MAGNITUDE OF IMPERVIOUS SURFACES

IN URBAN AREAS

by

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A THESIS

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DEDICATION

To My Parents Ileana and Vasile Bochis

Va multumesc ca ati crezut in mine
atunci cand gaseam dificil sa cred in mine insami…

Ca ati spus ce am avut nevoie sa aud uneori,
in loc de ceea ce doream sa aud…

Ca ati fost de partea mea…
Ca m-ati facut sa vad si o alta fateta a lucrurilor…

Pentru zilele in care m-am intors la voi
si v-am gasit mereu acolo,
Va multumesc din suflet.

Pentru zilele in care ati fost
gandul meu zambitor intr-un cer plin de nori,
Va multumesc calduros.

Pentru toate zilele in care mi-ati spus
ca maine va fi mai bine,
Va multumesc ca m-ati ajutat.

Pentru toate zilele in care
m-am putut baza pe voi,
Va multumesc din inima.

Pentru toate acestea,
si pentru multe altele care nu le-am spus,
Va multumesc!

Doresc sa stiti ca, chiar daca nu spun asta,
Va iubesc, iar acest sentiment
Nu va inceta niciodata!

LIST OF ABBREVIATIONS AND SYMBOLS

$	Dollars
μg/L	Microgram per Liter
%	Percentage
< / >	Less / Greater Than
ac	Acres
^oC	Degree Celsius
CDM	The Name of a Consulting, Engineering, Construction and Operation Firm
cfs	Cubic Feet per Second
CN	Curve Number
COD	Chemical Oxygen Demand
DCIA	Directly Connected Impervious Areas
DOQQ	Digital Ortho Quarter Quads
EIA	Effective Impervious Area
EPA	Environmental Protection Agency
F	Degree Fahrenheit
ft	Feet
ft^3	Cubic Feet
ft^3 /ac-yr	Cubic Feet per Acres-Year

GIS	Geographical Information System
ha	Hectares
I	Total Impervious Area
IKONOS	The Name of a Commercial Earth Observation Satellite
kg	Kilograms
kg/ha-yr	Kilograms per Hectare-Year
lb	Pounds
m	Meters
m^3/ha-yr	Meters Cubes per Hectare-Year
mg/L	Milligrams per Liter
MS4	Municipal Separate Storm Sewer System
NAPP	National Aerial Photography Program
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NSQD	National Stormwater Quality Database
NURP	Nationwide Urban Runoff Program
P	Phosphorus
PLSS	Public Land Survey System
QA/QC	Quality Assurance and Quality Control
Rv	Volumetric Runoff Coefficient

GIS Geographical Information System
ha Hectares
I Total Impervious Area

SLAMM	Source Loading and Management Model
SS	Suspended Solids
SWMA	Storm Water Management Authority
TIA	Total Impervious Area
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
USDA	Unite States Department of Agriculture
USGS	Unites States Geological Survey
WinSLAMM	The **Win**dows version of the **S**ource **L**oading **a**nd **M**anagement **M**odel
Zn	Zinc

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ABSTRACT

Impervious cover has become an increasing used indicator in measuring the impact of land development on drainage systems and aquatic life (Schueler 1994). Impervious cover is also one of the variables that can be quantified for different types of land development, although there are many different types of impervious surfaces and how they are connected to the drainage system is very important.

In order for a stormwater monitoring study to be successful, a careful examination of the study watershed is required. An urban area inventory of watershed development conditions is needed as part of a comprehensive stormwater quality plan for an area, and is needed to support many decision support activities. Past studies using WinSLAMM (Pitt and Voorhees 1995) have demonstrated the importance of knowing the areas of the different land covers in each land use category and the storm drainage characteristics (grass swales, curb and gutters, and the roof drains). In the first part of this thesis, 125 neighborhoods located in the Little Shades Creek Watershed, near Birmingham, AL and 40 neighborhoods located in five highly urbanized drainage areas situated in Jefferson County, AL were surveyed to determine the actual development characteristics.

The local residential watersheds are closer to the threshold between fair and poor biological conditions compared to the industrial and commercial watersheds, as expected. These general trends have been verified by biologists from the Jefferson County Storm Water Management Authority during their stream investigations. It is therefore likely that

stormwater controls that further reduce runoff discharges could be effective in improving receiving water biological conditions in these residential areas.

The second part of the thesis demonstrates how much additional controls will be necessary for these different areas to achieve acceptable receiving water conditions. A regionally calibrated version of WinSLAMM was used to analyze a new 228 acre commercial development in Hoover, AL. The major stormwater conservation design elements on this site included site bioretention with amended soils, plus regional grass swales, and wet detention ponds. WinSLAMM was used to evaluate the performance of the alternative site designs.

Chapter 1
Introduction

1.1 Introduction

Local development characteristics (such as land use, the amounts of impervious areas, and the drainage system type) are the most important elements that affect stormwater quality and quantity (Maestre and Pitt 2005). Water quality problems are amplified with increasing imperviousness and certain activities associated with the land use (Pitt et al. 2005a and 2005b). The non-point source water pollution discharge quantities from impervious areas are directly related to land use activities.

An urbanized area is defined by the US Census Bureau (US Census 2000) as "core census blocks that have a population density of at least 1,000 people per square mile and surrounding census blocks that have an overall density of at least 500 people per square mile." In other words, an urbanized area is a region of highly concentrated populations and its activities.

The US population was characterized as a rural (95%) and agricultural society in its early years; the United States then developed a vast network of cities in the course of the 19th century as part of the industrial revolution. In the 1800s, about 5% of Americans lived in cities. The urban percentage grew to 50% by 1920. Throughout the 19th century, the US continued to urbanize. Today, about 80% of the US population lives in cities and suburbs (about half in suburbs and around 30% in central cities) (US Census 2000).

Increases in urban populations and associated urban sprawl, has altered drainage basins and rivers. When watershed areas are urbanized, much of the vegetation and topsoil is replaced by impervious surfaces (roads, parking lots, and roof tops) and much of the remaining soils are compacted. Population increases therefore causes increases in impervious areas which results in less water soaking into the ground with more water going directly to urban streams during the rains, along with faster rises in runoff rates. In addition to the high flows caused by urbanization, the increased runoff also contains increased contaminants due to anthropogenic activities.

Imperviousness has become an increasingly used indicator in measuring the impact of land development on drainage systems and aquatic life (Schueler 1994). It is one of the variables that can be easily related to different types of land development.

1.2 Thesis Objectives

Good watershed area descriptions, accurate drainage area delineations, and descriptions of source areas of pollution are needed for all monitored sites if the intention is to determine the variations in runoff quantity and quality associated with variations in site characteristics. In order to determine how land development variability affects the quantity and quality of runoff, different land surfaces (roofs, streets, landscaped areas, parking lots, etc.) for different land uses (residential, commercial, industrial, institutional, etc.) have to be measured. This information can be used with stormwater models, including WinSLAMM (the Source Loading and Management Model for Windows, Pitt and Voorhees 1995; 2002) to calculate the runoff quantity and quality for each neighborhood investigated. The first objective of this thesis is to describe the method of field data collection and data processing that was used as part of the Little Shades Creek Corridor study to examine land use characteristics in a portion of Jefferson County, Alabama, that was in turn used in WinSLAMM modeling. Additional land use information was also collected at the sites used by the Storm Water Management Authority (SWMA) of Jefferson County as part of their stormwater permit monitoring program. SWMA also collected stormwater samples at sites that were then used to re-calibrate the model. The second objective of this thesis is to employ the re-calibrated version of WinSLAMM (Appendix A describes the model re-calibration) to model the runoff quantity and quality at one of the Jefferson County SWMA watersheds to examine the performance of different combinations of stormwater control devices for a highly impervious watershed.

In the Little Shades Creek Corridor study, 125 neighborhoods were surveyed to determine the actual development characteristics representing 16 major land use areas located in the Little Shades Creek watershed, near Birmingham, AL. This information was collected over a period of several years in the early 1990s as part of a volunteer effort using the Jefferson County "Earth Team" of the local US Department of Agriculture (USDA) office. Initially, this data was used along with source area and outfall monitoring data (Pitt et al. 1995 and 1999) to calibrate WinSLAMM and to calculate typical stormwater characteristics for the region. The current research is intended to determine the variability in stormwater characteristics associated with the variability of the development characteristics for each land use category, instead of using average development characteristics. Currently, additional data from the NSQD (National Stormwater Quality Database) MS4 (municipal separate storm sewer system) database (Maestre and Pitt 2005) for Jefferson County, Alabama, was used to conduct a re-validation of the model, before it was used to calculate the expected conditions for each of the SWMA land uses.

1.3 Introduction to SLAMM

The following information pertaining to SLAMM (and WinSLAMM) is summarized from model documentation and other reports (Pitt and Voorhees 1995; 2002).

