a permeable design component comprised mainly of street frontages. Once again, this reflects both purpose and urban form typologies associated with each design. Large, road frontages in Southlake Town Square surround the site with extensive turfgrass areas indicative of lower site density, major transportation networks and surface parking lots. Conversely, permeable streetscape measured in Addison Circle are few, and only in the areas where surface parking lots are located, demonstrating high density, impervious streetscape elements, and narrower street frontages due to lower building setbacks.

A considerable difference in parks and structural elements can be seen when looking at both sites. Both sites have a significant amount of structural components, but in Addison Circle, the ratio of structures to site area is noticeably larger; and is related to population density, vertical construction and characteristics related to higher density, residential neighborhoods with office and retail as secondary uses. Accompanying the higher site and population densities of Addison Circle is the larger ratio of Parks, as seen in Figure 4.28. This is understandable as Addison Circle is less vehicle dependant and contains a higher population of residents.

4.4.2. SWAT Stormwater Runoff and Pollution

The Soil and Water Assessment Tool (SWAT) modeling results are normally validated through comprehensive and detailed sensitivity analysis and model calibration based upon observational data. These processes are used not only to validate results, but increase the accuracy of long term simulations and prediction. For example, if a number water samples were taken from various significant storm events at Southlake Town Square and measured for pollutants, then that data could be used as a base for further simulation analysis and model calibration. Once the model is calibrated to best match observed results, then a forecast or long term simulation can be run with better results. Other types of observed data can include stream station gages, water quality monitoring in receiving waters and weather stations in close proximity to the area being modeled. Due to the difficulties in accessing observed data for this study, no sensitivity analyses or model calibrations were performed. Instead, this study relied on a collection of stormwater runoff and pollution studies done in areas with related land uses.

Looking at the annual average precipitation (PREC) of both Southlake Town Square and Addison Circle (Figure 4.29 and 4.30); it is shown that in both sites, greater than 50% of the water was discharged over the ground surface as stormwater runoff (SURQ). Although the precipitation and surface runoff numbers are different, the ratio of rainfall to surface runoff is proportionate, and may reflect similarities in land use density; Addison Circle 78% impervious and Southlake Town Square 75.6%.



	2000	2001	2002	2003	2004
🟦 PRECIPITATION	650.3	920.67	802.8	546.61	893.41
🟥 SURFACE RUNOFF	299.87	576.53	473.42	296.03	525.7

Figure 4.29: Annual Surface Runoff: Southlake Town Square

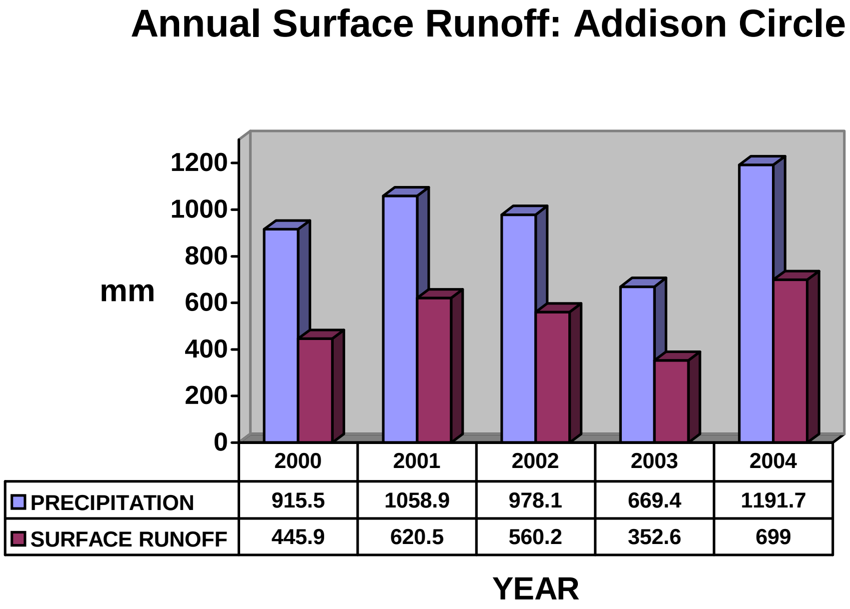
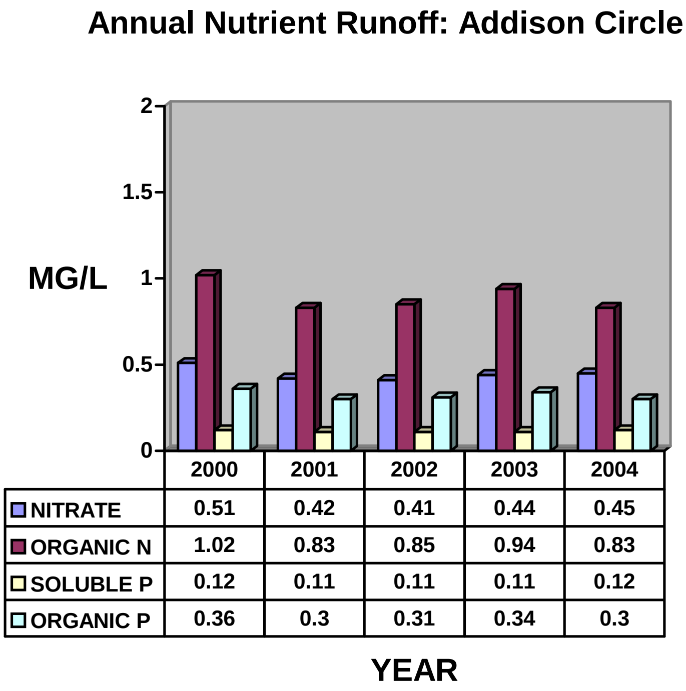


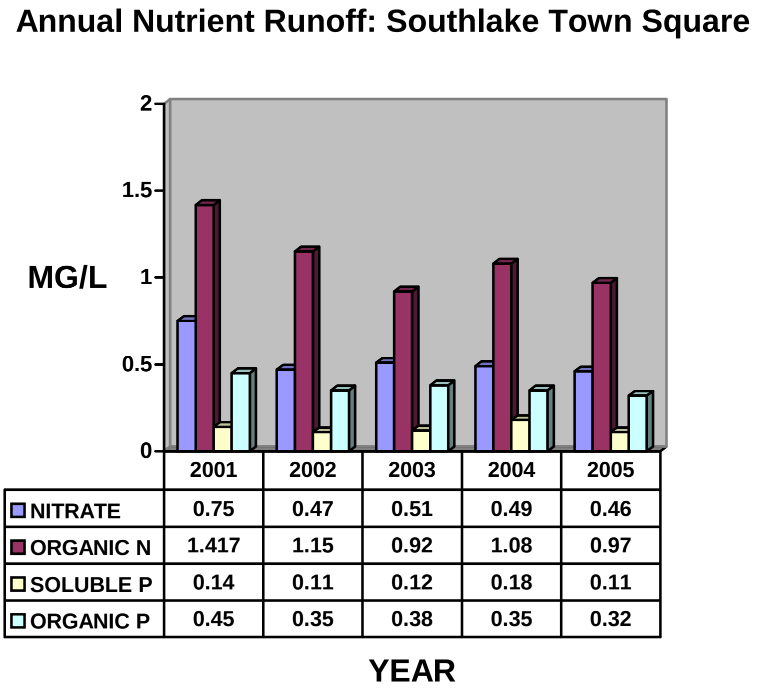
Figure 4.30: Annual Surface Runoff: Addison Circle

The generalized Soil and Water Assessment Tool (SWAT) output reports Nitrate (NO3), Organic Nitrogen, Soluble Phosphorus and Organic Phosphorus as primary nutrient pollutants. These are not the only pollutants that SWAT evaluates and it is capable of analyzing other pollutants depending on the detail of data incorporated into the model; other pollutants reported by SWAT are: other nutrient pollutants, chemicals, heavy metals and sediments.

The average annual basin values of nutrients in the surface runoff for Southlake Town Square are: 0.52 milligrams/liter (mg/l) of Nitrate (NO3SURQ), 1.12 mg/l of organic Nitrogen (NORGANIC), 0.18 mg/l of soluble Phosphorus (PSOLUBLE) and 0.36 mg/l of organic Phosphorus (PORGANIC). The average annual basin values of nutrients in the surface runoff for Addison Circle are: 0.57 mg/l of Nitrate (NO3SURQ), 0.82 mg/l of organic Nitrogen (NORGANIC), 0.11 mg/l of soluble Phosphorus (PSOLUBLE) and 0.30 mg/l of organic Phosphorus (PORGANIC). The yearly comparison of both sites can be seen in Figure 4.31.


Annual Nutrient Runoff: Addison Circle

	2000	2001	2002	2003	2004
■ NITRATE	0.51	0.42	0.41	0.44	0.45
■ ORGANIC N	1.02	0.83	0.85	0.94	0.83
■ SOLUBLE P	0.12	0.11	0.11	0.11	0.12
■ ORGANIC P	0.36	0.3	0.31	0.34	0.3


Annual Nutrient Runoff: Southlake Town Square

	2001	2002	2003	2004	2005
■ NITRATE	0.75	0.47	0.51	0.49	0.46
■ ORGANIC N	1.417	1.15	0.92	1.08	0.97
■ SOLUBLE P	0.14	0.11	0.12	0.18	0.11
■ ORGANIC P	0.45	0.35	0.38	0.35	0.32

Figure 4.31: Annual Nutrient Runoff: Southlake Town Square and Addison Circle

Organic Nitrogen in the surface runoff was noticeably higher in Southlake Town Square, at 1.12 mg/l as an annual average; compared to 0.82 mg/l at Addison Circle. Organic Nitrogen is attached to sediment and soil particles and can be transported by surface runoff into a receiving body of water or drainage network (Neitsch et al., 2005). NO3SURQ, or Nitrate from fertilizer in surface runoff for each site, as an annual average, were relatively similar between the two cases; 0.52 mg/l for Southlake Town Square and 0.57 mg/l for Addison Circle. These Nitrate levels do not reflect event-mean concentrations from water investigations report *Urban Stormwater Quality, Event-Mean Concentrations, and Estimates of Stormwater Pollutant Loads, Dallas-Fort Worth Area, Texas, 1992-93*, which can be seen in Figure 4.32 (Baldys et al., 1993) and Figure 4.33. Despite this, average annual basin stress days in both sites showed a relatively low amount of nitrogen stress.

Average Annual Stress Days- Southlake Town Square

- Water Stress Days = 0.50
- Temperature Stress Days = 12.39
- Nitrogen Stress Days = 7.82
- Phosphorus Stress Days= 14.41

Average Annual Stress Days- Addison Circle

- Water Stress Days = 0.80
- Temperature Stress Days = 22.22
- Nitrogen Stress Days = 20.59
- Phosphorus Stress Days= 25.16

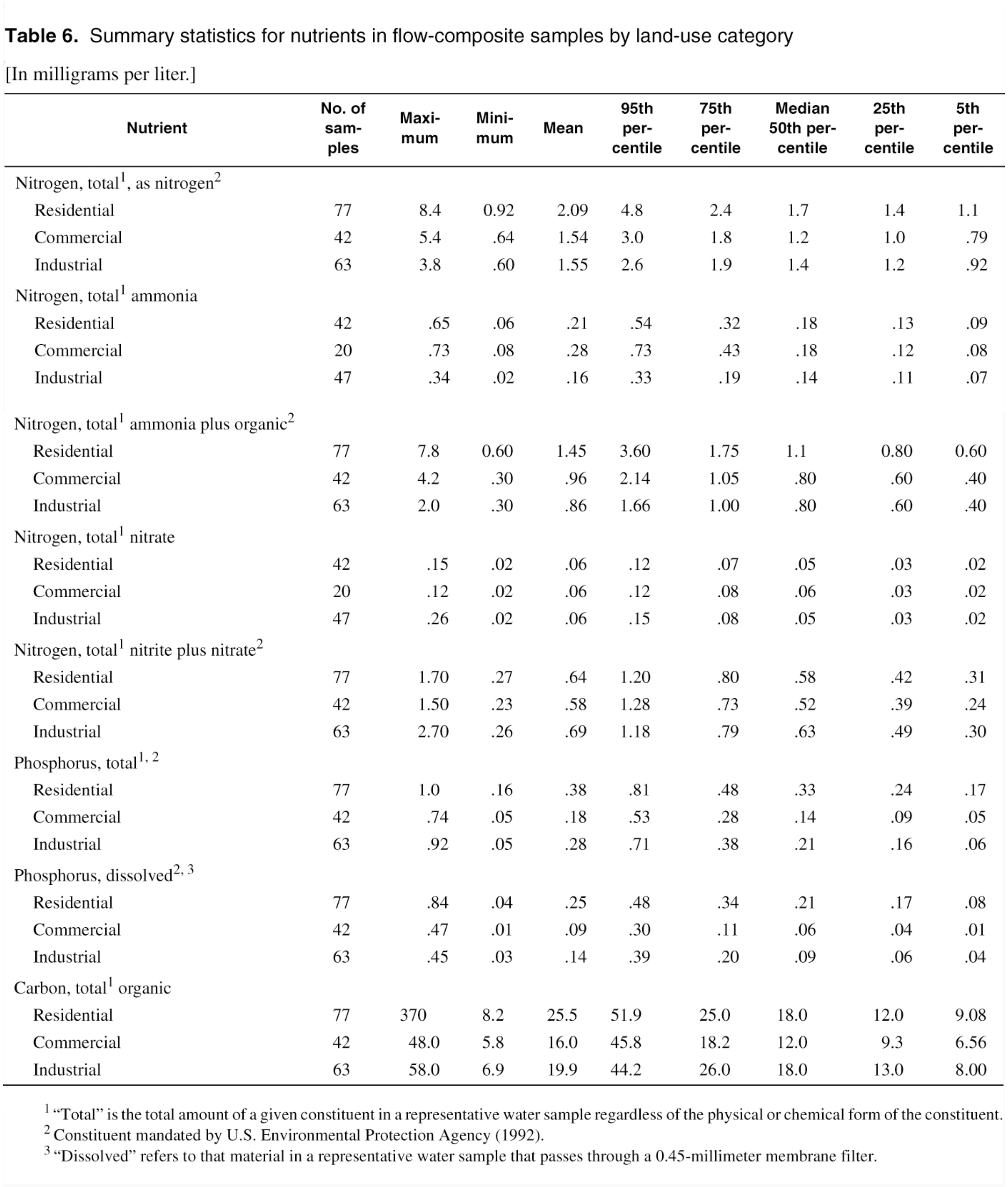


Table 6. Summary statistics for nutrients in flow-composite samples by land-use category

[In milligrams per liter.]