1.3.1 History and Attributes of SLAMM

WinSLAMM (the **Win**dows version of the **S**ource **L**oading **a**nd **M**anagement **M**odel) is an urban rainfall-runoff water quality model. It calculates runoff volumes and urban pollutant loadings from individual rain events. It also allows the user to reduce pollutant loadings from a source area such as a parking lots or roofs by using control measures such as detention ponds or infiltration devices. It was developed to obtain a better understanding of the relationships between “sources of urban runoff pollutants and runoff quality” (Pitt and Voorhees 1995; 2002). The program is used to identifying the appropriate runoff quantity and pollutant concentration values for a given rain depth, land use, and source area.

The development of SLAMM began in the mid 1970s as a data reduction tool for use in early street cleaning and pollutant source identification projects sponsored by the EPA’s Storm and Combined Sewer Pollution Control Program (Pitt 1979; Pitt and Bozeman 1982; Pitt 1984). Supplementary information contained in SLAMM was obtained during the EPA’s Nationwide Urban Runoff Program (NURP) (EPA 1983), especially the Alameda County, California (Pitt and Shawley 1982), the Bellevue, Washington (Pitt and Bissonnette 1984), and the Milwaukee (Bannerman et al. 1983) projects. Continued expansion of the model's capabilities was made possible by the remainder of the NURP projects and additional field studies and programming support sponsored by the Ontario Ministry of the Environment (Pitt and McLean 1986), the Wisconsin Department of Natural Resources (Pitt 1986; Bannerman et al. 1996; Legg et al. 1996), and Region V of the U.S. Environmental Protection Agency. The model has been continually expanded since the late 1970s and now includes a wide variety of source area and outfall control practices (such as infiltration practices, wet detention ponds, porous pavement, street cleaning, catchbasin cleaning, hydrodynamic devices, cisterns for stormwater reuse, bioretention devices and rain gardens, filtration practices, grass swales, etc.). SLAMM is heavily based on field observations, with minimal dependence on pure theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control, and to verify the performance of combinations of these stormwater controls, and to investigate different development options for a site. It can be applied to an individual project (such as a single building), a development project (such as a new retail shopping complex), a single drainage system and outfall as part of a watershed project, or a larger watershed (containing many drainage systems, such as Little Shades Creek).

Some of the model input parameters are directly measured in the field (areas, characteristics of the source areas in the watershed, street length, pollutant associations with particulate solids from these areas), while others (rainfall-runoff components, street cleaning effects, particulate accumulation rates) are based on conceptual models and they have been comprehensively verified during many prior studies and do not required local measurements. Parameters like infiltration, grass swale, catchbasin, and detention pond performance are based on standard theoretical approaches and have also been verified under various conditions.

Many available urban runoff models have as their basis drainage design methods where the focus historically is on very large and exceptional rains. However, stormwater quality problems are generally associated with common and relatively small rains. The assumptions and simplifications acceptably used with drainage design models are not appropriate for water quality models (Pitt 1987). Therefore, SLAMM incorporates unique process descriptions to more accurately predict the sources of runoff pollutants and flows for the storms of most interest in stormwater quality analyses. Furthermore, SLAMM can be used in conjunction with drainage design models to incorporate the mutual benefits of water quality controls on drainage design.

SLAMM has been used in many areas of the United States and Canada and it has been shown to correctly predict stormwater flows and pollutant characteristics for a large range of rains, development characteristics, and control practices. Its use requires accurate measurements of contributing areas and their characteristics, usually obtained from watershed examinations (field data) and aerial photographs. Calibrations of rainfall-runoff, particulate accumulation and washoff processes, and pollutant associations, are based on regional data. Model verification is based on sets of observed outfall events. Like all other models, SLAMM needs to be accurately calibrated and then tested as part of any local stormwater management effort.

One of the most important aspects of SLAMM is its ability to consider combinations of stormwater controls that affect source areas, drainage systems, and outfalls for a long series of rains. SLAMM also predicts the relative contributions of different source areas (roofs, streets, parking areas, landscaped areas, undeveloped areas, etc.) for each land use investigated. As a support in designing urban drainage systems, SLAMM also calculates correct NRCS curve numbers (CN) that reflect specific development and control characteristics for different classes of rains. The curve numbers can be used in conjunction with available urban drainage procedures to reflect the water quantity reduction benefits of stormwater quality controls. Another unique aspect of SLAMM is its capability to accurately describe a drainage area in sufficient detail for water quality investigations, but without requiring a lot of superfluous information.

One of the major problems with conventional stormwater models is the runoff volume estimates associated with small and medium sized storms (Pitt 1987). Early studies, such as the EPA's Nationwide Urban Runoff Program (NURP, EPA 1983) showed that more than a half of the runoff from an area can be associated with rain events smaller than the median runoff quantity for the area. A simple way of indicating that there are no significant trends of stormwater pollutant concentrations for different size events is when the runoff volume and pollutant discharge distributions are very similar for a study area. Therefore, accurate knowledge of the runoff volume is more important than knowing runoff flow rate variations when studying stormwater quality pollutant discharges. It has been shown that SLAMM predicts runoff volumes quite accurately for many rain types throughout the continental Unites States with this approach. Runoff is converted to hydrograph representations where rates of flow changes have important effects on performance of control devices (detention ponds, grass swales and infiltration devices, for example). Runoff problems would be better understood with a better understanding of the significance and runoff generation potential of the small and intermediate-sized rains for an area. Also, knowing the relative contributions of water and pollutants from each source area (street surfaces, impervious surfaces, pervious areas, back landscape, sidewalks, etc.) make it possible to evaluate source area runoff controls for different rains.

Most stormwater models use rainfall-runoff relationships that have been developed and used for many years for drainage design which is concerned with rain depths of at least several inches. Prediction of runoff associated with small storms (which are the most important in water quality investigations) can be highly inaccurate when the traditional drainage design procedures are used for estimating runoff quantities for these much smaller events. The volumetric runoff coefficient (the ratio of the runoff to the rain depth) observed at outfalls varies for each rain depth. As an example, for a medium density residential area, this ratio can be about 0.1 for storms of about 0.5 inches (12 mm), and may only approach about 0.4 for a moderate size storm of 2.5 inches (65 mm), or greater, that is typically associated with drainage events. However, the NURP study (EPA 1983) recommended the use of constant (average) volumetric runoff coefficients for the stormwater permit process, likely because the monitored storms were all within a relatively narrow range of rain depths. Common small storms would likely have their runoff volumes over-predicted and large storms would have their runoff volumes under-predicted, if a constant Rv was used. SLAMM makes runoff predictions using the small storm hydrology methods developed by Pitt (1987). The small storm hydrology model, which describes the shape of the relationship between rainfall and runoff, can be used to predict runoff volume yields for many different land uses and development conditions. It was specifically developed to determine runoff yields and corresponding water pollutant yields for small storms for stormwater quality investigations.

1.3.2 SLAMM Computational Processes

Most urban areas have a wide variety of drainage systems from concrete curb and gutters to grass swales, associated with directly connected roof drainage systems and/or drainage systems that drain to pervious areas. “Development characteristics” define the magnitude of drainage efficiency attributes, along with the areas associated with each surface type (road surfaces, roofs, landscaped areas, etc.). SLAMM shows that development characteristics significantly affect runoff quality and quantity, land use alone being most of the time not sufficient to describe these characteristics. The types of the drainage system (curbs and gutters or grass swales) and roof connections (directly connected or draining to pervious area), are probably the most important attributes that affect runoff characteristics. These attributes are not directly related to land use, but some trends are evident. For example, most roofs in strip commercial and shopping center areas are flat roofs and directly connected to the drainage system, and the roadside is most likely drained by curbs and gutters, while roofs in residential areas are pitched and usually are a mixture of being directly connected to the drainage system and drained to pervious areas. Different land uses are associated with different types and levels of pollutants. For example, industrial areas have the greatest pollutant accumulations due to material transfer and storage, and heavy truck traffic.

WinSLAMM uses the water volume and particulate solids quantities calculated at the outfall to calculate the other pollutant concentrations and loadings. The model keeps track of the portion of the total outfall particulate solids loading and runoff volume that originated from each source area. The particulate solids fractions are then used to develop weighted loading factors associated with each pollutant. Similarly, dissolved pollutant concentrations and loadings are calculated based on the percentage of the water volume that originates from each of the source areas within the drainage system. Also, WinSLAMM predicts urban runoff discharge parameters (total storm runoff flow volume, flow-weighted pollutant concentrations, and total storm pollutant yields) for many individual storms and for the complete study period. The model has incorporated Monte Carlo processes to consider many of the likely uncertainties in the model predictions. This allows the model output to be expressed in probabilistic terms that represent the possible range of expected results more accurately.

1.4 Thesis Arrangement

This thesis is organized in four chapters and two appendixes. Chapter 2 is a review of relevant literature on impervious surfaces and non-point sources of pollutants in stormwater. Next, a description of methodology utilized to collect, process the field data and to build the WinSLAMM files, and a description of the Birmingham watersheds is presented in Chapter 3. This chapter is organized as a journal paper and portions of it were presented at the *78th Annual Water Environment Federation Technical Exposition and Conference* in Washington, D.C. on Oct. 29 – Nov. 2, 2005, as “Impervious Surfaces in Urban Watersheds,” by Celina Bochis and Robert Pitt. Chapter 4, also organized as a journal paper, is a case study on one of the six watershed introduced in third chapter using the calibrated WinSLAMM model. Portions of this chapter were presented as a poster at the *79th Annual Water Environment Federation Technical Exposition and Conference* in Dallas, TX on Oct. 21 –Oct. 25, 2006, as "Modeled Flow Duration Variations, Pollutant Discharges, and Costs for Different Stormwater Controls", by Arvind Narayanan, Celina Bochis and Robert Pitt. Appendix A describes the WinSLAMM re-calibration processes using the local data. Appendix B contains the maps showing the locations of the five Jefferson County drainage areas, their aerial photographs and monitoring data used to re-calibrate the model.