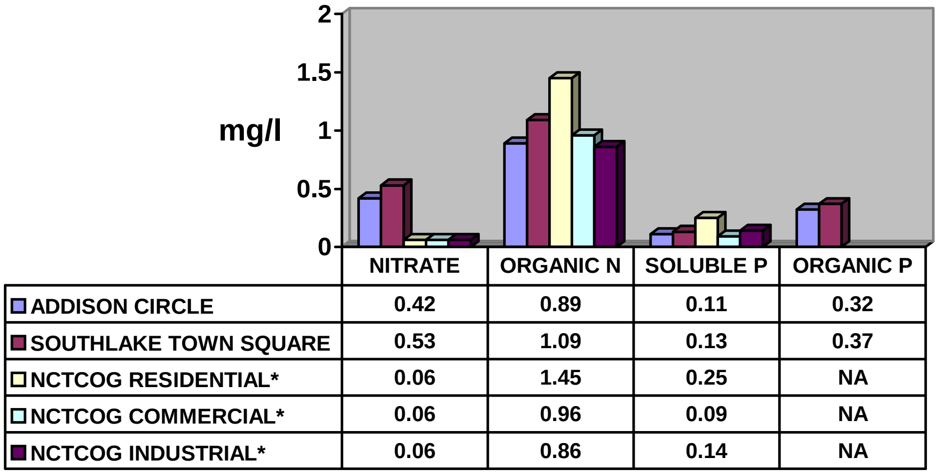
Nutrient	No. of samples	Maximum	Minimum	Mean	95th percentile	75th percentile	Median 50th percentile	25th percentile	5th percentile
Nitrogen, total[1], as nitrogen[2]									
Residential	77	8.4	0.92	2.09	4.8	2.4	1.7	1.4	1.1
Commercial	42	5.4	.64	1.54	3.0	1.8	1.2	1.0	.79
Industrial	63	3.8	.60	1.55	2.6	1.9	1.4	1.2	.92
Nitrogen, total[1] ammonia									
Residential	42	.65	.06	.21	.54	.32	.18	.13	.09
Commercial	20	.73	.08	.28	.73	.43	.18	.12	.08
Industrial	47	.34	.02	.16	.33	.19	.14	.11	.07
Nitrogen, total[1] ammonia plus organic[2]									
Residential	77	7.8	0.60	1.45	3.60	1.75	1.1	0.80	0.60
Commercial	42	4.2	.30	.96	2.14	1.05	.80	.60	.40
Industrial	63	2.0	.30	.86	1.66	1.00	.80	.60	.40
Nitrogen, total[1] nitrate									
Residential	42	.15	.02	.06	.12	.07	.05	.03	.02
Commercial	20	.12	.02	.06	.12	.08	.06	.03	.02
Industrial	47	.26	.02	.06	.15	.08	.05	.03	.02
Nitrogen, total[1] nitrite plus nitrate[2]									
Residential	77	1.70	.27	.64	1.20	.80	.58	.42	.31
Commercial	42	1.50	.23	.58	1.28	.73	.52	.39	.24
Industrial	63	2.70	.26	.69	1.18	.79	.63	.49	.30
Phosphorus, total[1, 2]									
Residential	77	1.0	.16	.38	.81	.48	.33	.24	.17
Commercial	42	.74	.05	.18	.53	.28	.14	.09	.05
Industrial	63	.92	.05	.28	.71	.38	.21	.16	.06
Phosphorus, dissolved[2, 3]									
Residential	77	.84	.04	.25	.48	.34	.21	.17	.08
Commercial	42	.47	.01	.09	.30	.11	.06	.04	.01
Industrial	63	.45	.03	.14	.39	.20	.09	.06	.04
Carbon, total[1] organic									
Residential	77	370	8.2	25.5	51.9	25.0	18.0	12.0	9.08
Commercial	42	48.0	5.8	16.0	45.8	18.2	12.0	9.3	6.56
Industrial	63	58.0	6.9	19.9	44.2	26.0	18.0	13.0	8.00

[1] "Total" is the total amount of a given constituent in a representative water sample regardless of the physical or chemical form of the constituent.

[2] Constituent mandated by U.S. Environmental Protection Agency (1992).

[3] "Dissolved" refers to that material in a representative water sample that passes through a 0.45-millimeter membrane filter.

Figure 4.32: Sampled Nutrient Pollution of Various Land Uses (Baldys, et al.; 1993)



	NITRATE	ORGANIC N	SOLUBLE P	ORGANIC P
□ ADDISON CIRCLE	0.42	0.89	0.11	0.32
■ SOUTHLAKE TOWN SQUARE	0.53	1.09	0.13	0.37
□ NCTCOG RESIDENTIAL*	0.06	1.45	0.25	NA
□ NCTCOG COMMERCIAL*	0.06	0.96	0.09	NA
■ NCTCOG INDUSTRIAL*	0.06	0.86	0.14	NA

Figure 4.33: Southlake Town Square and Addison Circle Nutrient Pollution Comparison

With the exception of high Nitrate levels, and the exclusion of other inorganic nitrogen (ammonia and Nitrate) reported in the SWAT general output, the total Nitrogen (organic + inorganic), Soluble Phosphorus and Organic Phosphorus of both sites are comparable to water investigations report *Urban Stormwater Quality, Event-Mean Concentrations, and Estimates of Stormwater Pollutant Loads, Dallas-Fort Worth Area, Texas, 1992-93* (Figure 4.32) and are summarized below:

<u>Southlake Town Square Annual Averages:</u>

- Organic Nitrogen+Nitrate = 1.64 mg/l
- Total PSOLUBLE = 0.12 mg/l
- Total PORGANIC = 0.36 mg/l

<u>Addison Circle Annual Averages:</u>

- Organic Nitrogen+Nitrate = 1.39 mg/l
- Total PSOLUBLE = 0.11 mg/l
- Total PORGANIC = 0.30 mg/l

CHAPTER 5

CONCLUSIONS

5.1 Introduction

The primary objective of this study is to evaluate stormwater runoff and water pollution of two mixed-use developments in North Texas in relation to land use density and the imperviousness of exterior design elements; the tools used to perform the analysis being the Soil and Water Assessment Tool (SWAT) and Geographic Information Systems (GIS). This study addressed varying design, planning and land management characteristics of mixed-use developments and how they may impact stormwater runoff and pollution in different types of developments. Additionally, and although not as explicit, a secondary objective is the understanding of SWAT capabilities and limitations connected to hydrologic modeling in high density urban scenarios, and whether it is an effective tool to measure such an impact.

A methodology, or process, was developed to inventory exterior design elements, measure land use density, apply likely land management scenarios, and correlate that information to SWAT input and output. Two cases are chosen to represent the study population and the criteria for selection is based primarily on differences in design, purpose, and urban form typologies; each case representing a common type of mixed-use development: (1) a horizontally developed, vehicle oriented, regional town center and (2) a vertically developed, high density, residential neighborhood center (New Urban News, 2003). The method applied is the same for each case, with only slight modifications resulting from varying site characteristics.

5.2 Evaluation of Stormwater Runoff and Pollution Performance

The analysis and findings of the data reported that both sites, Southlake Town Square and Addison Circle, had a high amount of imperviousness and the actual stormwater runoff exceeded 50% of the precipitation generated; more than half of the rain produced was discharged over the ground as runoff. There are a number of smaller permeable areas not calculated in both sites; primarily tree wells and very small private property foundation landscape and lawns. These elements are excluded due to accessibility difficulties in obtaining plans and construction documents; as well as logistical and interpretation problems associated with methodology. A large number of these elements would lower the measurement of land use density; however their effect on stormwater runoff is limited due to the umbrella effect caused by leaf area index of tree canopies and the drip line extending outside of the permeable tree well onto pavement.

Bermudagrass areas are the largest permeable surface areas and represent a significant presence in several exterior design elements: Public Space, Parks, Streetscapes and Parking Lot Islands. These areas have the greatest capacity to mitigate stormwater runoff quality and quantity; yet at the same time contribute to Nitrogen nutrient pollution resulting from land management operations. Transpiration and evaporation account for some water and nutrient loss; yet it is inconclusive how effective the large turfgrass areas in both sites are in reducing stormwater runoff and pollution.

The nutrient pollution discharged in surface runoff is fairly similar in both sites; with high levels of Nitrate (NO3), and possibly acceptable levels of Organic Nitrogen, Phosphorus and Soluble Phosphorus. The Nitrate is primarily from fertilizer applied to turfgrass areas to maintain health and appearance. The rate of application, .5lbs. of Nitrogen per 1000 square feet, is adequate for turfgrass areas where traffic and appearance are not major concerns. The general output file from the Soil and Water Assessment Tool (SWAT) simulation reported a low to moderately low number of Nitrogen and Phosphorus stress days on turfgrass areas for both sites.

<u>Average Annual Stress Days- Southlake Town Square</u>

- Water Stress Days = 0.50
- Temperature Stress Days = 12.39
- Nitrogen Stress Days = 7.82
- Phosphorus Stress Days= 14.41

<u>Average Annual Stress Days- Addison Circle</u>

- Water Stress Days = 0.80
- Temperature Stress Days = 22.22
- Nitrogen Stress Days = 20.59
- Phosphorus Stress Days= 25.16

The model reported a relatively high level of Nitrate pollution; the reason is unclear at this point. Any inaccuracy may be contributed to a number of factors; model calibration, soil structures, condition of turfgrass, timing of fertilizer applications and adjacent surface material. More research will be needed to validate the SWAT tool for use in various urban settings.

Site inspection revealed a series of retention and detention ponds located at Southlake Town Square. The primary purpose of these structural Best Management Practices (BMPs) is to manage stormwater runoff and water pollution on site; they also act as an amenity to Southlake Town Square users. With the exception of the retention and detention basins, no other BMPs are detected; because of this, the research was not able to ascertain their impact on stormwater runoff mitigation. Research does suggest that incorporation of stormwater management devices and design practices can significantly reduce overall quantity and quality of stormwater runoff. Green roofs, permeable pavement, infiltration trenches, bio-retention, and grass swales are all small scale mitigation tools that can be effectively utilized regardless of urban form and density; and should be considered as more than an option when stormwater management is a concern.

5.3 Land Use Density and Exterior Design Elements

Exterior design elements of both sites are combined into eight categories based on the site inventory and analysis, literature review and Soil and Water Assessment Tool (SWAT) data characteristics:

- Circulation: vehicle and pedestrian
- Public Space
- Parks
- Parking Lot Islands
- Foundation Landscape
- Streetscape
- Structural
- Water Features

As seen in the previous chapter, the exterior design elements directly reflect the purpose of each development as well as urban typologies associated with form, context and connectivity. Structural and Circulation exterior design elements are the largest contributors to imperviousness. Land use density is measured at 75.6% impervious for Southlake Town Square, and 78% for Addison Circle. The size and number of park and structural components in Addison Circle are noticeably different than in Southlake Town Square; and are representative of vertically constructed, high density residential neighborhoods that promote walkability and public transportation. Likewise, permeable streetscape elements are more significant, in size and number, in Southlake Town Square; representative of horizontally constructed, vehicle oriented, regional town centers. Parking lot islands are very limited in Addison Circle; conversely, they are an important component to overall design in Southlake Town Square.

5.4 Learning From Southlake Town Square and Addison Circle

Southlake Town Square and Addison Circle represent two distinct mixed-use development types; a regional, horizontally developed, vehicle oriented town center, and a highly dense, vertical, neighborhood center (New Urban News, 2003). In an attempt to understand how they perform environmentally, this study evaluates stormwater runoff and pollution, using Geographic Information Systems (GIS) and the Soil and Water Assessment Tool (SWAT), to identify how varying design, planning and land management characteristics may impact quality and quantity of surface runoff.

From a stormwater runoff and pollution point of view, based on methodology and the general output reported from SWAT; both sites exhibit a similar response to surface runoff in relation to land use density and imperviousness of exterior design elements. Over 50% of the annual precipitation is discharged over the ground surface as runoff in both sites. Nutrient pollution in the surface runoff is slightly higher in Southlake Town Square, whereas the amount of temperature and nutrient stress days are higher in Addison Circle. This is not so much a reflection on design, but rather related to urban form typologies.

From a methodological perspective, Addison Circle, with its vertical construction, high density and narrow building setbacks presented significant difficulties during the inventory and analysis of exterior design elements and measurement of land use density. This is important because the modified land use and crop cover (Bermudagrass) used in the SWAT modeling is dependent on the inventory. A significant amount of time was spent on site to determine how best to approach ambiguities associated with orthophotograph interpretation. As a result, some permeable exterior design elements are excluded from the land use density calculations. Inventory of exterior design element and SWAT modeling is considerably easier in Southlake Town Square due to site size, and urban form typology; less time is needed during site inspections for analysis. Additionally, physical site characteristics relevant to SWAT watershed delineation and Hydrological Response Unit analysis in Southlake Town Square helped to speed up the process.

From a design and planning perspective, each case study provides a different point of view as to how varying design and planning practices can play a role in stormwater runoff and water pollution. For example, the buildings in Southlake Town Square are dispersed throughout a larger landscape with a significant amount of area designated for surface parking required for daily business activities that occur on site. Although this study did not evaluate oil, grease and debris pollution associated with surface parking, it is reasonable to question how design can influence the stormwater runoff and water pollution performance by removing sections of surface parking with the addition of parking garages. Would these areas then become permeable turfgrass areas, and how would basic land management practices and maintenance effect the level of nutrient pollution in the surface runoff? Based on the results of this study, large permeable turfgrass areas do indeed provide mitigation to surface runoff; yet at the same time can contribute to nutrient pollution. In this instance, grading and plant selection become critical to the overall effectiveness of design in managing stormwater runoff and pollution. This dilemma, as it seems, provides a learning opportunity at the design, planning and policy making levels.

Addison Circle demonstrated smaller building set backs, verticality of the architecture and less reliance on the automobile, resulting in a dense composition of exterior design elements. Business related activities are not as prominent as in Southlake Town Square; surface parking is limited and parking structures more prevalent. Urban form typology and limited availability of open ground surfaces reduces the number of options to incorporate additional permeable plant cover areas for stormwater mitigation, and this is a common scenario in many high density clusters. The structural and circulation exterior design elements in Addison Circle comprise 78% of the surface area, yet none of these components had any stormwater mitigation devices such as green roofs, rain gardens, curbside infiltration trenches or permeable pavement. Would the stormwater runoff performance be better if the level of imperviousness had been reduced through the incorporation of green roofs and permeable pavement, and how can this be addressed through design and planning in future developments? These questions reinforce the significance of design as a critical factor in the overall performance of stormwater runoff and water pollution in higher density urban areas; and again, presents a learning opportunity for those involved in the future development of North Texas.

5.5 Significance of the Study

Over thirty years of research has gone into the development of the Soil and Water Assessment Tool (SWAT). Today it is used to quantify land management practices in large scale watersheds and river basins, and a considerable amount of literature has been produced regarding SWAT capabilities and limitations. Historically used in agricultural or rural settings, little research has been generated to assess SWAT modeling effectiveness in small scale, high density urban scenarios.

This is the first study to use SWAT to evaluate the stormwater runoff and water pollution performance of mixed-use developments in relation to land use density and the impervious of design elements. Additionally, very few studies, if any, have attempted to limit SWAT modeling to the confines of a specific site. Although field scale modeling has been performed in other hydrological modeling tools such as the Agricultural and Environmental Policy Extender (APEX), it is uncertain whether SWAT has been used in any previous assessments regarding stormwater runoff and pollution of mixed-use developments; and how varying design, planning and land management characteristics can impact the model results.

A secondary objective of this study is to analyze the Soil and Water Assessment Tool (SWAT) ability to simulate natural and land management processes in small scale, high density clusters. Mentioned previously, the primary purpose of SWAT is to assess these actions in large scale watersheds or river basins. Understandably, there are many considerations to account for in modeling high density clusters; but with a significant understanding of SWAT and research target, combined with quality observational data, it can be suggested that SWAT can be utilized to better understand stormwater runoff and pollution performance in urban scenarios. Further research is needed to define the limit, or threshold, for site size and model applicability; yet this may represent a significant opportunity for comprehensive modeling tools like SWAT to help relieve the burden of ambiguous and costly post construction and representative stormwater monitoring efforts.

5.6 Relevance to the Profession of Landscape Architecture

This study is relevant to the profession of landscape architecture in many ways. Stormwater runoff and pollution is generally considered a specialty of civil and agricultural engineers, stormwater managers and environmental scientists; and thus represents the primary users of comprehensive hydrologic modeling tools like SWAT. Landscape architecture perhaps more than any other profession, is capable of bridging the gap between agricultural, engineering and environmental disciplines and therefore could possibly represent a new user group for SWAT and other similar applications.

Design is a major component in the profession of landscape architecture and this research has further reinforced the idea that stormwater runoff and pollution is a critical factor to consider in the development process. Structural best management practices and Low Impact Development are all design tools or methods specifically used to help mitigate quality and quantity of stormwater runoff; and are often used today in landscape architectural design and planning. In this study, there were no mitigation devices to control *surface runoff*, and it is likely that the results would have been different.

There is value in the methods, or procedures, developed in this study to the profession of landscape architecture. They are not exceedingly technical and therefore are easy to understand and replicate. The inventory and analysis of exterior design elements and measurement of land use density can be performed with a basic understanding of Geographic Information Systems (GIS). The Soil and Water Assessment Tool (SWAT), although detailed and comprehensive, is very user friendly to those with a GIS background; and the ArcSWAT version has incorporated an interface to use with the ESRI ArcGIS platform.

This study utilized GIS and SWAT for a post construction evaluation of stormwater runoff and pollution in mixed-use developments as a way to better understand how they may impact the environment. Emphasis was placed on varying design and planning characteristics of these developments in relation to that performance; however, throughout the course of the research it was noticed that SWAT may be better utilized by the profession as a pre-construction evaluation during the inventory and analysis, and preliminary design stages of planning. Those in the profession with an understanding of the hydrologic cycle, soil structures, plant science and basic land management practices can effectively use SWAT for more than just post construction evaluation of stormwater runoff quality and quantity. For example, a design can be evaluated with SWAT and the results may indicate that permeable design elements capable of stormwater mitigation are located on impermeable clay soils; abrupt grade changes may impede natural drainage; or maintenance of plant materials may produce higher levels of pollutants.

5.7 Future Research

Concerned with environmental problems resulting from sprawl, communities in North Texas are looking for alternative planning approaches to growth. Mixed-use developments are being considered as way to address the current trend of development; yet little empirical knowledge exists pertaining to their environmental performance and how it impacts the region. More research is needed to better comprehend their environmental role in the future of North Texas in relation to water quality and quantity of stormwater runoff and imperviousness.

Results of this study and review of literature suggest that areas with high land use and population densities can produce lower amounts of nutrient pollution in the stormwater runoff. This is total pollution and pollution per person/per acre. Additional research using GIS and SWAT to compare stormwater runoff and water pollution and imperviousness between high density residential and single-family residential dwelling units could be valuable to community leaders, planners and designers in addressing concerns about future growth in North Texas.

This research evaluated the stormwater runoff performance in two mixed-use developments, each having a different form and function, representing a partial population of mixed-use development types found in North Texas. The two cases in this study represent primarily regional town centers and urban villages and districts. From a Soil and Water Assessment Tool modeling perspective, more empirical data is needed to assess the environmental performance of mixed-use sites containing a similar composition of area and design elements, such as traditional and historical town centers. Although multi-tower and integrated multi-tower mixed-use developments are common, it is questionable whether or not SWAT can model such developments, and represents an opportunity to expand research into SWAT capabilities and limitations.

Little or no structural best management practices or stormwater mitigation strategies were implemented to manage stormwater runoff surface flow and pollutants. Southlake Town Square does have a series of retention and detention basins, and ultimately their stormwater is managed on site, but they do little to minimize water quality and quantity of surface runoff. As a result, this study does not effectively measure the impact of structural design elements specifically used to minimize stormwater runoff and pollution. Supplementary research is needed using SWAT, and a study population of mixed-use developments containing stormwater runoff mitigation devices, to better understand what these urban forms can accomplish environmentally.

This study is the first to use the Soil and Water Assessment Tool within the constraints of site specific, high density urban environments; and represents a significant research opportunity to explore the methods and procedures used in this study, and how it can be applied to the profession of landscape architecture. Some questions related to this research for future consideration are:

1. Can the methods and procedures used in this study be modified to produce a more comprehensive evaluation of stormwater runoff and pollution in high density clusters using the Soil and Water Assessment Tool?
2. What is the threshold, or limit, in scale, where SWAT functionality is significantly hindered?
3. Can SWAT be an effective instrument to validate design decisions during pre-construction inventory and analysis, and preliminary design phases of development?
4. Can SWAT effectively evaluate the performance of small scale structural Best Management Practices within vertically oriented, high density, mixed-use developments?
5. Can additional research, using the tools and methods in this study, help to clarify ambiguities between stormwater management policy and design?
6. What empirical, or observed data, is best for SWAT modeling in mixed-use developments to increase accuracy of predictions?

7. Can SWAT be configured, or used, to address the uncertainty and complications associated with representative post-construction stormwater monitoring?

APPENDIX A

SOIL AND WATER ASSESSMENT TOOL INPUT FILES

.fig (watershed level file)	Watershed configuration file. This file defines the routing network in the watershed.
file.cio (watershed level file)	Control input/output file. This required file contains names of input files for all watershed level variables and subbasin level variables.
.cod (watershed level file)	Input control code file. This required file specifies the length of the simulation, the printing frequency, and selected options for various processes.
.bsn (watershed level file)	Basin input file. Required file for watershed level parameters. Catch-all file.
.pcp (watershed level file)	Precipitation input file. This optional file contains daily measured precipitation for a measuring gage(s). Up to 18 temperature files may be used in each simulation and each file can hold data for up to 300 stations. The data for a particular station is assigned to a subbasin in file.cio.
.tmp (watershed level file)	Temperature input file. This optional file contains daily measured maximum and minimum temperatures for a measuring gage(s). Up to 18 temperature files may be used in each simulation and each file can hold data for up to 150 stations. The data for a particular station is assigned to a subbasin in file.cio.
.slr (watershed level file)	Solar radiation input file. This optional file contains daily solar radiation for a measure gage(s). The solar radiation file can hold data for up to 300 stations. The data for a particular station is assigned to a subbasin in file.sio.
.wnd (watershed level file)	Wind speed input file. This optional file contains daily average wind speed for a measuring gage(s). The wind speed file can hold data for up to 300 stations. The data for a particular station is assigned to a subbasin in file.cio.
.hmd (watershed level file)	Relative humidity input file. This optional file contains daily relative humidity values for a measuring gage(s). The relative humidity file can hold data for up to 300 stations. The data for a particular station is assigned to a subbasin in file.cio.
.pet (watershed level file)	Potential evapotranspiration input file. This optional file contains daily PET values for the watershed.
crop.dat (watershed level file)	Land cover/plant growth database file. This required file contains plant growth parameters for all land covers simulated in the watershed.
.till.dat (watershed level file)	Tillage database file. This required file contains information on the amount and depth of mixing caused by tillage operations simulated in the watershed.
Pest.dat (watershed level file)	Pesticide database file. This required file contains information on mobility and degradation for all pesticides simulated in the watershed.
fert.dat (watershed level file)	Fertilizer database file. This required file contains information on the nutrient content of all fertilizers and manures simulated in the watershed.
urban.dat (watershed level file)	Urban database file. This required file contains information on the build-up/wash-off of solids in urban areas simulated in the watershed.
.sub (subbasin level file)	Subbasin input file. Required file for subbasin level parameters. Catch-all file.

.wgn (subbasin level file)	Weather generator input file. This required file contains the statistical data needed to generate representative daily climatic data for the subbasins.
.pnd (subbasin level file)	Pond/wetland input file. This optional file contains information for impoundments located within the subbasin.
.wus (subbasin level file)	Water use input file. This optional file contains information for consumptive water use in the subbasin.
.rte (subbasin level file)	Main channel input file. This required file contains parameters governing water and sediment movement in the main channel of the subbasin.
.wwq (watershed level file)	Watershed water quality input file. This optional file contains parameters used to model QUAL2E transformations in the main channels.
.swq (subbasin level file)	Stream water quality input file. This optional file contains parameters used to model pesticide and QUAL2E nutrient transformation in the main channel of the subbasin.
.hru (HRU level file)	Management input file. This required File contains management scenarios and specifies the land cover simulated in the HRU.
.mgt (HRU level file)	Management input file. This required file contains management scenarios and specifies the land cover simulated in the HRU.
.sol (HRU level file)	Soil input file. This required file contains information about the physical characteristics of the soil in the HRU.
.chm (HRU level file)	Soil chemical input file. This optional file contains information about initial nutrient and pesticide levels of the soil in the HRU.
.gw (HRU level file)	Groundwater input file. This required file contains information about the shallow and deep aquifer in the subbasin. Because land covers differ in their interaction with the shallow aquifer, information in the input file is allowed to be varied at the HRU level.
.res (reservoir file)	Reservoir input file. This optional file contains parameters used to model the movement of water and sediment through a reservoir.
.lwq (reservoir file)	Lake water quality input file. This optional file contains parameters used to model the movement of nutrients and pesticides through a reservoir.
recday.dat recmon.dat recyear.dat reccnst.dat (point source file)	Point source input file. These optional files contain information about loadings to the channel network from a point source. The type of file used to store data depends on how the data is summarized (daily, monthly, yearly, or average annual).