1.5 Conclusion and Future Research

The purpose of this thesis was to examine several source areas of pollution coming from different land uses and to describe in detail the method of data collection and processing that make the field data ready to be use with WinSLAMM model. The case study used the locally re-calibrated version of the model and combinations of stormwater control devices to model the runoff quality and quantity.

Future work will include statistical analyses conducted at several levels to establish the quantitative and qualitative runoff sensitivity associated with variations of these site characteristics, stressing the impervious surfaces. A large number of stormwater control devices (including filtration, biofilters) available in WinSLAMM will be applied to the Jefferson County watersheds to examine which combination of controls are more suitable (efficient, size and cost) as retrofitting options, and for new development.

Chapter 2
Literature Review

2.1 Stormwater and Impervious Surfaces

Precipitation in the form of rain contains some impurities that accumulate as it falls through the Earth's atmosphere, but usually does not contain any bacteria (Davis and Cornwell 1998). Once the precipitation reaches the Earth's surface, the possibility of it becoming contaminated (organic and inorganic substances, different forms of pollutants) is imminent (Davis and Cornwell 1998). In natural watersheds a part of the rainfall is infiltrated into the porous soil, stored as groundwater, and then it moves back into streams through seeps and springs. Thus, much of the rainfall does not directly enter streams during the rain event, which moderates stream flows during the rains while recharging groundwaters and supplies water for later dry season stream flows. Under natural conditions, about 90% of the rainfall infiltrates into the soil, while only about 10% directly enters the streams (Reilly et al. 2004). Impervious surfaces restrict this infiltration of water during rains, increasing stream flows and associated flooding, while decreasing groundwater recharge and resultant reduced dry weather flows. In urban areas, impervious surfaces include roads, parking lots, driveways, sidewalks, rooftops, and patios. In addition, severely compacted soils from development activities and continuous use also severely restrict infiltration (Pitt et al. 1999). Increased runoff quantities has been associated with frequent flooding (Reilly et al. 2004); changes in the stream and channels morphology (Reilly et al. 2004); changes in water quality, quantity and temperature (Reilly et al. 2004); changes in stream biodiversity (Schueler 1994); and reductions in groundwater recharge (Evett et al. 1994).

Land development and associated disturbances to the natural hydrologic conditions also cause stream bank erosion and scouring of channels. Sediment from eroded banks clogs the gills of fish; blocks light needed for plants, fill in stream channels, and degrade the habitat for plants and animals that depend on clean water (Gesford and Anderson 2006). Also, the impervious surfaces influence regional climate through the urban heat island effect. Impervious surfaces absorb heat during the day and release it at night, causing the summer air temperature of large cities to increase by about 3- 5^{o}C compared to surrounding areas (Stone 2004).

Imperviousness has been used as an indicator in measuring the impacts of land development on drainage systems (Schueler 1994). It is one of the variables that can be quantified, managed and controlled at each stage of land development (Schueler 1994). Water quality problems increase with increased imperviousness and intensity of land use. The change in hydrology, water quality and quantity, and biodiversity of aquatic systems is directly related with the imperviousness of the drainage area. The percentage of impervious surface within a particular watershed has been recognized as a key indicator of the effects of nonpoint runoff and of future water and ecosystem quality (Arnold and Gibbons 1996; USEPA 1994).

Research conducted in many geographic areas, using many different variables, and employing different methods, has reached a similar conclusion: stream degradation starts to occur in watersheds having relatively low levels of imperviousness (usually between 5 and 10%) (Schueler 1994), watershed health becomes severely impaired and considered degraded if the imperviousness exceeds 25 or 30% of the total watershed area (Arnold and Gibbons 1996).

2.2 Components of Imperviousness

In this thesis, I will refer to **impervious cover** as being any land surface that has been covered with material that significantly decreases or prevents the infiltration of runoff (but not considering compacted urban soils). I will use the term **imperviousness** to refer to the percentage of impervious cover within a specified area of land.

Impervious cover is composed of two principal components: building rooftops and the transportation system (roads, driveways, and parking lots). It is most visible in industrialized and commercial areas, but is also abundant in residential areas, even if not as common. Compacted soils and unpaved parking and driveway areas also have “impervious” characteristics in that they severely hinder the infiltration of water, although not composed of pavement or roofing material.

In terms of total impervious area, the transportation component often exceeds the rooftop component (Schueler 1994). In the City of Olympia, WA, for example, 11 residential multifamily and commercial areas were analyzed in detail. The areas associated with transportation-related uses comprised 63 to 70% of the total impervious cover (Wells 1995). A significant portion of these impervious areas, mainly parking lots, driveways, and road shoulders, experience only minimal traffic activity (Wells 1995). Most retail parking lots are sized to accommodate peak parking usage, which occurs only occasionally during the peak holiday shopping season, leaving most of the area unused for a majority of the time, while many business and school parking areas are used to their full capacity nearly every work day and during the school year. Other differences at parking areas relate to the turn-over of parking during the day. Parked vehicles in business and school lots are mostly stationary throughout the work and school hours. The lighter traffic in these areas results in less vehicle-associated pollutant deposition and less surface wear in comparison to the greater parking turn-over and larger traffic volumes in retail areas (Brattebo and Booth 2003).

The construction of impervious surfaces leads to multiple impacts on stream systems. Therefore, future development plans and water resource protection programs should take into consideration reducing impervious cover in the potential expansion of communities. Research (Schueler 1994; Wells 2000; Booth 2000; Stone 2004; Gregory et al. 2005) shows that reducing the size and dimensions of residential parcels, promoting cluster developments (clustered medium density residential areas in conjunction with open space, instead of large tracts of low density areas), building taller buildings, reducing the residential street width (local access streets), narrowing the width and/or building one-side sidewalks, reducing the size of paved parking areas to reflect the average parking needs instead peak needs, and using permeable pavement for intermittent/overflow parking, can reduce the traditional impervious cover in communities by 10-50% . Many of these benefits can also be met by paying better attention to how the pavement and roof areas are connected to the drainage system. Impervious surfaces that are “disconnected” by allowing their drainage water to flow to adjacent landscaped areas can result in reduced runoff quantities.

There are two main categories in which impervious cover should be classified: directly connected impervious areas and non-directly connected (disconnected) impervious area (Sutherland 1995; Gregory et al. 2005). Directly connected impervious areas (or effective impervious area) include impervious surfaces which drain directly to the sealed drainage system without flowing appreciable distances over pervious surfaces (usually a flow length less than 5 to 20 feet over pervious surfaces, depending on soil and slope characteristics and the amount of runoff). Those areas are the most important component causing stormwater runoff quantity and quality problems. Approximately 80% of directly connected impervious areas are associated with vehicle use areas (streets, driveways, and parking) (Heaney 2000).

A commonly used empirical equation that shows the relationship between the directly connected impervious area and the total impervious area for an area is based on samples from highly urbanized land uses in Denver, CO. This equation was presented by Alley and Veenhuis (1983) and cited by Gregory et al. (2005):

$$DCIA = 0.15 * I^{1.41} \qquad (2.1)$$

where: DCIA = directly connected impervious area

I = the total impervious area

Sutherland (1995) developed an equation that describes the relationship between effective impervious area and total impervious area. Its general form is:

$$EIA = A\,(TIA)^{B} \qquad (2.2)$$

Where: EIA = effective impervious area

TIA = total impervious area

A and B = unique combination of numbers that satisfy the following criteria:

TIA = 1 then EIA = 0%

TIA = 100 then EIA = 100%

This equation has several alternatives known as “Sutherland Equations” developed to apply to various conditions of subbasins which might exist in a watershed.

Values of imperviousness can vary significantly according to the method used to estimate the impervious cover (Lee and Heaney 2003). In a detailed analysis of urban imperviousness in Boulder, CO., Lee and Heaney (2003), found that hydrologic modeling of the study area (I of 35.9% and the DCIA of 13.0%) resulted in large variations (265% difference) in the calculations of peak discharge when impervious surface areas were determined using different methods. They concluded that the main focus should be on DCIA when examining the effects of urbanization on stormwater quantity and quality.

Runoff from disconnected impervious areas is allowed to spread over pervious surfaces as sheet flows, and given the opportunity to infiltrate, before reaching the drainage system. Therefore, there can be a substantial reduction in the runoff volume and a delay in the remaining runoff in entering the storm drainage collection system, depending on the soil infiltration rate, the depth of the flow, and the available flow length. Examples of disconnected impervious surfaces are rooftops that discharge into lawns, streets with swales, parking lots with runoff directed to adjacent open space or swales, etc. From a hydrological point of view, road-related imperviousness usually exerts larger impacts than the rooftop-related imperviousness, because roadways are usually directly connected while roofs can be disconnected, hydrologically (Schueler 1994).