APPENDIX B

SOIL AND WATER ASSESSMENT TOOL
SOUTHLAKE TOWN SQUARE
GENERAL OUTPUT

```
   SWAT  Sept '05 VERSION2005                                              0/ 0/   0      0: 0: 0

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

       Number of years in run:    7
       Area of watershed:        0.646 km2
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    1 of simulation

 UNIT                        PERCO  TILE                 WATER    SED    NO3    NO3    NO3    NO3       N      P      P
 TIME   PREC   SURQ  LATQ   GWQ  LATE     Q   SW     ET     PET  YIELD  YIELD   SURQ   LATQ  PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  15.40   4.39   0.00   0.01   0.00   0.00  63.31  10.26  64.74   4.24   0.04   0.06   0.00   0.00   0.03    0.10    0.01
0.03
   2  76.13  39.56   0.04   0.07   0.00   0.00  78.10  21.68  70.54  39.43   0.35   0.22   0.00   0.00   0.76    0.53    0.05
0.16
   3  46.88  19.85   0.05   0.16   0.00   0.00  70.82  34.34 125.84  19.90   0.18   0.14   0.00   0.00   3.40    0.32    0.03
0.10
   4  41.02  13.69   0.03   0.17   0.00   0.00  62.09  36.04 172.45  13.69   0.12   0.14   0.00   0.00   6.58    0.26    0.03
0.08
   5  38.20  19.70   0.03   0.16   0.00   0.00  46.23  34.33 206.25  19.83   0.19   0.15   0.00   0.00   3.07    0.27    0.03
0.08
   6  78.52  38.46   0.06   0.15   0.00   0.00  44.21  42.01 259.84  38.45   0.38   0.36   0.00   0.00   0.11    0.55    0.05
0.17
   7  70.85  31.03   0.04   0.14   0.00   0.00  42.22  41.76 256.48  31.08   0.32   0.27   0.00   0.00   3.05    0.49    0.05
0.15
   8  64.40  32.71   0.04   0.11   0.00   0.00  46.91  26.65 251.38  32.74   0.33   0.24   0.00   0.00   0.00    0.44    0.04
0.14
   9  41.35  22.30   0.04   0.10   0.00   0.00  34.96  31.28 227.84  22.40   0.23   0.13   0.00   0.00   0.00    0.29    0.03
0.09
  10  17.77   6.21   0.03   0.09   0.00   0.00  32.71  13.80 158.62   6.29   0.06   0.07   0.00   0.00   0.00    0.11    0.01
0.03
  11  91.03  44.65   0.05   0.13   0.00   0.00  43.89  35.12 103.35  44.32   0.40   0.29   0.00   0.00   0.00    0.61    0.06
0.19
  12  68.77  27.34   0.04   0.25   0.39   0.00  65.65  19.18  56.58  27.26   0.24   0.18   0.00   0.28   0.22    0.44    0.04
0.14

 2000 650.30 299.87   0.45   1.53   0.39   0.00  65.65 346.451953.91 299.62   2.83   2.24   0.01   0.28  17.22     4.41
0.43    1.36
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    2 of simulation

 UNIT                        PERCO  TILE                 WATER    SED    NO3    NO3    NO3    NO3       N      P      P
 TIME   PREC   SURQ  LATQ   GWQ  LATE     Q   SW     ET     PET  YIELD  YIELD   SURQ   LATQ  PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  82.99  39.45   0.09   0.99   2.35   0.00  70.55  26.07  65.84  40.12   0.49   0.19   0.00   1.32   1.78    0.54    0.05
0.16
```

```
    2  17.69  11.72   0.04   1.21   0.00   0.00  72.86  13.80  69.09  12.88   0.11   0.07   0.00   0.00   2.28     0.18    0.02
0.05
    3  18.21   6.43   0.03   0.76   0.00   0.00  61.59  23.05 193.76   7.09   0.05   0.07   0.00   0.00   3.16     0.12    0.01
0.04
    4 161.70 113.98   0.06   0.38   2.31   0.00  76.13  29.84 185.51 114.30   1.66   0.46   0.00   0.46   1.90     1.29    0.11
0.38
    5 185.79 148.01   0.12   3.12  12.64   0.00  62.80  39.25 204.31 151.11   2.22   0.53   0.00   1.19   3.51     1.51    0.13
0.44
    6 122.52  78.66   0.09   6.33   3.04   0.00  67.24  35.52 238.87  84.99   1.06   0.40   0.00   0.21   1.25     0.86    0.08
0.27
    7 105.86  60.24   0.07   4.23   0.61   0.00  68.31  43.75 270.40  64.38   0.82   0.33   0.00   0.05   3.12     0.73    0.07
0.23
    8  10.54   3.49   0.07   1.75   0.73   0.00  48.60  26.91 267.14   5.22   0.04   0.04   0.00   0.03   0.00     0.07    0.01
0.02
    9  40.31  19.88   0.03   0.70   0.00   0.00  46.86  22.14 224.78  20.49   0.21   0.15   0.00   0.00   0.00     0.25    0.03
0.08
   10  38.74  19.51   0.04   0.33   0.00   0.00  45.75  20.31 151.63  19.78   0.19   0.12   0.00   0.00   0.00     0.24    0.03
0.08
   11  55.84  27.16   0.04   0.19   0.00   0.00  52.94  21.44 112.83  27.20   0.23   0.17   0.00   0.00   0.00     0.34    0.04
0.11
   12  80.50  47.98   0.05   0.34   5.07   0.00  63.81  16.49  62.91  48.05   0.52   0.22   0.00   1.07   0.27     0.52    0.06
0.17

 2001 920.67 576.53   0.72  20.32  26.75   0.00  63.81 318.562047.07 595.62   7.59   2.73   0.01   4.34  17.27     6.64
0.63    2.02
1
    SWAT  Sept '05 VERSION2005

    General Input/Output section (file.cio): ArcSWAT 2.3.4
    3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year     3 of simulation

 UNIT                          PERCO   TILE                   WATER    SED    NO3    NO3    NO3    NO3       N       P       P
 TIME   PREC   SURQ   LATQ    GWQ   LATE      Q    SW     ET     PET  YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
        (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
    1  18.05   7.27   0.05   2.20   0.77   0.00  58.43  15.37  76.39   9.40   0.06   0.05   0.00   0.11   1.88     0.11    0.01
0.04
    2  46.50  25.31   0.03   1.85   2.47   0.00  63.25  13.86  72.60  26.99   0.22   0.13   0.00   0.05   1.69     0.30    0.03
0.10
    3  29.96   8.24   0.04   2.20   0.59   0.00  50.89  33.49 189.33  10.17   0.08   0.09   0.00   0.01   0.38     0.19    0.02
0.06
    4  89.90  55.95   0.06   2.42   4.58   0.00  50.54  29.64 177.74  58.15   0.50   0.29   0.00   0.07   2.07     0.56    0.06
0.19
    5 176.79 108.87   0.07   3.13  10.87   0.00  68.18  38.88 176.98 111.77   1.41   0.52   0.00   0.55   4.52     1.20    0.12
0.38
    6 109.20  62.55   0.13   7.08   7.86   0.00  51.42  55.83 245.03  69.62   0.80   0.32   0.00   0.46   0.35     0.73    0.08
0.23
    7   9.45   3.90   0.07   6.48   0.00   0.00  36.28  20.68 323.10  10.44   0.04   0.03   0.00   0.00   3.08     0.06    0.01
0.02
    8  10.16   3.77   0.02   1.86   0.00   0.00  26.71  15.95 292.71   5.64   0.04   0.05   0.00   0.00   0.00     0.06    0.01
0.02
    9  72.54  41.52   0.05   0.72   0.00   0.00  29.96  27.71 227.75  42.06   0.40   0.25   0.00   0.00   0.00     0.45    0.05
0.15
   10 131.14  86.53   0.06   0.45   0.70   0.00  48.30  25.43 166.87  86.94   1.20   0.37   0.00   0.09   0.00     0.87    0.09
0.28
   11  93.22  64.83   0.10   1.23   3.39   0.00  49.78  23.47 120.85  66.04   1.14   0.26   0.00   0.75   0.00     0.65    0.07
0.20
   12  15.89   4.67   0.04   1.61   0.00   0.00  49.95  10.94  80.54   6.22   0.05   0.05   0.00   0.00   0.29     0.10    0.01
0.03

 2002 802.80 473.42   0.72  31.24  31.22   0.00  49.95 311.242149.89 503.44   5.94   2.41   0.01   2.10  14.27     5.28
0.55    1.70
1
```

```
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    4 of simulation

 UNIT                          PERCO  TILE                 WATER    SED    NO3    NO3    NO3    NO3       N       P      P
 TIME   PREC   SURQ   LATQ    GWQ   LATE     Q    SW     ET     PET  YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  43.02  20.32   0.04   0.80   3.14   0.00  52.43  17.13  79.49  20.92   0.17   0.12   0.00   0.55   1.95     0.27    0.03
0.09
   2  18.46   1.49   0.02   1.49   0.00   0.00  49.47   6.53  55.78   2.94   0.02   0.04   0.00   0.00   1.64     0.03    0.00
0.01
   3   7.13   8.80   0.01   1.19   0.37   0.00  40.39  20.42 165.65   9.86   0.14   0.07   0.00   0.00   0.71     0.14    0.01
0.04
   4   0.25   0.00   0.01   0.40   0.00   0.00  36.57   4.08 199.59   0.40   0.00   0.00   0.00   0.00   1.88     0.00    0.00
0.00
   5 139.01  82.58   0.05   0.93   5.04   0.00  50.07  37.76 212.89  83.23   0.98   0.41   0.00   0.11   4.99     0.89    0.10
0.29
   6  26.67  16.06   0.05   2.12   0.22   0.00  34.19  26.27 279.73  18.19   0.17   0.10   0.00   0.00   0.20     0.17    0.02
0.06
   7  56.30  29.26   0.04   0.96   0.00   0.00  28.88  32.31 308.70  30.18   0.33   0.21   0.00   0.00   3.20     0.35    0.04
0.12
   8  13.96   6.41   0.02   0.36   0.00   0.00  29.48   6.77 302.66   6.76   0.05   0.05   0.00   0.00   0.00     0.08    0.01
0.03
   9   7.63   2.75   0.01   0.16   0.00   0.00  21.59  12.94 238.75   2.87   0.03   0.03   0.00   0.00   0.00     0.05    0.01
0.02
  10 106.37  66.73   0.07   0.11   0.00   0.00  40.45  20.69 122.04  66.80   0.79   0.30   0.00   0.00   0.00     0.66    0.07
0.22
  11  96.01  47.53   0.06   0.22   5.48   0.00  60.43  22.78  86.43  47.36   0.46   0.26   0.00   1.22   0.00     0.60    0.07
0.20
  12  31.80  14.09   0.07   2.84   3.23   0.00  52.86  22.15  75.31  16.82   0.13   0.09   0.00   0.57   0.23     0.20    0.02
0.07

 2003 546.61 296.03   0.45  11.59  17.48   0.00  52.86 229.832127.01 306.33   3.25   1.70   0.01   2.45  14.80     3.44
0.37    1.13
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    5 of simulation

 UNIT                          PERCO  TILE                 WATER    SED    NO3    NO3    NO3    NO3       N       P      P
 TIME   PREC   SURQ   LATQ    GWQ   LATE     Q    SW     ET     PET  YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  40.85  19.66   0.04   3.24   3.20   0.00  54.15  16.65  64.38  22.49   0.23   0.12   0.00   0.33   1.95     0.27    0.03
0.08
   2  68.96  35.95   0.06   3.98   7.28   0.00  58.10  21.71  62.01  39.55   0.34   0.19   0.00   0.33   1.46     0.43    0.05
0.14
   3  46.69  16.14   0.07   5.86   4.23   0.00  54.82  29.54 151.99  21.80   0.17   0.13   0.00   0.11   0.60     0.30    0.03
0.09
   4  70.54  44.37   0.05   4.60   3.72   0.00  49.29  27.92 197.90  48.91   0.53   0.21   0.00   0.04   2.91     0.44    0.05
0.14
   5 173.14 114.15   0.08   4.32  11.27   0.00  58.56  38.30 191.17 118.31   1.63   0.50   0.00   0.34   4.36     1.15    0.13
0.37
   6  72.02  34.91   0.09   6.14   0.70   0.00  53.74  41.18 253.75  40.99   0.36   0.23   0.00   0.02   0.29     0.43    0.05
0.14
   7  24.99  11.93   0.07   3.67   1.09   0.00  31.26  34.44 341.96  15.57   0.14   0.07   0.00   0.00   3.15     0.16    0.02
0.05
```

```
   8  93.03  59.34   0.05   1.31   0.00   0.00  34.57  30.32 290.36  60.60   0.93   0.29   0.00   0.00   0.00     0.60    0.06
0.20
   9  83.20  45.70   0.08   0.67   0.79   0.00  37.46  33.75 214.51  46.30   0.57   0.24   0.00   0.09   0.00     0.52    0.06
0.17
  10   0.10   0.00   0.03   0.57   0.00   0.00  31.75   5.81 147.84   0.60   0.00   0.00   0.00   0.00   0.00     0.00    0.00
0.00
  11 184.29 127.11   0.05   0.30   4.27   0.00  62.76  20.55 108.74 127.22   1.76   0.52   0.00   0.81   0.00     1.15    0.13
0.39
  12  35.59  16.46   0.10   4.12   8.47   0.00  53.41  21.16  71.56  20.25   0.13   0.10   0.00   1.99   0.38     0.23    0.02
0.07

 2004 893.41 525.70   0.78  38.78  45.02   0.00  53.41 321.352096.17 562.58   6.79   2.60   0.01   4.07  15.10     5.67
0.62    1.86
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    6 of simulation

 UNIT                            PERCO  TILE                  WATER    SED    NO3    NO3    NO3    NO3       N       P       P
 TIME   PREC   SURQ  LATQ    GWQ   LATE      Q   SW     ET     PET  YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1   0.00   0.00   0.03   4.61   0.00   0.00  46.12   7.29  97.22   4.64   0.00   0.00   0.00   0.00   2.04     0.00    0.00
0.00
   2  41.15  21.11   0.03   2.35   2.20   0.00  52.20  11.72  73.34  23.36   0.19   0.17   0.00   0.04   1.90     0.25    0.03
0.08
   3  55.79  26.28   0.05   2.65   4.03   0.00  49.67  27.96 156.26  28.82   0.28   0.16   0.00   0.01   0.85     0.35    0.04
0.11
   4 136.17 103.49   0.08   4.40   8.37   0.00  46.77  27.13 159.17 107.84   1.66   0.37   0.00   0.11   1.90     0.87    0.10
0.29
   5 119.52  69.93   0.08   5.84   7.94   0.00  50.54  37.77 173.43  75.58   0.95   0.33   0.00   0.07   5.39     0.73    0.08
0.24