For small rain depths, almost all the runoff and pollutants originate from directly connected impervious area, as disconnected areas have most of their flows infiltrated (Pitt 1987). For larger storms, both directly connected and disconnected impervious areas contribute runoff to the stormwater management system. In many cases, pervious areas are not hydrologically active until the rain depths are relatively large and are not significant runoff contributors until the rainfall exceeds about 25 millimeters for many land uses and soil conditions.

2.3 Impervious Cover Estimation Techniques

Land uses in large watersheds having several communities and involving several local government jurisdictions are usually regulated at the lot or parcel level, such that adjacent properties can have different zoning and impervious cover characteristics (Gregory et al. 2005). The big challenge stays in linking the imperviousness to the zoning and development status of each individual parcel. In such watersheds, the evaluation of impervious surface impacts is labor intensive and time consuming, and requires demanding amounts of data and computational efforts along with the use of Geographic Information Systems (GIS) and other digital analysis and processing tools. Some of the common measurements methods to gather land use/land cover information are (Lee and Heaney 2003; Gregory et al. 2005):

- *Existing Data Conversion* – digitizing existing maps or converting existing files. This requires a lot of human judgment and the result is not always reasonable.
- *Survey* – the most expensive and time consuming method used for measuring the impervious cover, but is the most accurate method.

- *Aerial Photograph Interpretation* – land cover characteristics are measured from photographs taken by aircraft, which roll, pitch, and yaw during flight and require corrections (Goetz et al. 2003). The interpretation is greatly improved when used in conjunction with watershed surveys and/or building footprints.
- *Satellite Remote Sensing* – the latest technology with several advantages over aerial photographs. Satellite images can have high-resolution and possibly digital multi-spectral information. The limiting factor for this method is image pixel size in urban areas. A pixel size of 10 meters or more could easily lead to misinterpretations of surfaces in some land uses.

Historically, land use/land cover information was acquired by a combination of field measurements and aerial photographic analysis, methods that required intensive interpretation, and cross validation to guarantee that the analyst's interpretations were reliable (Goetz et al. 2003). Most recently, satellite images have become available at high spatial resolution (<1 to 5 meter resolution) and have the advantage of digital multi-spectral information more complete even than those provided by digital orthophotographs (DOQs). Some of the problems include difficulties in obtaining consistent sequential acquisition dates, intensive computer processing time requirements, and large disk spaces required to store massive amounts of image information. In this research, IKONOS satellite imagery was utilized as an alternative to classical aerial photography to map the characteristics of the land uses, plus verified ground truth surveys. IKONOS is the first commercially owned satellite providing 1-meter resolution panchromatic image data and 4-meter multi-spectral imagery (Goetz et al. 2003).

In spite of the method used to estimate imperviousness, some kind of field verification is necessary, not to mention that field verification is the only trustworthy way to estimate the directly connected portion of the impervious area (Gregory et al. 2005).

2.4 Imperviousness Impacts

2.4.1 Water Quantity

As urbanization continues at a large scale, drastic modifications on the land surfaces are made, accompanied by a replacement of natural vegetation with impervious surfaces. Because there is less vegetation to slow the flow of stormwater, more runoff and erosion results, and more sediment is washed into streams. Urban streams may therefore have very high flood peaks shortly after intense rainfalls. Less rain is also able to infiltrate and a rise in runoff and streamflow over short time periods will occur (Reilly et al. 2004).

Other environmental consequences in lands and waterbodies may not be so obvious, as some impacts are cumulative, affecting wildlife and fish and imposing a threat to the ecological system.

The volumetric runoff coefficient (Rv) is the fraction of the rainfall volume that is directly converted into the storm runoff volume, and ranges from zero to one. Rv varies for different land uses and land covers: highly pervious, forested ground typically has a low value, possibly near zero (almost no water reaches the channel), while paved surfaces have values approaching 1 (Booth 2000). The figure below (Figure 1) is based on over 40 runoff monitoring sites across the nation and illustrates the increase in the site Rv as a result of its DCIA (Schueler 1994). From this figure it is easily observed that Rv values increase with the increases in the percentage of impervious cover (DCIA).

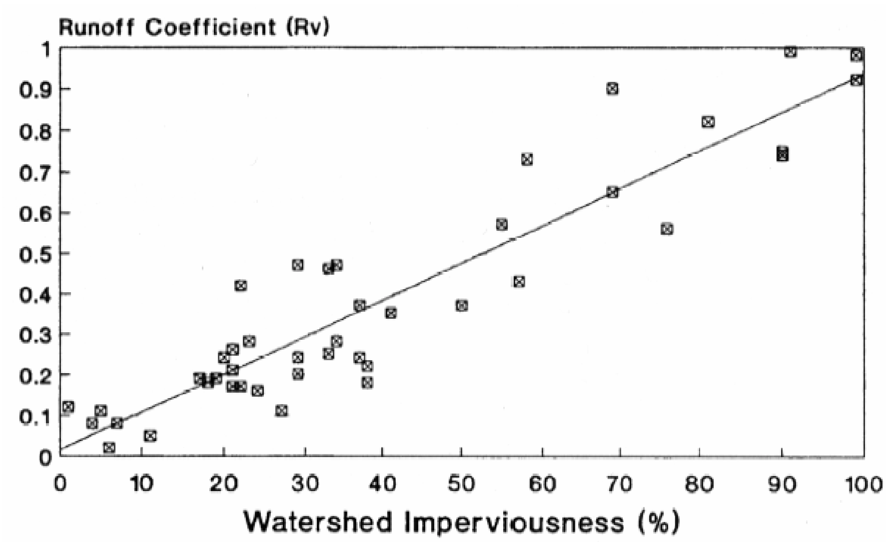

Fig.1. Watershed Imperviousness and the Storm Runoff Volumetric Coefficients, Rv (Schueler 1994)

Studies have shown that an increase in impervious area will give a linearly proportional increase in runoff volume (Gregory et al. 2005) and obviously, the infiltration is reduced in impervious areas (Schueler 1994). Consequently, groundwater recharge is also reduced, which can result in lower dry weather stream flows. However, monitoring data demonstrate that this effect can be inconsistent (Schueler 1994). Evett et al. (1994), after analyzing16 North Carolina watersheds, could not find any statistically significant difference in low stream flows between urban and rural watersheds. Simmons and Reynolds (1982) did note that dry weather flows dropped 20 to 85% after development in several urban watersheds in Long Island, New York (as cited by Schueler 1994). Many west coast streams show dramatic decreases in stream flow with urbanization during dry weather (Pitt and Bissonnette 1984 in Bellevue, WA; Pitt and Shawley 1982 in Castro Valley, CA; Pitt and Bozeman 1982 in Coyote Creek, CA, for example). However, in some arid mountain cities (such as Denver), dry weather flows in urbanized areas actually increase with urbanization, due to increased artificial irrigation of landscaped areas and increased soil moisture and over-watering runoff.

2.4.2 Steam Channel Stability

The increased presence of hard and impermeable surfaces within a watershed leads to frequent and severe floods, followed by the stream channels response. This response is usually in the form of increasing the cross-sectional area (Schueler 1994) through increases in channel width (Figure 2).

Studies in the Pacific Northwest Region by Booth (1991) and Booth and Reinelt (1993), suggest the existence of a threshold at 10% of total impervious areas for suitable urban stream stability, followed by unstable and eroding channels with increasing levels of paved surfaces. The widening and destabilization of urban stream channels has resulted in habitat degradation (Figure 2). In this Northwest region, they concluded that the fundamental hydrologic effect of urban development is the loss of water storage in the soil column (Booth 2000) due to either soil compaction/exposure during development, or because impervious surfaces convert subsurface runoff to direct overland flow.

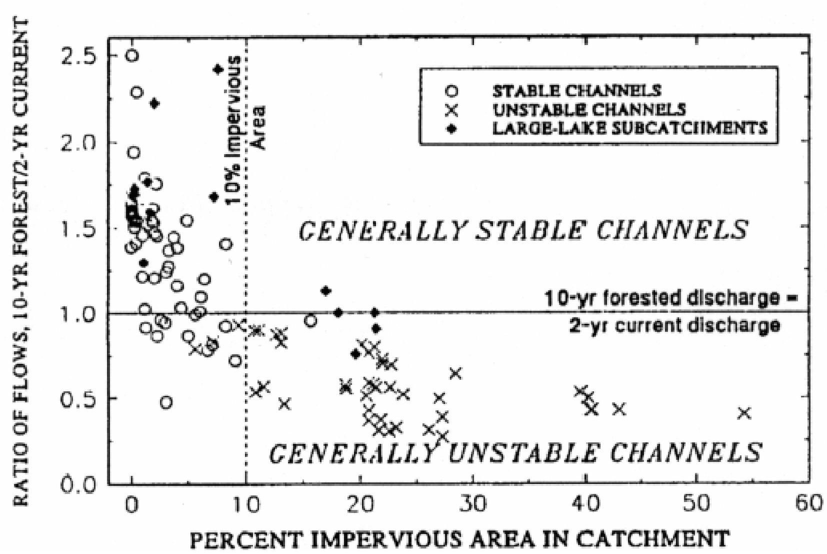

Fig. 2. Channel Stability as a Function of Imperviousness (Schueler 1994 from Booth and Reinelt 1993)

Hydrologic processes dictate the formation and functioning of the aquatic habitat, and changes in hydrology are omnipresent in urban settings. From the hydrologic elements relevant to urbanization, the most important is the storm runoff volume. Modifications of the land surface during urbanization produce changes in both the magnitude and the type of runoff processes.