   6  44.31  23.79   0.05   5.20   0.00   0.00  43.16  27.87 253.43  28.97   0.27   0.14   0.00   0.00   0.32     0.27    0.03
0.09
   7 158.09 108.02   0.07   1.83   6.99   0.00  48.49  37.61 284.53 109.68   1.89   0.46   0.00   0.34   3.39     1.02    0.11
0.34
   8  17.30   7.78   0.08   3.67   0.00   0.00  34.42  23.58 333.86  11.50   0.08   0.06   0.00   0.00   0.02     0.11    0.01
0.04
   9 127.02  86.73   0.07   1.85   3.31   0.00  41.59  29.71 231.85  88.59   1.39   0.38   0.00   0.53   0.00     0.79    0.09
0.27
  10 204.65 141.63   0.13   4.72  16.44   0.00  50.47  37.53 142.61 146.08   2.21   0.59   0.01   4.36   0.00     1.27    0.15
0.43
  11  91.52  44.83   0.12   9.18  10.89   0.00  59.90  26.26  77.18  53.77   0.48   0.25   0.00   2.14   0.00     0.54    0.06
0.18
  12  91.38  58.97   0.10  10.40   8.78   0.00  58.78  24.66  88.49  69.28   0.72   0.27   0.00   0.98   0.25     0.55    0.06
0.19

 20051086.89 692.57   0.88  56.70  68.96   0.00  58.78 319.092071.36 748.12  10.10   3.19   0.02   8.58  16.06     6.74
0.78    2.25
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    7 of simulation

 UNIT                            PERCO  TILE                  WATER    SED    NO3    NO3    NO3    NO3       N       P       P
 TIME   PREC   SURQ  LATQ    GWQ   LATE      Q   SW     ET     PET  YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
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   1   0.00   0.00   0.00   0.33   0.15   0.00  57.76   0.87   1.41   0.33   0.00   0.00   0.00   0.01   0.08    0.00    0.00    0.00

 2006   0.00   0.00   0.00   0.33   0.15   0.00  57.76   0.87   1.41   0.33   0.00   0.00   0.00   0.01   0.08    0.00    0.00
0.00
1
  SWAT  Sept '05 VERSION2005

  General Input/Output section (file.cio): ArcSWAT 2.3.4
  3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

  FINAL VALUES

1
  SWAT  Sept '05 VERSION2005

  General Input/Output section (file.cio): ArcSWAT 2.3.4
  3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

                           Average Crop Values
                        Crop 1           Crop 2           Crop 3
                      Yld     Biomass   Yld    Biomass     Yld     Biomass
                    (kg/ha)   (kg/ha)  (kg/ha)  (kg/ha)    (kg/ha)   (kg/ha)


 BERM  HRU     11 Rot  1     0.0   3155.8       0.0       0.0       0.0       0.0
 BERM  HRU     11 Rot  2     0.0   1098.1       0.0       0.0       0.0       0.0
 BERM  HRU     11 Rot  3     0.0   2948.9       0.0       0.0       0.0       0.0
 BERM  HRU     11 Rot  4     0.0   3746.2       0.0       0.0       0.0       0.0
 BERM  HRU     11 Rot  5     0.0   4418.6       0.0       0.0       0.0       0.0
 BERM  HRU     12 Rot  1     0.0   3132.3       0.0       0.0       0.0       0.0
 BERM  HRU     12 Rot  2     0.0   1100.6       0.0       0.0       0.0       0.0
 BERM  HRU     12 Rot  3     0.0   2944.5       0.0       0.0       0.0       0.0
 BERM  HRU     12 Rot  4     0.0   3751.7       0.0       0.0       0.0       0.0
 BERM  HRU     12 Rot  5     0.0   4397.9       0.0       0.0       0.0       0.0
 BERM  HRU     25 Rot  1     0.0   3152.1       0.0       0.0       0.0       0.0
 BERM  HRU     25 Rot  2     0.0   1097.6       0.0       0.0       0.0       0.0
 BERM  HRU     25 Rot  3     0.0   2946.1       0.0       0.0       0.0       0.0
 BERM  HRU     25 Rot  4     0.0   3743.1       0.0       0.0       0.0       0.0
 BERM  HRU     25 Rot  5     0.0   4411.9       0.0       0.0       0.0       0.0
 BERM  HRU     34 Rot  1     0.0   3134.4       0.0       0.0       0.0       0.0
 BERM  HRU     34 Rot  2     0.0   1101.1       0.0       0.0       0.0       0.0
 BERM  HRU     34 Rot  3     0.0   2938.4       0.0       0.0       0.0       0.0
 BERM  HRU     34 Rot  4     0.0   3749.1       0.0       0.0       0.0       0.0
 BERM  HRU     34 Rot  5     0.0   4401.1       0.0       0.0       0.0       0.0
 BERM  HRU     35 Rot  1     0.0   3155.7       0.0       0.0       0.0       0.0
 BERM  HRU     35 Rot  2     0.0   1098.0       0.0       0.0       0.0       0.0
 BERM  HRU     35 Rot  3     0.0   2948.9       0.0       0.0       0.0       0.0
 BERM  HRU     35 Rot  4     0.0   3746.1       0.0       0.0       0.0       0.0
 BERM  HRU     35 Rot  5     0.0   4418.4       0.0       0.0       0.0       0.0
 BERM  HRU     46 Rot  1     0.0   3155.4       0.0       0.0       0.0       0.0
 BERM  HRU     46 Rot  2     0.0   1098.2       0.0       0.0       0.0       0.0
 BERM  HRU     46 Rot  3     0.0   2949.5       0.0       0.0       0.0       0.0
 BERM  HRU     46 Rot  4     0.0   3746.8       0.0       0.0       0.0       0.0
 BERM  HRU     46 Rot  5     0.0   4415.9       0.0       0.0       0.0       0.0
 BERM  HRU     47 Rot  1     0.0   3135.0       0.0       0.0       0.0       0.0
 BERM  HRU     47 Rot  2     0.0   1101.2       0.0       0.0       0.0       0.0
 BERM  HRU     47 Rot  3     0.0   2936.8       0.0       0.0       0.0       0.0
 BERM  HRU     47 Rot  4     0.0   3748.3       0.0       0.0       0.0       0.0
 BERM  HRU     47 Rot  5     0.0   4402.0       0.0       0.0       0.0       0.0
 BERM  HRU     52 Rot  1     0.0   3156.2       0.0       0.0       0.0       0.0
 BERM  HRU     52 Rot  2     0.0   1098.1       0.0       0.0       0.0       0.0
 BERM  HRU     52 Rot  3     0.0   2949.1       0.0       0.0       0.0       0.0
 BERM  HRU     52 Rot  4     0.0   3746.4       0.0       0.0       0.0       0.0
 BERM  HRU     52 Rot  5     0.0   4419.0       0.0       0.0       0.0       0.0
 BERM  HRU     60 Rot  1     0.0   3132.9       0.0       0.0       0.0       0.0
 BERM  HRU     60 Rot  2     0.0   1100.9       0.0       0.0       0.0       0.0
 BERM  HRU     60 Rot  3     0.0   2941.2       0.0       0.0       0.0       0.0
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 BERM  HRU     60 Rot   4     0.0    3750.4       0.0       0.0       0.0       0.0
 BERM  HRU     60 Rot   5     0.0    4398.8       0.0       0.0       0.0       0.0
 BERM  HRU     61 Rot   1     0.0    3156.2       0.0       0.0       0.0       0.0
 BERM  HRU     61 Rot   2     0.0    1098.1       0.0       0.0       0.0       0.0
 BERM  HRU     61 Rot   3     0.0    2949.2       0.0       0.0       0.0       0.0
 BERM  HRU     61 Rot   4     0.0    3746.4       0.0       0.0       0.0       0.0
 BERM  HRU     61 Rot   5     0.0    4419.0       0.0       0.0       0.0       0.0
 BERM  HRU     67 Rot   1     0.0    3132.8       0.0       0.0       0.0       0.0
 BERM  HRU     67 Rot   2     0.0    1100.8       0.0       0.0       0.0       0.0
 BERM  HRU     67 Rot   3     0.0    2942.4       0.0       0.0       0.0       0.0
 BERM  HRU     67 Rot   4     0.0    3750.9       0.0       0.0       0.0       0.0
 BERM  HRU     67 Rot   5     0.0    4398.5       0.0       0.0       0.0       0.0
 BERM  HRU     68 Rot   1     0.0    3155.8       0.0       0.0       0.0       0.0
 BERM  HRU     68 Rot   2     0.0    1098.1       0.0       0.0       0.0       0.0
 BERM  HRU     68 Rot   3     0.0    2948.9       0.0       0.0       0.0       0.0
 BERM  HRU     68 Rot   4     0.0    3746.2       0.0       0.0       0.0       0.0
 BERM  HRU     68 Rot   5     0.0    4418.6       0.0       0.0       0.0       0.0

   HRU STATISTICS

             AVE ANNUAL VALUES

 HRU  SUB CPMN SOIL    AREAkm2     CN    AWCmm USLE_LS   IRRmm AUTONkh AUTOPkh   MIXEF  PRECmm
SURQmm   GWQmm    ETmm   SEDth  NO3kgh ORGNkgh  BIOMth   YLDth
    1   1 BARRCALLISBU.848E-03   97.84  186.44    0.26    0.00    0.00    0.00    0.23  816.41  586.39   22.93  237.97
20.47    3.79    8.50    0.00    0.00
    2   1 BARRCALLISBU.389E-02   95.40  186.44    0.18    0.00    0.00    0.00    0.23  816.41  546.53    4.72  275.58
10.64    3.47    6.72    0.00    0.00
    3   1 BARRCALLISBU.993E-04   95.40  186.44    1.15    0.00    0.00    0.00    0.23  816.41  546.36  179.22  274.14
68.67    4.17    8.43    0.00    0.00
    4   1 BARRCALLISBU.484E-03   77.00  186.44    2.01    0.00    0.00    0.00    0.23  816.41  151.15  101.40  534.63
87.32    0.50    6.79    0.00    0.00
    5   1 BARRCALLISBU.150E-02   77.00  186.44    0.20    0.00    0.00    0.00    0.23  816.41  152.60   90.86  536.56
8.65    0.40    3.02    0.00    0.00
    6   2 BARRCALLISBU.122E-01   97.20  186.44    0.15    0.00    0.00    0.00    0.23  816.41  573.54    1.73  250.34
7.01    3.38    6.30    0.00    0.00
    7   2 BARRCALLISBU.161E-03   97.20  186.44    1.28    0.00    0.00    0.00    0.23  816.41  573.38  113.86  248.95
60.58    4.16    8.24    0.00    0.00
    8   2 BARRCALLISBU.333E-01   97.84  186.44    0.13    0.00    0.00    0.00    0.23  816.41  586.40    1.24  238.08
3.09    3.05    6.76    0.00    0.00
    9   2 BARRCALLISBU.348E-03   97.84  186.44    1.28    0.00    0.00    0.00    0.23  816.41  586.35   51.20  236.65
36.74    4.02    9.01    0.00    0.00
   10   2 BARRCALLISBU.308E-02   95.40  186.44    0.14    0.00    0.00    0.00    0.23  816.41  546.53    6.94  275.63
10.60    3.51    6.75    0.00    0.00
   11   2 BERMCALLISBU.124E-01   72.00  186.44    0.23    0.00    0.00    0.00    0.23  816.41  105.17  164.60  483.95
0.03    0.55    0.03    3.27    0.00
   12   2 BERMCALLISBU.273E-02   72.00  186.44    1.31    0.00    0.00    0.00    0.23  816.41  104.56  170.02  481.06
0.18    0.78    0.17    3.26    0.00
   13   2 BARRCALLISBU.151E-02   77.00  186.44    1.47    0.00    0.00    0.00    0.23  816.41  151.44   92.69  535.03
76.53    0.48    6.67    0.00    0.00
   14   2 BARRCALLISBU.158E-01   77.00  186.44    0.31    0.00    0.00    0.00    0.23  816.41  152.54   84.22  536.50
18.77    0.41    4.44    0.00    0.00
   15   2 BARRCALLISBU.459E-02   92.00  186.44    0.15    0.00    0.00    0.00    0.23  816.41  344.31    2.06  456.52
21.53    1.53    5.27    0.00    0.00
   16   2 BARRCALLISBU.195E-03   92.00  186.44    1.18    0.00    0.00    0.00    0.23  816.41  341.26   62.49  455.24
107.26    1.56    7.41    0.00    0.00
   17   3 BARRCALLISBU.181E-03   81.88  186.44    0.98    0.00    0.00    0.00    0.23  816.41  290.40   94.82  492.10
44.45    1.15    4.77    0.00    0.00
   18   3 BARRCALLISBU.227E-01   81.88  186.44    0.15    0.00    0.00    0.00    0.23  816.41  292.04    9.07  493.77
11.02    1.02    3.48    0.00    0.00
   19   3 BARRCALLISBU.303E-03   97.20  186.44    1.50    0.00    0.00    0.00    0.23  816.41  573.36   57.06  248.78
54.78    4.04    7.97    0.00    0.00
   20   3 BARRCALLISBU.116E-01   97.20  186.44    0.14    0.00    0.00    0.00    0.23  816.41  573.55    1.72  250.35
6.83    3.39    6.30    0.00    0.00
   21   3 BARRCALLISBU.718E-04   97.84  186.44    1.33    0.00    0.00    0.00    0.23  816.41  586.35  229.41  236.60
81.33    4.41    9.92    0.00    0.00
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    22   3 BARRCALLISBU.200E-01   97.84  186.44    0.15    0.00    0.00    0.00    0.23  816.41  586.40    1.31  238.05
4.00    3.15    6.98    0.00    0.00
    23   3 BARRCALLISBU.367E-03   95.40  186.44    1.31    0.00    0.00    0.00    0.23  816.41  546.34   47.27  274.00
48.15    3.91    7.88    0.00    0.00
    24   3 BARRCALLISBU.163E-01   95.40  186.44    0.15    0.00    0.00    0.00    0.23  816.41  546.53    1.53  275.62
6.39    3.25    6.19    0.00    0.00
    25   3 BERMCALLISBU.406E-03   72.00  186.44    0.10    0.00    0.00    0.00    0.23  816.41  105.49  186.64  483.55
0.00    0.53    0.00    3.27    0.00
    26   3 BARRCALLISBU.150E-01   77.00  186.44    0.21    0.00    0.00    0.00    0.23  816.41  152.59   84.16  536.54
12.55    0.40    3.69    0.00    0.00
    27   3 BARRCALLISBU.123E-02   77.00  186.44    1.64    0.00    0.00    0.00    0.23  816.41  151.35   94.07  534.89