Figure 3 shows a conceptual outline of how land use transformations are manifested in the physical form of an urban stream channel. Additional elements, such as biological interactions and water chemistry, are not included in the diagram because they do not influence channel morphology. However, they are critical in determining biological condition (Booth 2000).

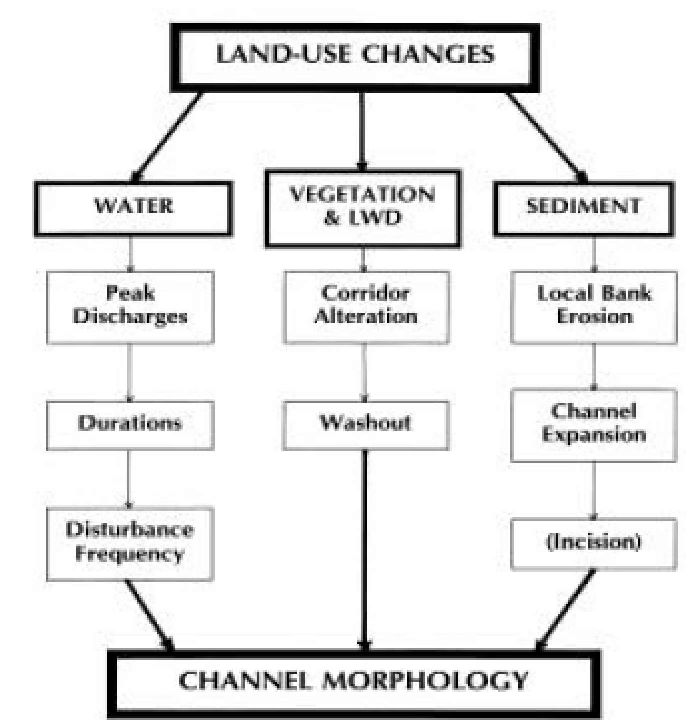

Fig. 3. Theoretical Framework of How Land Use Changes are Visible in the Morphology of an Urban Stream Channel (Booth 2000)

Increased imperviousness leads to poorer water quality and pollution discharges to urban receiving waters. Research has consistently demonstrated that a threshold in habitat quality exists at about 10-15% imperviousness, beyond which urban stream habitat quality is classified as poor. It has been found that there are two thresholds in stream degradation process (Figure 4) (Center of Watershed Protection 2003). The first threshold is observed to be at about 10-15% impervious cover, when steam degradation starts to occur and sensitive steam elements vanish from the system. Below 10% impervious cover, most streams are in excellent condition. The second threshold is at about the 25-30% imperviousness level, after which considerable degradation is observed, the steams are in poor conditions and the aquatic habitat is severely damaged.

2.4.3 Water Quality

In addition to high flows caused by urbanization, the increased runoff volumes also contain increased amounts of contaminants. Impervious surfaces are sources of contamination because they accumulate pollutants between rainfalls events from the atmosphere, vehicle leakage, litter, etc., which then partially wash off during rains. Monitoring has shown that automobiles and metal panels used on roofs and sides of buildings are sources of heavy metals to urban runoff and receiving waters. Tire wear is an important source of zinc, while metal roofs are source of zinc and cooper (Pitt et al. 2005a, and 2005b). Many studies have concluded that urban pollutant loads are directly related to the impervious surfaces within the watershed (Schueler 1994), the available loads for washoff being affected by both rain intensity and surface texture (Pitt 1987; Pitt et al. 2005c). Therefore, imperviousness is used as a key predictive variable in models used to predict pollutant loads from urban areas.

Based on the relationship between steam quality and watershed imperviousness, the Center for Watershed Protection (2003) created an urban stream classification scheme, named the “Impervious Cover Model”. This model serves as a planning tool to facilitate initial screening of the condition of a watershed based on impervious surfaces, to supply a classification system with management options (protection and improvement needs of a watershed), and to predict the existing and future quality of streams based on expected changes in imperviousness. The classification system contains three stream categories, based on the percentage of impervious cover (Figure 4 and Table 1):

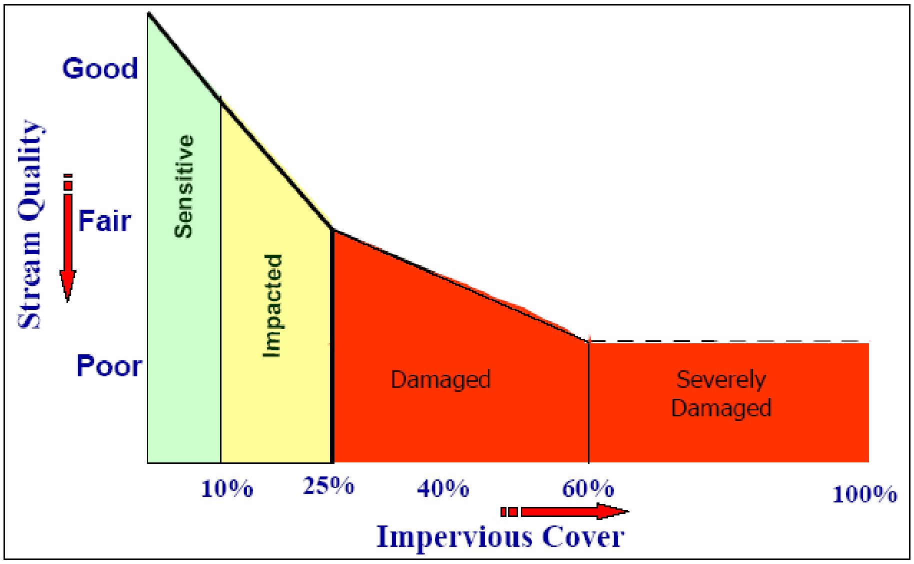

Fig. 4. Relationship between Stream Quality and Watershed Imperviousness (Center of Watershed Protection 2003)

“**Sensitive Streams:** Sensitive streams usually have a watershed impervious cover of less than 10%. They are of high quality, and are characterized by stable channels, excellent habitat structure, good to excellent water quality, and diverse communities of both fish and aquatic insects. They do not experience frequent flooding and other hydrological changes that come with the urbanization.

Impacted Streams: Impacted streams have a watershed impervious cover of about 11 to 25%, and provide evidence of degradation associated with the level of watershed urbanization. Their channel geometry is modified by frequent flooding, erosion and channel bed widening are visible, banks are unstable, and physical habitat in the stream clearly declines. Stream water quality changes into the fair/good category during both storms and dry weather periods. Stream biodiversity declines to fair levels, with the most sensitive fish and aquatic insects disappearing from the stream.

Damaged or Non-Supporting Streams: Damaged streams have an impervious cover of more than 25% in their watersheds. In this case, the stream water quality crosses the second threshold into the fair to poor category, and water contact recreation is no longer possible due to the presence of high bacterial levels. These streams are no longer able to support a diverse stream community, their channel becomes highly unstable, many stream reaches experience severe widening, down-cutting and stream bank erosion. The biological quality of non-supporting streams is generally considered poor, and is dominated by pollution-tolerant insects and fish.

Table 1. Classification of Urban Streams based on Ultimate Imperviousness

Urban Steam Classification	**Sensitive (0 – 10% Imperv.)**	**Impacted (11– 25% Imperv.)**	**Damaged (26–100% Imperv.)**
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good	Fair	Fair/Poor
Stream Biodiversity	Good/Excellent	Fair/Good	Poor
Resource Objective	Protect Biodiversity and Channel Stability	Maintain Critical Elements of Stream Quality	Minimize Downstream Pollutants Load
Water Quality Objectives	Sediment and Temperature	Nutrient and Metal Loads	Control Bacteria
Riparian Buffers	Widest Buffer Network	Average Buffer Width	Greenways

Source: Schueler, Thomas. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*. Center for Watershed Protection 1(3): 100-111

Steedman (1988), as cited by Booth (2000), concluded that the rapid decline in biotic diversity in urban streams is an outcome of both increasing impervious cover and decreasing forest cover on in-stream biological conditions. Figure 5 shows a conceptual relationship between urban land use, forest cover, and biological conditions using the specific values and descriptors (“Good,” “Poor”, ”Excellent”) as designated by Steedman (1988).

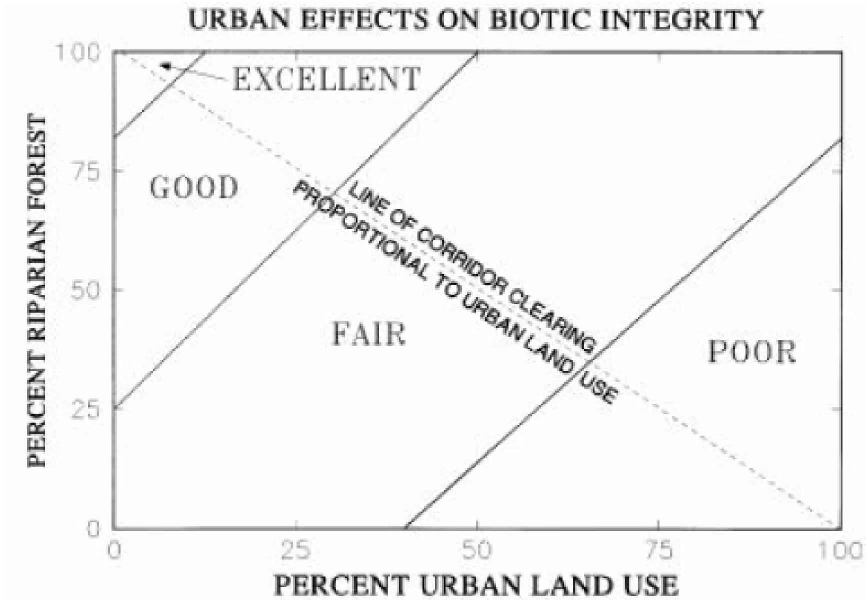

Fig.5. Conceptual Relationship between Urban Land Use, Forest Cover, and Biological Conditions (Booth 2000 from Steedman 1988)

2.4.4 Stream Temperature

Increases of air and water temperature are a direct consequence of urbanization. Impervious surfaces, especially dark colored surfaces, have a higher thermal capacity than surfaces found in a natural landscape. Therefore, urban areas are hotter due to the urban heat island effect and they heat the rainwater as its hits. In the summer daytime, urban areas can have a rise of about 6 to 8F in the air temperature (Gregory et al. 2005) and a parking lot sitting in hot sunshine can reach a surface temperature of 120F, yielding a 10F increase in rainfall temperature (Frazer 2005). The runoff from heated impervious surfaces raises the temperature of receiving waters, posing instantaneous threat to aquatic species and their habitat. Also, removing the vegetation and trees along the river banks that would otherwise provide shade, leads to increases in stream water temperature and threat to the habitat.

2.5 Sources of Urban Runoff

Urban runoff is a collection of many separate source area flow components that are combined within the drainage area before entering the receiving waters (Pitt 1987 and 2000; Pitt et al. 2005a; 2005b; and 2005c). A popular way to identify sources of urban runoff is to divide the urban watershed in major land uses categories according to their main land use (residential, institutional, industrial, commercial, open space, freeway). For local planning and modeling purpose, those major land uses can be further sub-categorized according to the population density (high density, medium density, low density, apartments, multi-family, trailer parks, suburban for residential land use), with the dominant activity that takes place in the land use (strip commercial, shopping center, office park, downtown business district for commercial land use; manufacturing, non-manufacturing, high/medium industrial for industrial land use; education, hospital for institutional land use; cemeteries, parks, undeveloped for open space land use) (Pitt and Voorhees 1995).

One problem in evaluating an urban area for potential stormwater controls is the need to understand the sources of the pollutants of concern under different rain conditions. Thus, a functional way of partitioning urban areas is by the nature of the impervious cover and by its connection to the drainage system. Therefore, an area can be divided into following components: roofs, streets, sidewalk, driveways, parking lots, storage area, playgrounds, front landscape, back landscape, undeveloped area, and other pervious areas (Pitt and Voorhees 1995). This partitioning is helping to better predict the outfall characteristics and/or the effect of source area controls. Pitt and Voorhees (1995) show the runoff characteristics of a residential area in Milwaukee, WI (Figure 6).

The figure shows the percentage of runoff volume originated from different sources, as a function of rain depth, and the areas from where water is originating. In this example, for precipitation depths of 0.1 inches, about one-half of the runoff is coming from streets. This contribution decreases to about 20% for storms greater than about 0.25 inches in depth. The decrease in the importance of streets as a source of runoff is associated with an increase of landscape area contributions (which makes up more than 75% of this area, which has compacted clayey soils). Similarly, the significance of runoff from driveways and roofs starts off relatively high and then decreases with increasing storm depths as the landscaped areas become more important.

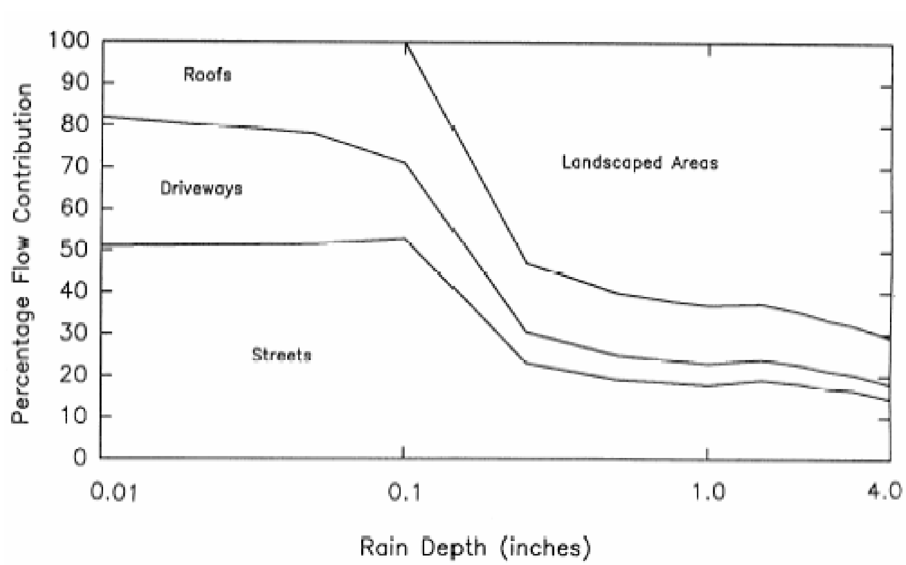

Fig. 6. Flow Sources for Example Medium Density Residential Area having Clayey Soils (Pitt and Voorhees 1995)

As mentioned above, the relative contribution of source areas are site specific and rain pattern dependent. However, the initial runoff is always generated by the directly connected impervious areas, with pervious areas contributing runoff only during the larger rains. The length of curbs and gutters or drainage swales in an area is an important factor when predicting the role that streets have in producing pollutant discharges and the effects of street cleaning or infiltration in grass swales drainages (Sartor and Boyd 1972; Pitt 1987).

Many studies have indicated that there are significant differences in stormwater constituents for different land use categories (Pitt et al. 2004). This is supported by databases like NURP (EPA 1983), CDM (Smullen and Cave 2002), USGS (Driver et al. 1985) and NSQD (Maestre and Pitt 2005). Estimation of stormwater characteristics based on land use is a normal approach and generally accepted by researchers, because it is related to the activity in the watershed and, in addition, many site features are consistent within each land use, including imperviousness. Pitt et al. (2004) analyzed several constituents (TKN, copper, lead, zinc, phosphorus, nitrates, fecal coliforms, COD, etc) for different major land use categories (from NSQD) and found significant differences for land use categories for all pollutants.

2.6 Chapter Summary

Urbanization radically transforms natural watershed conditions and introduces impervious surfaces into the previously natural landscape. Total impervious areas are mostly composed of rooftop and transport components that can be either directly connected or disconnected to the drainage system. The impervious areas that are directly connected to the storm drainage system are the greatest contributor of runoff and contamination under most conditions.

Reported hydrologic and geomorphic impacts, associated with increases in impervious surfaces, are summarizes in the below table (Table 2).

Table 2. Impacts on Streams due to Increased Impervious Surface Areas

	Resulting Impacts				
Increased Imperviousness Leads to:	**Flooding**	**Habitat Loss**	**Erosion**	**Channel Widening**	**Streambed Alteration**
Increased runoff volume	✓	✓	✓	✓	✓
Increased peak flow rates	✓	✓	✓	✓	✓
Increased peak flow durations	✓	✓	✓	✓	✓
Changes in sediment loadings	✓	✓	✓	✓	✓
Increased stream temperature	n/a	✓	n/a	n/a	n/a
Decreased base flows	n/a	✓	n/a	n/a	n/a

Source: Environmental Protection Agency. Urbanization and Streams: Studies of Hydrologic Impacts (http://www.epa.gov/owow/nps/urbanize/report.html)

These impacts are often cumulative and affect fish and wildlife, causing ecological and monetary losses to local agencies and governments within a watershed. Research conducted in many geographical areas has similarly concluded that stream degradation starts to occur when the watershed is composed of approximately 10-15% total impervious areas. Channel stability and fish habitat quality rapidly decline after this amount of development. In addition, the general conclusion of many studies is that in urban areas, the amount of stormwater generated has increased since the early years of the 20th century because of the tendency toward greater automobile use, which is associated with the facilities necessary to accommodate them (larger street, parking lots, and garages). Also, the tendency toward bigger houses and adjacent parking has increased imperviousness in urban watersheds.