83.20    0.49    6.75    0.00    0.00
    28   4 BARRCALLISBU.109E-01   97.20  186.44    0.21    0.00    0.00    0.00    0.23  816.41  573.54    1.62  250.29
8.80    3.40    6.40    0.00    0.00
    29   4 BARRCALLISBU.548E-03   97.20  186.44    1.25    0.00    0.00    0.00    0.23  816.41  573.38   33.89  248.97
44.33    3.92    7.71    0.00    0.00
    30   4 BARRCALLISBU.846E-04   97.20  186.44    1.42    0.00    0.00    0.00    0.23  816.41  573.37  205.40  248.85
76.49    4.29    8.53    0.00    0.00
    31   4 BARRCALLISBU.427E-01   97.20  186.44    0.12    0.00    0.00    0.00    0.23  816.41  573.55    0.97  250.37
4.67    3.20    5.84    0.00    0.00
    32   4 BARRCALLISBU.113E+00   97.84  186.44    0.14    0.00    0.00    0.00    0.23  816.41  586.40    0.90  238.07
2.02    2.84    6.28    0.00    0.00
    33   4 BARRCALLISBU.128E-02   97.84  186.44    1.42    0.00    0.00    0.00    0.23  816.41  586.35   13.71  236.54
21.47    3.72    8.32    0.00    0.00
    34   4 BERMCALLISBU.486E-02   72.00  186.44    1.73    0.00    0.00    0.00    0.23  816.41  104.04  169.59  481.27
0.25    0.84    0.25    3.26    0.00
    35   4 BERMCALLISBU.175E-01   72.00  186.44    0.23    0.00    0.00    0.00    0.23  816.41  105.18  164.38  483.93
0.03    0.55    0.03    3.27    0.00
    36   4 BARRCALLISBU.153E-03   92.00  186.44    1.36    0.00    0.00    0.00    0.23  816.41  340.92   83.89  455.10
111.44    1.56    7.40    0.00    0.00
    37   4 BARRCALLISBU.232E-02   92.00  186.44    0.21    0.00    0.00    0.00    0.23  816.41  344.19    4.48  456.48
28.82    1.53    5.79    0.00    0.00
    38   5 BARRCALLISBU.291E-03   97.84  186.44    1.36    0.00    0.00    0.00    0.23  816.41  586.35   59.51  236.59
40.33    4.06    9.11    0.00    0.00
    39   5 BARRCALLISBU.143E-02   97.84  186.44    0.20    0.00    0.00    0.00    0.23  816.41  586.39   14.05  238.01
15.32    3.68    8.22    0.00    0.00
    40   6 BARRCALLISBU.141E-01   97.20  186.44    0.18    0.00    0.00    0.00    0.23  816.41  573.54    1.57  250.31
7.70    3.36    6.29    0.00    0.00
    41   6 BARRCALLISBU.917E-03   97.20  186.44    1.67    0.00    0.00    0.00    0.23  816.41  573.34   18.16  248.66
49.14    3.83    7.50    0.00    0.00
    42   6 BARRCALLISBU.333E-03   97.20  186.44    1.44    0.00    0.00    0.00    0.23  816.41  573.36   51.98  248.82
52.74    4.02    7.93    0.00    0.00
    43   6 BARRCALLISBU.127E-01   97.20  186.44    0.13    0.00    0.00    0.00    0.23  816.41  573.55    1.61  250.36
6.41    3.38    6.25    0.00    0.00
    44   6 BARRCALLISBU.325E-01   97.84  186.44    0.17    0.00    0.00    0.00    0.23  816.41  586.40    1.13  238.03
3.38    3.06    6.78    0.00    0.00
    45   6 BARRCALLISBU.312E-03   97.84  186.44    1.10    0.00    0.00    0.00    0.23  816.41  586.36   54.57  236.79
38.11    4.04    9.07    0.00    0.00
    46   6 BERMCALLISBU.130E-01   72.00  186.44    0.26    0.00    0.00    0.00    0.23  816.41  105.16  164.63  483.92
0.04    0.55    0.04    3.27    0.00
    47   6 BERMCALLISBU.349E-02   72.00  186.44    1.82    0.00    0.00    0.00    0.23  816.41  103.91  170.10  481.37
0.26    0.85    0.25    3.26    0.00
    48   6 BARRCALLISBU.292E-03   92.00  186.44    1.10    0.00    0.00    0.00    0.23  816.41  341.41   46.03  455.29
110.82    1.56    7.48    0.00    0.00
    49   6 BARRCALLISBU.215E-02   92.00  186.44    0.26    0.00    0.00    0.00    0.23  816.41  344.13    4.95  456.44
34.78    1.53    6.11    0.00    0.00
    50   7 BARRCALLISBU.223E-04   97.20  186.44    0.13    0.00    0.00    0.00    0.23  816.41  573.55  488.65  250.36
132.66    4.56    8.41    0.00    0.00
    51   7 BARRCALLISBU.747E-05   97.84  186.44    0.11    0.00    0.00    0.00    0.23  816.41  586.40  496.95  238.10
282.69    5.04   11.26    0.00    0.00
    52   7 BERMCALLISBU.420E-05   72.00  186.44    0.24    0.00    0.00    0.00    0.23  816.41  105.14  256.03  483.99
0.00    0.55    0.00    3.27    0.00
    53   8 BARRCALLISBU.145E-01   81.88  186.44    0.24    0.00    0.00    0.00    0.23  816.41  291.93    9.50  493.68
17.82    1.03    4.07    0.00    0.00
    54   8 BARRCALLISBU.613E-03   81.88  186.44    1.39    0.00    0.00    0.00    0.23  816.41  289.91   41.77  491.63
77.54    1.14    5.36    0.00    0.00
```

```
   55   8 BARRCALLISBU.959E-03   97.20  186.44    1.61    0.00    0.00    0.00    0.23  816.41  573.35   17.38  248.70
47.75    3.82    7.48    0.00    0.00
   56   8 BARRCALLISBU.234E-01   97.20  186.44    0.18    0.00    0.00    0.00    0.23  816.41  573.54    1.12  250.31
7.09    3.29    6.12    0.00    0.00
   57   8 BARRCALLISBU.571E-01   97.84  186.44    0.14    0.00    0.00    0.00    0.23  816.41  586.40    0.89  238.07
2.55    2.96    6.55    0.00    0.00
   58   8 BARRCALLISBU.347E-03   97.84  186.44    1.28    0.00    0.00    0.00    0.23  816.41  586.35   51.10  236.65
36.80    4.02    9.01    0.00    0.00
   59   8 BARRCALLISBU.919E-03   95.40  186.44    0.12    0.00    0.00    0.00    0.23  816.41  546.54   25.12  275.66
17.95    3.72    7.17    0.00    0.00
   60   8 BERMCALLISBU.121E-02   72.00  186.44    1.56    0.00    0.00    0.00    0.23  816.41  104.29  173.16  481.09
0.19    0.82    0.18    3.26    0.00
   61   8 BERMCALLISBU.919E-02   72.00  186.44    0.24    0.00    0.00    0.00    0.23  816.41  105.13  164.60  484.00
0.03    0.55    0.03    3.27    0.00
   62   9 BARRCALLISBU.358E-04   97.20  186.44    0.10    0.00    0.00    0.00    0.23  816.41  573.55  446.40  250.39
101.78    4.46    8.21    0.00    0.00
   63   9 BARRCALLISBU.128E-01   97.20  186.44    0.13    0.00    0.00    0.00    0.23  816.41  573.55    1.50  250.36
6.38    3.37    6.25    0.00    0.00
   64   9 BARRCALLISBU.228E-03   97.84  186.44    1.05    0.00    0.00    0.00    0.23  816.41  586.36   82.71  236.83
44.36    4.12    9.25    0.00    0.00
   65   9 BARRCALLISBU.513E-01   97.84  186.44    0.14    0.00    0.00    0.00    0.23  816.41  586.40    0.95  238.07
2.65    2.98    6.59    0.00    0.00
   66   9 BARRCALLISBU.103E-02   95.40  186.44    0.13    0.00    0.00    0.00    0.23  816.41  546.54   21.29  275.64
17.13    3.70    7.14    0.00    0.00
   67   9 BERMCALLISBU.172E-02   72.00  186.44    1.47    0.00    0.00    0.00    0.23  816.41  104.38  171.99  481.08
0.19    0.80    0.18    3.26    0.00
   68   9 BERMCALLISBU.133E-01   72.00  186.44    0.23    0.00    0.00    0.00    0.23  816.41  105.17  164.52  483.95
0.03    0.55    0.03    3.27    0.00
   69   9 BARRCALLISBU.113E-02   92.00  186.44    0.26    0.00    0.00    0.00    0.23  816.41  344.12   11.63  456.44
31.86    1.53    5.95    0.00    0.00
   70   9 BARRCALLISBU.102E-03   92.00  186.44    1.44    0.00    0.00    0.00    0.23  816.41  340.78  104.12  455.04
102.45    1.57    7.19    0.00    0.00


             AVE MONTHLY BASIN VALUES
               SNOW                WATER             SED
  MON     RAIN     FALL   SURF Q   LAT Q   YIELD      ET    YIELD      PET
        (MM)     (MM)     (MM)     (MM)     (MM)     (MM)   (T/HA)    (MM)
   1    33.21    14.62    15.10    0.04    16.93    15.52    0.16    74.51
   2    45.87    20.75    23.05    0.04    24.76    15.24    0.21    68.81
   3    34.11     3.00    14.29    0.04    16.27    28.13    0.15   163.80
   4    83.26     0.00    55.25    0.05    57.21    25.78    0.75   182.06
   5   138.74     0.00    90.54    0.07    93.31    37.71    1.23   194.17
   6    75.54     0.00    42.40    0.08    46.87    38.11    0.51   255.11
   7    70.92     0.00    40.73    0.06    43.56    35.09    0.59   297.53
   8    34.90     0.00    18.92    0.05    20.41    21.69    0.24   289.69
   9    62.01     0.00    36.48    0.05    37.12    26.25    0.47   227.58
  10    83.13     0.00    53.43    0.06    54.42    20.59    0.74   148.27
  11   101.98     0.84    59.35    0.07    60.98    24.94    0.75   101.56
  12    53.99    17.82    28.25    0.07    31.31    19.10    0.30    72.56

    AVE ANNUAL BASIN STRESS DAYS
          WATER STRESS DAYS =     0.50
          TEMPERATURE STRESS DAYS =    12.39
          NITROGEN STRESS DAYS =     7.82
          PHOSPHORUS STRESS DAYS =    14.41
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

        AVE ANNUAL BASIN VALUES

             PRECIP =    816.4 MM
```

```
     SNOW FALL =   56.60 MM
     SNOW MELT =    56.08 MM
     SUBLIMATION =     0.53 MM
     SURFACE RUNOFF Q =   477.13 MM
     LATERAL SOIL Q =    0.67 MM
     TILE Q =     0.00 MM
     GROUNDWATER (SHAL AQ) Q =    26.74 MM
     REVAP (SHAL AQ => SOIL/PLANTS) =    3.17 MM
     DEEP AQ RECHARGE =     1.61 MM
     TOTAL AQ RECHARGE =   32.19 MM
     TOTAL WATER YLD =   502.44 MM
     PERCOLATION OUT OF SOIL =   31.65 MM
     ET =    307.8 MM
     PET =   2073.5MM
     TRANSMISSION LOSSES =     2.09 MM
     TOTAL SEDIMENT LOADING =     6.081 T/HA
     POND BUDGET
       EVAPORATION =    0.000 MM
       SEEPAGE =    0.000 MM
       RAINFALL ON POOL =   0.000 MM
       INFLOW
         WATER =    0.000 MM
         SEDIMENT =    0.000 T/HA
       OUTFLOW
         WATER =    0.000 MM
         SEDIMENT =    0.000 T/HA
     RESERVOIR BUDGET
       EVAPORATION =    0.000 MM
       SEEPAGE =    0.000 MM
       RAINFALL ON RESERVOIR =    0.000 MM
       INFLOW
         WATER =    0.000 MM
         SEDIMENT =    0.000 T/HA
       OUTFLOW
         WATER =    0.000 MM
         SEDIMENT =    0.000 T/HA
     YIELD LOSS FROM PONDS
       WATER =   0.000 MM
       SEDIMENT =   0.000 T/HA
     YIELD LOSS FROM RESERVOIRS
       WATER =   0.000 MM
       SEDIMENT =   0.000 T/HA
1
 SWAT  Sept '05 VERSION2005

 General Input/Output section (file.cio): ArcSWAT 2.3.4
 3/28/2010 12:00:00 AMARCGIS-SWAT interface AV

     AVE ANNUAL BASIN VALUES


     NUTRIENTS
       ORGANIC N =     5.362 (KG/HA)
       ORGANIC P =     1.719 (KG/HA)
       NO3 YIELD (SQ) =     2.478 (KG/HA)
       NO3 YIELD (SSQ) =    0.012 (KG/HA)
       SOL P YIELD =    0.564 (KG/HA)
       NO3 LEACHED =     3.635 (KG/HA)
       P LEACHED =     0.205 (KG/HA)
       N UPTAKE =    15.791 (KG/HA)
       P UPTAKE =    5.353 (KG/HA)
       NO3 YIELD (GWQ) =     2.569 (KG/HA)
       ACTIVE TO SOLUTION P FLOW =    -1.807 (KG/HA)
       ACTIVE TO STABLE P FLOW =    -0.088 (KG/HA)
       N FERTILIZER APPLIED =   13.050 (KG/HA)
       P FERTILIZER APPLIED =    1.414 (KG/HA)
```

```
N FIXATION =    0.000 (KG/HA)
DENITRIFICATION =    0.000 (KG/HA)
HUMUS MIN ON ACTIVE ORG N =     0.921 (KG/HA)
ACTIVE TO STABLE ORG N =    -0.159 (KG/HA)
HUMUS MIN ON ACTIVE ORG P =    0.161 (KG/HA)
MIN FROM FRESH ORG N =    3.396 (KG/HA)
MIN FROM FRESH ORG P =    0.924 (KG/HA)
NO3 IN RAINFALL =     8.159 (KG/HA)
INITIAL NO3 IN SOIL =      60.774 (KG/HA)
FINAL NO3 IN SOIL =      48.891 (KG/HA)
INITIAL ORG N IN SOIL =    1242.967 (KG/HA)
FINAL ORG N IN SOIL =    1216.208 (KG/HA)
INITIAL MIN P IN SOIL =    1087.596 (KG/HA)
FINAL MIN P IN SOIL =    1061.381 (KG/HA)
INITIAL ORG P IN SOIL =     152.263 (KG/HA)
FINAL ORG P IN SOIL =     151.060 (KG/HA)
NO3 IN FERT =    13.050 (KG/HA)
AMMONIA IN FERT =     0.000 (KG/HA)
ORG N IN FERT =     0.000 (KG/HA)
MINERAL P IN FERT =     1.414 (KG/HA)
ORG P IN FERT =     0.000 (KG/HA)
N REMOVED IN YIELD =     0.000 (KG/HA)
P REMOVED IN YIELD =     0.000 (KG/HA)
AMMONIA VOLATILIZATION =     0.000 (KG/HA)
AMMONIA NITRIFICATION =    0.000 (KG/HA)
NO3 EVAP-LAYER 2 TO 1 =   22.693

DIE-GRO P Q =       0.0 (No/HA)
DIE-GRO LP Q =       0.0 (No/HA)
DIE-GRO P SED =      0.0 (No/HA)
DIE-GRO LP SED =      0.0 (No/HA)
BACT P RUNOFF =      0.0 (No/HA)
BACT LP RUNOFF =      0.0 (No/HA)
BACT P SEDIMENT =      0.0 (No/HA)
BACT LP SEDIMENT =      0.0 (No/HA)
BACT P INCORP =      0.0 (No/HA)
BACT LP INCORP =      0.0 (No/HA)
```