The amount of impervious cover has become recognized as a tool for evaluating the health of a watershed and serves as an indicator of urban stream quality. It also can be used as a management tool in reducing the impacts of development within a watershed.

Table 3 is a summary of why impervious cover is a critical factor in urban areas and is based on the key findings of recent research regarding the impacts of urbanization on aquatic systems (Center of Watershed Protection 2003).

Table 3. Review of Key Findings of Recent Research Examining the Relationship of Urbanization on Aquatic Systems

Watershed Indicator	Key Finding	Reference	Year	Location
Aquatic insects	Negative relationship between number of insect species and urbanization in 21 streams.	Benke, *et al*.	1981	Atlanta
Aquatic habitat	There is a decrease in the quantity of large woody debris (LWD) found in urban streams at around 10% impervious cover.	Booth, *et al*.	1996	Washington
Fish, habitat & channel stability	Channel stability and fish habitat quality declined rapidly after 10% impervious area.	Booth	1991	Seattle
Fish, habitat	As watershed population density increased, there was a negative impact on urban fish and habitat	Couch, *et al*.	1997	Atlanta
Aquatic insects and fish	A comparison of three stream types found urban streams had lowest diversity and richness	Crawford & Lenat	1989	North Carolina
Stream temperature	Stream temperature increased directly with subwatershed impervious cover.	Galli	1991	Maryland
Aquatic insects	A significant decline in various indicators of wetland aquatic macro invertebrate community health was observed as impervious cover increased to levels of 8-9%.	Hicks & Larson	1997	Connecticut
Insects, fish, habitat water quality, riparian zone	Steepest decline of biological functioning after 6% imperviousness. There was a steady decline, with approx 50% of initial biotic integrity at 45% impervious area.	Horner, *et al*.	1996	Puget Sound Washington
Aquatic insects and fish	Unable to show improvements at 8 sites downstream of BMPs as compared to reference conditions.	Jones, *et al*.	1996	Northern Virginia
Aquatic insects	Urban streams had sharply lower insect diversity with human population above 4/acre. (About 10%)	Jones & Clark	1987	Northern Virginia
Aquatic insects & fish	Macro invertebrate and fish diversity decline significantly beyond 10-12% impervious area.	Klein	1979	Maryland
Aquatic insects	Drop in insect taxa from 13 to 4 noted in urban streams.	Garie and McIntosh	1986	New Jersey

Table 3. - *Continued*

Watershed Indicator	Key Finding	Reference	Year	Location
Fish spawning	Resident and anadromous fish eggs & larvae declined in 16 streams with > 10% impervious area.	Limburg & Schmidt	1990	New York
Fish	Shift from less tolerant coho salmon to more tolerant cutthroat trout pop.-between 10-15% impervious areas at 9 sites.	Luchetti & Fuersteburg	1993	Seattle
Stream channel stability	Urban stream channels often enlarge their cross-sectional area by a factor of 2 to 5. Enlargement begins at relatively low levels of impervious cover.	MacRae	1996	British Columbia
Aquatic insects & stream habitat	No significant difference in biological and physical metrics for 8 BMP sites versus 31 sites without BMPs (with varying impervious area).	Maxted and Shaver	1996	Delaware
Insects, fish, habitat, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the percentage of total impervious area exceeded the 5-10% range.	May, *et al*.	1997	Washington
Aquatic insects and fish	There was significant decline in the diversity of aquatic insects and fish at 10% impervious cover.	MWCOG	1992	Washington, DC
Aquatic insects	As watershed development levels increased, the macro invertebrate community diversity decreased.	Richards, *et al.*	1993	Minnesota
Aquatic insects	Biotic integrity decreases with increasing urbanization in study involving 209 sites, with a sharp decline at 10% I. Riparian condition helps mitigate effects.	Steedmen	1988	Ontario
Wetland plants, amphibians	Mean annual water fluctuation inversely correlated to plant & amphibian density in urban wetlands. Declines noted beyond 10% impervious area.	Taylor	1993	Seattle
Wetland water quality	There is a significant increase in water level fluctuation, conductivity, fecal coliform bacteria, and total phosphorus in urban wetlands as impervious cover exceeds 3.5%.	Taylor, *et al.*	1995	Washington
Sediment loads	About 2/3 of sediment delivered into urban streams comes from channel erosion.	Trimble	1997	California
Water quality-pollutant conc.	Annual P, N, COD, & metal loads increased in direct proportion with increasing impervious area.	US EPA	1983	National
Fish	As watershed development increased to about 10%, fish communities simplified to more habitat and trophic generalists.	Weaver	1991	Virginia
Aquatic insects & fish	All 40 urban sites sampled had fair to very poor index of biotic integrity (IBI) scores, compared to undeveloped reference sites.	Yoder	1991	Ohio

Source: Center for Watershed Protection. 2003. *The Impervious Cover Model*

The objective of this thesis is to describe the methods of field data collection, data processing and measurements of impervious cover, and other land surfaces necessary for all monitored watersheds when one wants to study the impact of urbanization on water quality and quantity. The second objective is to employ a stormwater management model (WinSLAMM) for a highly impervious watershed to predict the runoff quantity and quality and to study the performance of different combinations of stormwater control devices.

Chapter 3
Site Development Characteristics for Stormwater Modeling [1]

3.1 Introduction

In order for an urban runoff study to be successful, a careful evaluation of the study watershed is required. An urban area inventory of watershed development conditions is needed as part of a comprehensive stormwater quality plan for an area. It is also needed in order to use most stormwater models, including WinSLAMM, for a specific area. Past studies using WinSLAMM have demonstrated the importance of knowing the areas of the different land covers in each land use category, the pavement conditions, and the storm drainage characteristics (grass swales, curb and gutters, and the roof drains). Delineation of the watershed and neighborhoods is mandatory and an inventory sheet needs to be filled out at several locations in the watershed. About 6 to 12 homogeneous neighborhoods usually need to be surveyed for the inventory task per study area land use. Aerial photographs or satellite images of each site are also needed. They are used to measure the specific land cover areas at each inventory location.

Impervious cover has become an increasing important indicator in measuring the impact of land development on drainage systems and aquatic life (Schueler 1994). Impervious cover is also one of the variables that can be quantified for different types of land development, although there are many different types of impervious surfaces and

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[1]Portions of the following were presented at the *78th Annual Water Environment Federation Technical Exposition and Conference*. Washington, D.C. Oct. 29 – Nov. 2, 2005, as "Impervious Surfaces in Urban Watersheds," by Celina Bochis and Robert Pitt

how they are connected to the drainage system. Although much interest has been expressed concerning impervious areas in urban areas, actual data for the patterns of use of these surfaces is generally lacking. The procedures described in this paper to obtain this information were developed by Pitt (1979) as part of early stormwater research projects in San Jose, CA, and have been used for many years in stormwater research projects. These methods were successfully used in several Nationwide Urban Runoff Program (NURP) projects that were conducted in the San Francisco Bay Area (Castro Valley, CA), in Bellevue, WA, and in Milwaukee, WI (EPA 1983). Pitt and McLean 1986 also extensively used these procedures to determine the characteristics in test watersheds in Toronto, ON, Canada.

The objective of this on-going research effort described here is to measure the variations in runoff quantity and quality associated with variations in site characteristics, especially impervious cover. In order to determine how land development variability affects the quantity and quality of runoff, different land surfaces (roofs, streets, landscaped areas, parking lots, etc.) for different land uses (residential, commercial, industrial, institutional, etc.) were measured. The field data will be used with WinSLAMM (the Source Loading and Management Model for Windows, Pitt and Voorhees 1995; 2002) to model the runoff quantity and quality for each neighborhood investigated. Statistical analyses will be conducted at several levels to establish the quantitative and qualitative runoff sensitivity associated with variations of site characteristics.

In this study, data from 125 neighborhoods that were surveyed to determine the actual development characteristics representing 16 major land use areas (Table 4) were used. The area is located in the Little Shades Creek Watershed, near Birmingham, AL. This information was collected over a period of several years as part of a volunteer effort using the Jefferson County "Earth Team" of the local USDA office during the mid 1990s. Initially, this data was used along with source area and outfall monitoring data to calibrate WinSLAMM for the area (Pitt et al. 1996). This current research is intended to measure the variability in stormwater characteristics associated with the variability of the development characteristics for each land use category. Currently, additional regional data from the NSQD (National Stormwater Quality Database) MS4 (Municipal Separate Storm Sewer System) database (Maestre and Pitt 2005) for Jefferson County, Alabama, provided by the Storm Water Management Authority (SWMA), was used to conduct a re-validation of the model for current local conditions. This thesis mainly focuses on the data gathering techniques, reporting of the data and its variability, describing likely pollutant sources in a test watershed, and evaluating different stormwater management practices in this watershed. Future work will focus on the predicted variability of the stormwater characteristics as a function of the land development variability.