APPENDIX C

SOIL AND WATER ASSESSMENT TOOL
ADDISON CIRCLE
GENERAL OUTPUT

```
1
   SWAT  Sept '05 VERSION2005                                               0/ 0/   0      0: 0: 0

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

       Number of years in run:    6
       Area of watershed:        0.397 km2
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    1 of simulation

 UNIT                        PERCO   TILE                  WATER    SED    NO3    NO3    NO3    NO3       N      P      P
 TIME   PREC   SURQ  LATQ   GWQ  LATE     Q   SW    ET     PET  YIELD  YIELD   SURQ   LATQ  PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
    1  28.89   9.89   0.00   0.02   0.00   0.00  67.72  18.18  68.54   9.64   0.08   0.10   0.00   0.00   0.35    0.14    0.02
0.05
    2  99.28  56.32   0.00   0.16   0.00   0.00  84.30  26.32  80.51  56.07   0.44   0.27   0.00   0.00   4.08    0.49    0.06
0.18
    3  68.79  33.99   0.02   0.69   1.76   0.00  74.79  42.72 126.15  34.45   0.31   0.20   0.00   1.16   9.33    0.35    0.04
0.12
    4  62.85  26.70   0.00   0.87   0.04   0.00  61.28  49.62 170.56  27.43   0.26   0.20   0.00   0.03   5.90    0.32    0.04
0.11
    5  52.69  28.77   0.00   0.46   0.00   0.00  36.17  49.03 200.59  29.11   0.26   0.17   0.00   0.00   6.12    0.26    0.03
0.09
    6  99.08  50.84   0.00   0.26   0.06   0.00  27.83  56.51 241.31  50.85   0.46   0.35   0.00   0.05   0.38    0.50    0.06
0.18
    7  90.57  49.09   0.00   0.21   0.00   0.00  25.03  44.27 243.87  49.20   0.50   0.34   0.00   0.00   5.74    0.45    0.06
0.16
    8  52.70  24.97   0.00   0.13   0.00   0.00  22.57  30.20 238.53  24.99   0.26   0.26   0.00   0.00   0.01    0.26    0.03
0.09
    9  73.46  42.68   0.00   0.10   0.00   0.00  17.49  35.86 220.65  42.72   0.42   0.26   0.00   0.00   0.06    0.36    0.04
0.13
   10  32.48  12.33   0.00   0.11   0.00   0.00  16.16  21.48 162.24  12.29   0.12   0.14   0.00   0.00   0.00    0.16    0.02
0.06
   11 135.15  71.62   0.00   0.25   0.07   0.00  44.36  35.26 102.26  71.12   0.53   0.40   0.00   0.03   0.00    0.67    0.08
0.24
   12 119.56  54.57   0.00   0.44   0.55   0.00  87.45  21.32  53.81  54.28   0.43   0.29   0.00   0.31   0.43    0.58    0.07
0.21

 2000 915.50 461.76   0.03   3.70   2.48   0.00  87.45 430.771909.01 462.15   4.06   2.98   0.00   1.58  32.39     4.53
0.55    1.63
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    2 of simulation

 UNIT                        PERCO   TILE                  WATER    SED    NO3    NO3    NO3    NO3       N      P      P
 TIME   PREC   SURQ  LATQ   GWQ  LATE     Q   SW    ET     PET  YIELD  YIELD   SURQ   LATQ  PERC   CROP
ORGANIC SOLUBLE ORGANIC
      (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
    1  97.13  56.24   0.16   3.33  15.78   0.00  81.09  31.24  68.77  59.31   0.43   0.26   0.03   8.24   3.34    0.48    0.06
0.17
    2  34.96  20.66   0.03   6.45   2.50   0.00  71.28  21.67  76.01  26.93   0.14   0.11   0.00   0.27   2.16    0.17    0.02
0.06
```

```
   3  83.46  52.48   0.03   5.40   3.52   0.00  62.36  36.36 193.14  57.81   0.49   0.28   0.00   0.00   0.57     0.40    0.05
0.15
   4 205.62 153.85   0.16   6.06  15.71   0.00  60.14  38.12 182.79 159.86   1.26   0.75   0.00   0.14   4.10     0.96    0.13
0.37
   5  82.06  51.19   0.02   8.37   0.80   0.00  56.74  32.49 199.66  59.40   0.42   0.31   0.00   0.02   6.55     0.38    0.05
0.15
   6 106.61  68.46   0.08   7.16   7.94   0.00  43.68  44.16 223.11  75.32   0.59   0.37   0.00   0.00   2.18     0.52    0.07
0.19
   7 118.46  73.39   0.04   4.89   4.05   0.00  41.95  42.70 248.31  78.21   0.72   0.37   0.00   0.00   6.02     0.57    0.07
0.21
   8  12.45   2.64   0.00   2.55   0.00   0.00  25.74  26.02 267.56   5.09   0.03   0.11   0.00   0.00   0.01     0.07    0.01
0.02
   9  64.12  34.16   0.00   0.96   0.00   0.00  34.24  21.46 220.80  35.07   0.33   0.80   0.00   0.00   0.00     0.31    0.04
0.11
  10  31.02  14.40   0.00   0.42   0.00   0.00  30.34  20.51 160.83  14.74   0.13   0.21   0.00   0.00   0.00     0.16    0.02
0.06
  11  81.75  43.19   0.04   0.73   4.41   0.00  44.20  20.25 116.65  43.65   0.36   0.39   0.00   0.55   0.00     0.39    0.05
0.14
  12 141.34  94.40   0.13   3.05  13.37   0.00  63.32  14.32  60.27  97.01   0.72   0.39   0.01   3.22   0.52     0.67    0.09
0.25

 20011058.98 665.07   0.68  49.38  68.08   0.00  63.32 349.292017.90 712.41   5.62   4.35   0.04  12.45  25.45     5.08
0.66    1.90
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    3 of simulation

 UNIT                          PERCO   TILE                  WATER    SED    NO3    NO3    NO3    NO3       N       P       P
 TIME   PREC   SURQ   LATQ    GWQ   LATE      Q    SW      ET     PET   YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
       (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  24.43  11.21   0.03   6.85   2.32   0.00  58.70  15.49  76.08  18.00   0.09   0.07   0.00   0.38   3.53     0.12    0.01
0.04
   2  61.73  33.68   0.05   5.44   4.81   0.00  62.10  19.78  82.09  39.00   0.27   0.17   0.00   0.00   1.15     0.30    0.04
0.11
   3  52.65  25.71   0.03   5.11   2.25   0.00  49.39  37.40 194.57  30.48   0.19   0.15   0.00   0.00   0.83     0.26    0.03
0.09
   4 148.34  91.90   0.16   5.99  15.51   0.00  53.06  37.11 155.35  97.60   0.71   0.41   0.00   0.08   6.51     0.71    0.09
0.26
   5 179.08 117.42   0.12   9.63  11.73   0.00  59.42  42.96 189.58 126.91   1.00   0.53   0.00   0.00   5.57     0.85    0.11
0.32
   6 109.88  61.43   0.06   9.68   5.95   0.00  49.49  52.86 229.18  71.01   0.62   0.33   0.00   0.00   1.59     0.55    0.07
0.20
   7  13.01   6.10   0.00   5.17   0.01   0.00  23.93  32.45 293.67  11.27   0.06   0.04   0.00   0.00   5.83     0.07    0.01
0.02
   8  54.51  31.83   0.00   1.78   0.00   0.00  24.99  21.61 276.18  33.54   0.30   0.49   0.00   0.00   0.01     0.26    0.03
0.10
   9  24.29  10.50   0.00   0.70   0.00   0.00  21.03  17.75 231.30  11.09   0.09   0.20   0.00   0.00   0.00     0.12    0.01
0.04
  10  89.58  51.76   0.00   0.40   0.22   0.00  38.60  20.03 175.61  52.06   0.50   0.49   0.00   0.00   0.00     0.43    0.05
0.16
  11 199.32 150.69   0.15   1.73  15.75   0.00  50.82  20.50 124.00 152.31   1.32   0.57   0.01   3.58   0.00     0.91    0.14
0.36
  12  21.32   5.79   0.01   6.45   0.35   0.00  52.12  13.71  79.53  12.02   0.05   0.05   0.00   0.07   0.56     0.10    0.01
0.03

 2002 978.13 598.02   0.62  58.94  58.90   0.00  52.12 331.642107.14 655.28   5.21   3.49   0.01   4.11  25.58     4.68
0.61    1.75
1
   SWAT  Sept '05 VERSION2005
```

```
  General Input/Output section (file.cio): ArcSWAT 2.3.4
  4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    4 of simulation

 UNIT                     PERCO  TILE              WATER   SED   NO3   NO3   NO3   NO3     N     P     P
 TIME   PREC  SURQ  LATQ   GWQ  LATE     Q   SW     ET    PET  YIELD  YIELD  SURQ  LATQ  PERC  CROP
ORGANIC SOLUBLE ORGANIC
      (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  52.20  23.19   0.08   5.04   7.83   0.00  57.67  15.72  84.40  28.01   0.19   0.13   0.00   1.15   3.73    0.26   0.03
0.09
   2  28.26   6.00   0.01   4.92   0.06   0.00  56.53   8.09  65.03  10.81   0.04   0.04   0.00   0.00   1.16    0.06   0.01
0.02
   3  12.12  12.05   0.02   3.81   2.00   0.00  44.17  25.64 167.11  15.58   0.09   0.08   0.00   0.00   0.92    0.14   0.02
0.05
   4   0.10   0.00   0.00   1.31   0.00   0.00  29.78  14.49 197.86   1.31   0.00   0.00   0.00   0.00   4.15    0.00   0.00
0.00
   5 130.18  77.10   0.06   1.55   5.84   0.00  40.87  36.07 215.51  78.44   0.69   0.37   0.00   0.00   9.12    0.63   0.08
0.23
   6  70.30  39.48   0.00   2.43   0.00   0.00  37.43  33.59 259.66  41.84   0.38   0.21   0.00   0.00   0.42    0.33   0.04
0.12
   7  73.82  42.23   0.00   0.94   0.00   0.00  30.97  38.72 283.19  43.13   0.44   0.29   0.00   0.00   6.09    0.36   0.05
0.13
   8   0.30   0.01   0.00   0.37   0.00   0.00   4.94  26.33 283.23   0.38   0.00   0.00   0.00   0.00   0.01    0.00   0.00
0.00
   9  19.90  10.29   0.00   0.14   0.00   0.00   3.03  11.52 230.64  10.42   0.10   0.19   0.00   0.00   0.00    0.10   0.01
0.04
  10 137.80  82.13   0.00   0.09   0.03   0.00  38.28  20.39 129.37  82.08   0.80   0.53   0.00   0.00   0.00    0.65   0.08
0.25
  11 110.62  64.52   0.00   0.10   0.01   0.00  66.07  17.18  89.71  64.36   0.50   0.28   0.00   0.00   0.00    0.53   0.07
0.20
  12  33.82  13.24   0.08   2.39   8.65   0.00  60.52  18.51  75.55  14.98   0.10   0.09   0.01   2.83   0.43    0.18   0.02
0.06

 2003 669.43 370.25   0.25  23.08  24.43   0.00  60.52 266.262081.28 391.34   3.33   2.19   0.01   3.99  26.03    3.26
0.41    1.20
1
  SWAT  Sept '05 VERSION2005

  General Input/Output section (file.cio): ArcSWAT 2.3.4
  4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    5 of simulation

 UNIT                     PERCO  TILE              WATER   SED   NO3   NO3   NO3   NO3     N     P     P
 TIME   PREC  SURQ  LATQ   GWQ  LATE     Q   SW     ET    PET  YIELD  YIELD  SURQ  LATQ  PERC  CROP
ORGANIC SOLUBLE ORGANIC
      (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm)  (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1  45.13  20.78   0.06   4.04   6.18   0.00  63.64  14.99  68.75  24.33   0.14   0.11   0.00   1.48   3.72    0.22   0.03
0.08
   2 102.38  55.73   0.12   4.97  13.34   0.00  78.44  18.37  67.91  60.15   0.38   0.27   0.00   0.16   2.47    0.50   0.07
0.18
   3  76.33  41.48   0.14  10.74  11.58   0.00  64.97  36.63 151.04  51.96   0.35   0.20   0.00   0.01   1.21    0.38   0.05
0.14
   4  70.79  39.14   0.05  10.04   4.85   0.00  52.82  38.91 194.17  48.98   0.36   0.19   0.00   0.00   6.94    0.35   0.04
0.13
   5 115.67  72.13   0.09   8.00   8.27   0.00  48.78  39.23 194.41  80.06   0.61   0.31   0.00   0.00   6.73    0.56   0.07
0.21
   6 134.20  80.14   0.03   6.61   3.19   0.00  52.67  46.74 240.73  86.54   0.70   0.36   0.00   0.00   0.76    0.63   0.08
0.24
   7  41.67  21.19   0.02   4.28   2.20   0.00  31.39  39.74 311.89  25.43   0.21   0.11   0.00   0.00   5.99    0.21   0.03
0.08
   8  45.46  22.51   0.00   1.84   0.00   0.00  30.49  23.84 271.27  24.23   0.20   0.16   0.00   0.00   0.01    0.22   0.03
0.08
```

```
   9 129.35  86.03   0.10   2.09   9.27   0.00  39.24  25.21 207.33  88.04   0.81   0.42   0.00   0.24   0.00    0.61    0.08
0.23
  10  19.82  10.66   0.00   4.18   0.07   0.00  34.79  13.54 151.91  14.82   0.10   0.07   0.00   0.00   0.00    0.10    0.01
0.04
  11 203.16 146.74   0.14   3.56  15.09   0.00  58.29  17.68 105.76 150.03   1.22   0.57   0.01   2.97   0.00    0.95    0.14
0.36
  12 207.77 160.53   0.22  11.02  21.12   0.00  65.09  19.10  67.35 171.19   1.09   0.55   0.01   3.14   0.67    0.96    0.15
0.38

 20041191.73 757.06   0.97  71.38  95.16   0.00  65.09 333.972032.51 825.76   6.16   3.33   0.03   8.00  28.49    5.69
0.78    2.13
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year    6 of simulation

 UNIT                           PERCO   TILE                  WATER    SED    NO3    NO3    NO3    NO3       N       P       P
 TIME   PREC   SURQ   LATQ    GWQ   LATE     Q    SW     ET     PET  YIELD  YIELD   SURQ   LATQ   PERC   CROP
ORGANIC SOLUBLE ORGANIC
       (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm)   (mm) (t/ha)  -----------------(kg nutrient/ha)-------------
-----
   1   0.00   0.00   0.00   0.46   0.22   0.00  64.52   0.34   2.12   0.47   0.00   0.00   0.00   0.02   0.14    0.00    0.00    0.00

 2005   0.00   0.00   0.00   0.46   0.22   0.00  64.52   0.34   2.12   0.47   0.00   0.00   0.00   0.02   0.14    0.00    0.00
0.00
1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

   FINAL VALUES

1
   SWAT  Sept '05 VERSION2005

   General Input/Output section (file.cio): ArcSWAT 2.3.4
   4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

                                Average Crop Values
                        Crop 1            Crop 2            Crop 3
                     Yld     Biomass   Yld     Biomass     Yld     Biomass
                   (kg/ha)   (kg/ha)  (kg/ha)  (kg/ha)    (kg/ha)   (kg/ha)

 BERM  HRU      5 Rot   1    0.0     754.2       0.0       0.0       0.0       0.0
 BERM  HRU      5 Rot   2    0.0    1997.1       0.0       0.0       0.0       0.0
 BERM  HRU      5 Rot   3    0.0    2772.7       0.0       0.0       0.0       0.0
 BERM  HRU      5 Rot   4    0.0    3595.9       0.0       0.0       0.0       0.0
 BERM  HRU      5 Rot   5    0.0    4409.6       0.0       0.0       0.0       0.0
 BERM  HRU      6 Rot   1    0.0     754.0       0.0       0.0       0.0       0.0
 BERM  HRU      6 Rot   2    0.0    1996.6       0.0       0.0       0.0       0.0
 BERM  HRU      6 Rot   3    0.0    2771.7       0.0       0.0       0.0       0.0
 BERM  HRU      6 Rot   4    0.0    3596.2       0.0       0.0       0.0       0.0
 BERM  HRU      6 Rot   5    0.0    4411.1       0.0       0.0       0.0       0.0
 BERM  HRU     13 Rot   1    0.0     754.0       0.0       0.0       0.0       0.0
 BERM  HRU     13 Rot   2    0.0    1996.6       0.0       0.0       0.0       0.0
 BERM  HRU     13 Rot   3    0.0    2771.7       0.0       0.0       0.0       0.0
 BERM  HRU     13 Rot   4    0.0    3596.1       0.0       0.0       0.0       0.0
 BERM  HRU     13 Rot   5    0.0    4411.1       0.0       0.0       0.0       0.0
 BERM  HRU     22 Rot   1    0.0     754.1       0.0       0.0       0.0       0.0
 BERM  HRU     22 Rot   2    0.0    1996.8       0.0       0.0       0.0       0.0
 BERM  HRU     22 Rot   3    0.0    2772.1       0.0       0.0       0.0       0.0
 BERM  HRU     22 Rot   4    0.0    3595.9       0.0       0.0       0.0       0.0
```

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 BERM  HRU     22 Rot   5     0.0    4410.3       0.0       0.0       0.0       0.0
 BERM  HRU     23 Rot   1     0.0     754.0       0.0       0.0       0.0       0.0
 BERM  HRU     23 Rot   2     0.0    1996.5       0.0       0.0       0.0       0.0
 BERM  HRU     23 Rot   3     0.0    2771.6       0.0       0.0       0.0       0.0
 BERM  HRU     23 Rot   4     0.0    3596.1       0.0       0.0       0.0       0.0
 BERM  HRU     23 Rot   5     0.0    4411.1       0.0       0.0       0.0       0.0
 SWRN  HRU     24 Rot   1     0.0       0.0    1909.9    2759.7       0.0       0.0
 FRSD  HRU     25 Rot   1     0.0   14569.3       0.0   17239.2       0.0       0.0
 BERM  HRU     31 Rot   1     0.0     754.1       0.0       0.0       0.0       0.0
 BERM  HRU     31 Rot   2     0.0    1996.7       0.0       0.0       0.0       0.0
 BERM  HRU     31 Rot   3     0.0    2772.0       0.0       0.0       0.0       0.0
 BERM  HRU     31 Rot   4     0.0    3595.8       0.0       0.0       0.0       0.0
 BERM  HRU     31 Rot   5     0.0    4410.0       0.0       0.0       0.0       0.0
 BERM  HRU     32 Rot   1     0.0     754.0       0.0       0.0       0.0       0.0
 BERM  HRU     32 Rot   2     0.0    1996.5       0.0       0.0       0.0       0.0
 BERM  HRU     32 Rot   3     0.0    2771.6       0.0       0.0       0.0       0.0
 BERM  HRU     32 Rot   4     0.0    3596.1       0.0       0.0       0.0       0.0
 BERM  HRU     32 Rot   5     0.0    4411.1       0.0       0.0       0.0       0.0
 BERM  HRU     39 Rot   1     0.0     754.1       0.0       0.0       0.0       0.0
 BERM  HRU     39 Rot   2     0.0    1996.8       0.0       0.0       0.0       0.0
 BERM  HRU     39 Rot   3     0.0    2772.0       0.0       0.0       0.0       0.0
 BERM  HRU     39 Rot   4     0.0    3595.8       0.0       0.0       0.0       0.0
 BERM  HRU     39 Rot   5     0.0    4410.2       0.0       0.0       0.0       0.0
 BERM  HRU     40 Rot   1     0.0     754.0       0.0       0.0       0.0       0.0
 BERM  HRU     40 Rot   2     0.0    1996.5       0.0       0.0       0.0       0.0
 BERM  HRU     40 Rot   3     0.0    2771.6       0.0       0.0       0.0       0.0
 BERM  HRU     40 Rot   4     0.0    3596.1       0.0       0.0       0.0       0.0
 BERM  HRU     40 Rot   5     0.0    4411.1       0.0       0.0       0.0       0.0
 SWRN  HRU     41 Rot   1     0.0       0.0    1909.8    2759.4       0.0       0.0
 FRSD  HRU     42 Rot   1     0.0   14569.4       0.0   17239.2       0.0       0.0

   HRU STATISTICS

            AVE ANNUAL VALUES

 HRU  SUB CPMN SOIL    AREAkm2     CN    AWCmm USLE_LS   IRRmm AUTONkh AUTOPkh   MIXEF  PRECmm
SURQmm   GWQmm    ETmm   SEDth  NO3kgh ORGNkgh  BIOMth   YLDth
    1   1 BARRAUSTIN  .399E-05   96.40  137.16    0.93    0.00    0.00    0.00    0.24  962.23  690.16  582.74  276.40
349.78    6.23    8.07    0.00    0.00
    2   1 BARRAUSTIN  .600E-04   96.40  137.16    0.26    0.00    0.00    0.00    0.24  962.23  690.17  436.16  276.45
77.81    5.69    6.83    0.00    0.00
    3   1 BARRAUSTIN  .699E-03   97.60  137.16    1.85    0.00    0.00    0.00    0.24  962.23  722.26   31.56  246.04
42.74    4.71    9.19    0.00    0.00
    4   1 BARRAUSTIN  .740E-03   97.60  137.16    0.33    0.00    0.00    0.00    0.24  962.23  722.26   32.25  246.11
27.30    4.69    9.15    0.00    0.00
    5   1 BERMAUSTIN  .864E-05   72.00  137.16    1.95    0.00    0.00    0.00    0.24  962.23  159.45  290.61  581.10
0.00    1.98    0.00    2.86    0.00
    6   1 BERMAUSTIN  .641E-05   72.00  137.16    0.17    0.00    0.00    0.00    0.24  962.23  159.56  283.97  581.33
0.00    0.71    0.00    2.86    0.00
    7   2 BARRAUSTIN  .149E-05   96.40  137.16    0.98    0.00    0.00    0.00    0.24  962.23  690.16  582.75  276.40
610.88    6.45    8.59    0.00    0.00
    8   2 BARRAUSTIN  .143E-01   96.40  137.16    0.13    0.00    0.00    0.00    0.24  962.23  690.17    2.02  276.45
8.97    4.84    4.87    0.00    0.00
    9   2 BARRAUSTIN  .362E-05   96.40  137.16    0.80    0.00    0.00    0.00    0.24  962.23  690.16  582.74  276.40
369.61    6.25    8.12    0.00    0.00
   10   2 BARRAUSTIN  .268E-02   96.40  137.16    0.18    0.00    0.00    0.00    0.24  962.23  690.17    6.14  276.45
15.82    5.07    5.41    0.00    0.00
   11   2 BARRAUSTIN  .414E-03   97.60  137.16    1.53    0.00    0.00    0.00    0.24  962.23  722.26   67.42  246.05
46.95    4.84    9.49    0.00    0.00
   12   2 BARRAUSTIN  .313E-01   97.60  137.16    0.14    0.00    0.00    0.00    0.24  962.23  722.26    1.41  246.12
4.69    3.87    7.23    0.00    0.00
   13   2 BERMAUSTIN  .170E-02   72.00  137.16    0.18    0.00    0.00    0.00    0.24  962.23  159.56  171.11  581.33
0.03    0.72    0.01    2.86    0.00
   14   3 BARRAUSTIN  .204E-03   96.40  137.16    1.03    0.00    0.00    0.00    0.24  962.23  690.16  135.56  276.39
65.68    5.47    6.36    0.00    0.00
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   15   3 BARRAUSTIN  .345E-01   96.40  137.16    0.14    0.00    0.00    0.00    0.24  962.23  690.17    1.33  276.45
8.81    4.73    4.61    0.00    0.00
   16   3 BARRAUSTIN  .189E-02   96.40  137.16    0.09    0.00    0.00    0.00    0.24  962.23  690.17   11.82  276.45
13.65    5.12    5.52    0.00    0.00
   17   3 BARRAUSTIN  .744E-05   92.80  137.16    0.87    0.00    0.00    0.00    0.24  962.23  615.17  514.54  348.38
246.33    5.33    7.76    0.00    0.00
   18   3 BARRAUSTIN  .348E-02   92.80  137.16    0.12    0.00    0.00    0.00    0.24  962.23  615.19    6.03  348.45
11.42    4.26    5.31    0.00    0.00
   19   3 BARRAUSTIN  .669E-01   97.60  137.16    0.12    0.00    0.00    0.00    0.24  962.23  722.26    1.23  246.12
3.49    3.72    6.89    0.00    0.00
   20   3 BARRAUSTIN  .203E-03   97.60  137.16    1.03    0.00    0.00    0.00    0.24  962.23  722.26  139.43  246.07
57.84    5.02    9.93    0.00    0.00
   21   3 BARRAUSTIN  .156E-02   92.80  137.16    0.11    0.00    0.00    0.00    0.24  962.23  615.19   14.51  348.45
15.11    4.37    5.58    0.00    0.00
   22   3 BERMAUSTIN  .116E-03   72.00  137.16    0.96    0.00    0.00    0.00    0.24  962.23  159.49  222.19  581.21
0.08    1.52    0.02    2.86    0.00
   23   3 BERMAUSTIN  .121E-01   72.00  137.16    0.17    0.00    0.00    0.00    0.24  962.23  159.56  163.39  581.34
0.04    0.71    0.01    2.86    0.00
   24   3 SWRNAUSTIN  .183E-03   74.00  137.16    0.07    0.00    0.00    0.00    0.24  962.23  125.54  134.43  711.71
0.44    0.29    0.02    2.76    1.91
   25   3 FRSDAUSTIN  .326E-02   77.00  137.16    0.12    0.00    0.00    0.00    0.24  962.23  153.69   95.94  676.57
0.05    0.38    0.00   18.01    0.00
   26   4 BARRAUSTIN  .421E-02   96.40  137.16    0.14    0.00    0.00    0.00    0.24  962.23  690.17    5.28  276.45
12.13    5.00    5.26    0.00    0.00
   27   4 BARRAUSTIN  .786E-02   96.40  137.16    0.13    0.00    0.00    0.00    0.24  962.23  690.17    3.85  276.45
9.97    4.92    5.05    0.00    0.00
   28   4 BARRAUSTIN  .365E-04   96.40  137.16    1.23    0.00    0.00    0.00    0.24  962.23  690.16  505.51  276.39
106.13    5.78    7.06    0.00    0.00
   29   4 BARRAUSTIN  .123E-01   97.60  137.16    0.15    0.00    0.00    0.00    0.24  962.23  722.26    2.44  246.12
6.69    4.06    7.67    0.00    0.00
   30   4 BARRAUSTIN  .765E-03   97.60  137.16    1.33    0.00    0.00    0.00    0.24  962.23  722.26   26.07  246.06
36.74    4.68    9.13    0.00    0.00
   31   4 BERMAUSTIN  .396E-03   72.00  137.16    1.25    0.00    0.00    0.00    0.24  962.23  159.48  191.84  581.18
0.15    1.68    0.05    2.85    0.00
   32   4 BERMAUSTIN  .207E-01   72.00  137.16    0.16    0.00    0.00    0.00    0.24  962.23  159.56  163.37  581.34
0.04    0.70    0.01    2.86    0.00
   33   5 BARRAUSTIN  .309E-04   96.40  137.16    1.33    0.00    0.00    0.00    0.24  962.23  690.16  530.05  276.38
114.17    5.81    7.13    0.00    0.00
   34   5 BARRAUSTIN  .306E-01   96.40  137.16    0.13    0.00    0.00    0.00    0.24  962.23  690.17    1.49  276.45
8.29    4.74    4.65    0.00    0.00
   35   5 BARRAUSTIN  .801E-02   96.40  137.16    0.13    0.00    0.00    0.00    0.24  962.23  690.17    3.40  276.45
9.97    4.91    5.05    0.00    0.00
   36   5 BARRAUSTIN  .701E-01   97.60  137.16    0.12    0.00    0.00    0.00    0.24  962.23  722.26    1.33  246.12
3.45    3.71    6.87    0.00    0.00
   37   5 BARRAUSTIN  .340E-03   97.60  137.16    1.08    0.00    0.00    0.00    0.24  962.23  722.26   95.07  246.07
46.48    4.89    9.61    0.00    0.00
   38   5 BARRAUSTIN  .442E-02   92.80  137.16    0.10    0.00    0.00    0.00    0.24  962.23  615.19    5.39  348.45
9.82    4.22    5.23    0.00    0.00
   39   5 BERMAUSTIN  .279E-03   72.00  137.16    1.10    0.00    0.00    0.00    0.24  962.23  159.48  207.37  581.20
0.11    1.60    0.03    2.86    0.00
   40   5 BERMAUSTIN  .573E-01   72.00  137.16    0.14    0.00    0.00    0.00    0.24  962.23  159.56  162.86  581.34
0.03    0.69    0.01    2.86    0.00
   41   5 SWRNAUSTIN  .904E-03   74.00  137.16    0.08    0.00    0.00    0.00    0.24  962.23  125.54  103.05  711.72
0.95    0.29    0.04    2.76    1.91
   42   5 FRSDAUSTIN  .256E-02   77.00  137.16    0.10    0.00    0.00    0.00    0.24  962.23  153.69   97.68  676.58
0.04    0.38    0.00   18.01    0.00


             AVE MONTHLY BASIN VALUES
               SNOW                WATER           SED
 MON     RAIN     FALL   SURF Q    LAT Q   YIELD      ET    YIELD       PET
       (MM)     (MM)     (MM)     (MM)     (MM)     (MM)   (T/HA)     (MM)
   1    49.24    14.47    24.11     0.07    27.77    19.07     0.19    73.26
   2    66.70    25.16    35.21     0.04    39.41    19.24     0.26    75.88
   3    58.67     4.92    33.14     0.05    38.06    35.75     0.29   166.40
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  4   97.54     0.00    62.32     0.07    67.04    35.65     0.52   180.15
  5  111.94     0.00    69.32     0.06    74.78    39.95     0.60   199.95
  6  104.01     0.00    60.07     0.04    65.11    46.77     0.55   238.80
  7   67.50     0.00    38.40     0.01    41.45    39.58     0.39   276.19
  8   33.08     0.00    16.39     0.00    17.65    25.60     0.16   267.35
  9   62.22     0.00    36.73     0.02    37.47    22.36     0.35   222.14
 10   62.14     0.00    34.26     0.00    35.20    19.19     0.33   155.99
 11  146.00     0.00    95.35     0.07    96.29    22.17     0.78   107.67
 12  104.76    16.98    65.71     0.09    69.90    17.39     0.48    67.30

  AVE ANNUAL BASIN STRESS DAYS
        WATER STRESS DAYS =     0.80
        TEMPERATURE STRESS DAYS =    22.22
        NITROGEN STRESS DAYS =    20.59
        PHOSPHORUS STRESS DAYS =    25.16
1
 SWAT  Sept '05 VERSION2005

 General Input/Output section (file.cio): ArcSWAT 2.3.4
 4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

    AVE ANNUAL BASIN VALUES

       PRECIP =    962.2 MM
       SNOW FALL =   61.08 MM
       SNOW MELT =    60.47 MM
       SUBLIMATION =     0.61 MM
       SURFACE RUNOFF Q =   570.12 MM
       LATERAL SOIL Q =    0.51 MM
       TILE Q =     0.00 MM
       GROUNDWATER (SHAL AQ) Q =    41.37 MM
       REVAP (SHAL AQ => SOIL/PLANTS) =    4.22 MM
       DEEP AQ RECHARGE =     2.47 MM
       TOTAL AQ RECHARGE =   49.41 MM
       TOTAL WATER YLD =   609.15 MM
       PERCOLATION OUT OF SOIL =   49.83 MM
       ET =    342.3 MM
       PET =   2028.9MM
       TRANSMISSION LOSSES =     2.85 MM
       TOTAL SEDIMENT LOADING =     4.873 T/HA
       POND BUDGET
          EVAPORATION =    0.000 MM
          SEEPAGE =    0.000 MM
          RAINFALL ON POOL =   0.000 MM
          INFLOW
             WATER =    0.000 MM
             SEDIMENT =    0.000 T/HA
          OUTFLOW
             WATER =    0.000 MM
             SEDIMENT =    0.000 T/HA
       RESERVOIR BUDGET
          EVAPORATION =    0.000 MM
          SEEPAGE =    0.000 MM
          RAINFALL ON RESERVOIR =    0.000 MM
          INFLOW
             WATER =    0.000 MM
             SEDIMENT =    0.000 T/HA
          OUTFLOW
             WATER =    0.000 MM
             SEDIMENT =    0.000 T/HA
       YIELD LOSS FROM PONDS
          WATER =   0.000 MM
          SEDIMENT =   0.000 T/HA
       YIELD LOSS FROM RESERVOIRS
          WATER =   0.000 MM
          SEDIMENT =   0.000 T/HA
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1
 SWAT  Sept '05 VERSION2005

 General Input/Output section (file.cio): ArcSWAT 2.3.4
 4/4/2010 12:00:00 AMARCGIS-SWAT interface AV

      AVE ANNUAL BASIN VALUES


      NUTRIENTS
         ORGANIC N =     4.645 (KG/HA)
         ORGANIC P =     1.720 (KG/HA)
         NO3 YIELD (SQ) =     3.266 (KG/HA)
         NO3 YIELD (SSQ) =    0.020 (KG/HA)
         SOL P YIELD =    0.601 (KG/HA)
         NO3 LEACHED =     6.028 (KG/HA)
         P LEACHED =     0.184 (KG/HA)
         N UPTAKE =    27.602 (KG/HA)
         P UPTAKE =   10.113 (KG/HA)
         NO3 YIELD (GWQ) =     4.361 (KG/HA)
         ACTIVE TO SOLUTION P FLOW =    -3.758 (KG/HA)
         ACTIVE TO STABLE P FLOW =    -0.435 (KG/HA)
         N FERTILIZER APPLIED =   23.838 (KG/HA)
         P FERTILIZER APPLIED =    2.582 (KG/HA)
         N FIXATION =    0.000 (KG/HA)
         DENITRIFICATION =    0.000 (KG/HA)
         HUMUS MIN ON ACTIVE ORG N =     1.395 (KG/HA)
         ACTIVE TO STABLE ORG N =    -0.202 (KG/HA)
         HUMUS MIN ON ACTIVE ORG P =    0.252 (KG/HA)
         MIN FROM FRESH ORG N =    5.430 (KG/HA)
         MIN FROM FRESH ORG P =    1.588 (KG/HA)
         NO3 IN RAINFALL =     9.616 (KG/HA)
         INITIAL NO3 IN SOIL =      61.322 (KG/HA)
         FINAL NO3 IN SOIL =      33.421 (KG/HA)
         INITIAL ORG N IN SOIL =    1717.031 (KG/HA)
         FINAL ORG N IN SOIL =    1724.046 (KG/HA)
         INITIAL MIN P IN SOIL =     563.499 (KG/HA)
         FINAL MIN P IN SOIL =     527.705 (KG/HA)
         INITIAL ORG P IN SOIL =     210.336 (KG/HA)
         FINAL ORG P IN SOIL =     214.191 (KG/HA)
         NO3 IN FERT =    23.838 (KG/HA)
         AMMONIA IN FERT =     0.000 (KG/HA)
         ORG N IN FERT =     0.000 (KG/HA)
         MINERAL P IN FERT =     2.582 (KG/HA)
         ORG P IN FERT =     0.000 (KG/HA)
         N REMOVED IN YIELD =     0.037 (KG/HA)
         P REMOVED IN YIELD =     0.005 (KG/HA)
         AMMONIA VOLATILIZATION =     0.000 (KG/HA)
         AMMONIA NITRIFICATION =    0.000 (KG/HA)
         NO3 EVAP-LAYER 2 TO 1 =   27.999

         DIE-GRO P Q =       0.0 (No/HA)
         DIE-GRO LP Q =       0.0 (No/HA)
         DIE-GRO P SED =      0.0 (No/HA)
         DIE-GRO LP SED =      0.0 (No/HA)
         BACT P RUNOFF =      0.0 (No/HA)
         BACT LP RUNOFF =      0.0 (No/HA)
         BACT P SEDIMENT =      0.0 (No/HA)
         BACT LP SEDIMENT =      0.0 (No/HA)
         BACT P INCORP =      0.0 (No/HA)
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BIOGRAPHICAL INFORMATION

Brian Parker was born in Laredo, Texas, the United States of America. Growing up in a military family, he has lived in Texas, Ohio, New Mexico, Arizona, Alabama and New York, and has a deep appreciation for cultures and landscapes of the Southwest as well as the natural beauty of the Catskill Mountains in upstate New York.

Mr. Parker worked professionally as a horticulturist prior to his enrollment at the University of Texas at Arlington where he earned his Bachelor of Science in Interdisciplinary Studies; focusing on design theory, earth and plant sciences. Upon graduation, he enrolled in the Landscape Architecture program at the School of Architecture, the University of Texas at Arlington. His research and professional interests are related to stormwater management, planning and Geographic Information Systems.

Mr. Parker has over 8 years experience working in GIS environmental and natural hazard mapping. He is currently employed at Jacobs Engineering working as a Lead GIS Specialist where his primary role is 3D ground and water surface modeling in relation to floodplain re-delineation.