3.2 Field Data Collection

The new field data comes from five drainage areas that have been monitored as part of the Jefferson County, AL, stormwater permit program, by the Jefferson County Storm Water Management Authority. These field data are incorporated in the NSQD (National Stormwater Quality Database) MS4 (Municipal Separate Storm Sewer System) database for Jefferson County, Alabama (Pitt et al. 2004; Maestre and Pitt 2005). This database is part of research conducted by the University of Alabama, Department of

Civil, Construction and Environmental Engineering and can be found at the Internet location: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

The University of Alabama and the Center for Watershed Protection were awarded an Environmental Protection Agency (EPA) Office of Water 104(b) 3 grant in 2001 to collect and evaluate stormwater data from a representative number of NPDES (National Pollutant Discharge Elimination System) MS4 stormwater permit holders. The database, the National Stormwater Quality Database (NSQD, version 1.1) also contains information that was collected and reviewed to describe the characteristics of these data, to provide guidance for future sampling needs, and to have these data as a benchmark for comparison with locally collected data.

The field data used with WinSLAMM to model the runoff quantity and quality was collected during an earlier study of Little Shades Creek Watershed, near Birmingham, AL, as part of a cooperative study conducted by the University of Alabama at Birmingham, the Jefferson County office of the U.S. Soil Conservation Service (now The U.S. Natural Resources Conservation Service), U.S. Army Corps of Engineers, and other city and county governments. Local runoff quality data collected during EPA sponsored runoff projects (Pitt et al.1995), detailed development information (field information) conducted by volunteers of the Soil Conservation's Earth Team and additional information provided by local government agencies, form the database for this research. Initially, this data was used along with source area and outfall monitoring data to calibrate WinSLAMM and to examine the alternative controls in this rapidly developing area. The present research uses the same field data and is intended to measure the variability in stormwater characteristics associated with the variability of the development characteristics for each land use category.

An "Area Description" field sheet is used to record the important characteristics of the study areas during field surveys (Figure 7). In addition, aerial photographs from TerraServer USA http://terraservice.net/ (Figure 8) and satellite images provided by Storm Water Management Authority in Birmingham http://www.swma.com/ (Figure 9) were used to measure the actual coverage of each type of surface in each neighborhood studied. The following briefly explains the important elements of the field sheet. Field training of the people responsible for collecting the information was carried out to assure data consistency.

• ***Location***: The block number range and the street name are noted. A sub-area name could also be used to describe the drainage area. Descriptions were made for homogeneous block segments (neighborhoods) in the study area. Specific blocks to be surveyed were randomly selected and located on the aerial photographs before the survey began. Each site had at least two photographs taken: one was a general scene (Figure 10) and the other was a close-up showing about 25 by 40 centimeters of pavement (Figure 11). Additional photographs were usually taken to record unusual conditions. These photographs are very important to confirm the descriptions recorded on the sheets and to verify the consistency of information for the many areas. The photographs are also very important when additional site information is needed, but not recorded on the data sheets.

• ***Land Use***: The land-use type that best describes the block is circled. If more than one land-use is present, the estimated distribution is shown. The approximate income level for residential areas is also circled. The specific types of industrial activities (warehouses, metal plating, bottling, electronics, gas station, etc.) for industrial and commercial areas are also written in. Also, the approximate age of development is circled.

• ***Roof Drainage***: The discharge locations of the roof drains are noted. The approximate distribution is also noted if more than one discharge location is evident. The “underground” location may be to storm sewers, sanitary sewers, or dry wells.

Some areas have the roof drains apparently directed underground but are actually discharged to the roadside gutter or drainage ditch. If they lead to the gutter, then the “to gutter” category is circled. Additionally, if the flow path length is less than about five feet over pervious ground, it is functionally directly connected to impervious areas, requiring circling the “to impervious” category. The roof types and building heights are also indicated (again, the approximate distributions are noted if more than one type was present). It is necessary to take an inventory of all visible roof drains in the study block by keeping tallies of each type of drain connection. The distribution of the percentage per connection type is also put on the sheet. If other categories of characteristics vary in the study block (paved or unpaved driveway categories is another common variation), then these are also tallied for each category. The roof types are also indicated.

• ***Sediment Sources***: Sediment sources near the drainage (street, drainage way, or gutter), such as construction sites, unpaved driveways, unpaved parking areas or storage lots, or eroding vacant land, are described and photographed.

• ***Street and Pavement***: Traffic and parking characteristics are noted. Pavement condition and texture are quite different. Condition implies the state of repair, specifically relating to cracks and holes in the pavement. Texture implies roughness. A rough street may be in excellent condition: many new street overlays result in very rough streets. Some much worn streets may also be quite smooth, but with many cracks. A close-up photograph of the street surface is needed to make final determinations of street texture. An overview photograph of the street is also taken to make the final determination of the street condition. The gutter/street interface condition is an indication of how well the street pavement and the gutter material join.

Many new streets overlay jobs are uneven, resulting in a several centimeter ridge along the gutter/street interface. If the street interface has poor condition or is uneven, an extra photograph is taken to show the interface close-up. The litter perception is also circled. Another photograph is also taken of heavily littered areas.

After the test area descriptions were filled out for each neighborhood surveyed, the corresponding aerial photographs were examined and the individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc) were measured, and the data were then summarized in an Excel spreadsheet (Table 4).

This information was used to build the WinSlamm files to describe each land use area. This information had to be manually measured from the photographs, as automated mapping software resulted in many errors and could not distinguish the necessary surface components. Mapping software may be used to total the main surface categories, but accuracy must be verified.

The field data collected for the five Jefferson County drainage basins was performed to supplement the aerial photographic information. Watershed maps and additional information about the outfalls location and safety issues were provided by Storm Water Management Authority Inc.

Location: Site number:
Date: Time:
Photo numbers:
Land-use and industrial activity:
Residential: low medium high density single family
multiple family
trailer parks
high rise apartments
Income level: low medium high
Age of development: <1960 1960-1980 >1980
Institutional: school hospital other (type):
Commercial: strip shopping center downtown hotel offices
Industrial: light medium heavy (manufacturing) describe:
Open space: undeveloped park golf cemetery
Other: freeway utility ROW railroad ROW other:
Maintenance of building: excellent moderate poor
Heights of buildings: 1 2 3 4+ stories
Roof drains: % underground % gutter % impervious % pervious
Roof types: flat composition shingle wood shingle other:
Sediment source nearby? No Yes (describe):
Treated wood near street? No telephone poles fence other:
Landscaping near road:
Quantity: none some much
Type: deciduous evergreen lawn
Maintenance: excessive adequate poor
Leafs on street: none some much
Topography:
Street slope: flat (<2%) medium (2-5%) steep (>5%)
Land slope: flat (<2%) medium (2-5%) steep (>5%)
Traffic speed: <25mph 25-40mph >40mph
Traffic density: light moderate heavy
Parking density: none light moderate heavy
Width of street: number of parking lanes:
number of driving lanes:
Condition of street: good fair poor
Texture of street: smooth intermediate rough
Pavement material: asphalt concrete unpaved
Driveways: paved unpaved
Condition: good fair poor
Texture: smooth intermediate rough
Gutter material: grass swale lined ditch concrete asphalt
Condition: good fair poor
Street/gutter interface: smooth fair uneven
Litter loadings near street: clean fair dirty
Parking/storage areas (describe):
Condition of pavement: good fair poor
Texture of pavement: smooth intermediate rough unpaved
Other paved areas (such as alleys and playgrounds), describe:
Condition: good fair poor
Texture: smooth intermediate rough
Notes:

Fig. 7. Little Shades Creek Corridor Test Area Description

Fig. 8. Example of Monochromatic Aerial Photograph having 1-meter Resolution (USGS Photo)

Fig. 9. Example of High Resolution Color Satellite Image
(http://maps.google.com/)

Table 4. Little Shade Creek Watershed, near Birmingham, AL: Average Source Areas by Land Use (Percent Unless Otherwise Noted)

Land Use	Curb Miles/ 100 ac	Street Area	Driveways Paved Connected	Driveways Paved Disconnected	Driveways Unpaved	Parking Paved Connected	Parking Paved Disconnected	Parking Unpaved	Playground Paved Disconnected	Playground Unpaved
High Dens. Residential	6.9	7.8	1.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Med. Dens. Residential (<1960)	5.0	5.6	1.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Dens. Residential (1961-80)	5.8	6.7	1.3	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Med. Dens. Residential (>1980)	6.5	7.5	0.0	1.1	1.1	0.0	0.0	0.0	0.0	0.0
Low Dens. Residential	4.6	5.3	0.23	0.80	0.0	0.0	0.0	0.0	0.0	0.0
Apartments	8.2	9.8	0.52	1.0	0.0	6.6	3.9	0.0	0.84	0.0
Multiple Families	6.3	7.3	0.60	0.60	0.0	8.7	0.0	0.0	0.16	0.0
Offices	13	16	1.1	0.62	0.0	25	1.9	0.0	0.0	0.0
Shopping Centers	14	16	0.74	0.0	0.0	29	0.0	0.61	0.0	0.0
Schools	3.6	4.2	0.10	0.10	0.0	5.7	0.0	0.0	0.0	15
Churches	16	18	0.38	0.38	0.0	25	0.0	4.8	0.0	0.0
Industrial	7.1	8.0	0.32	0.10	0.0	8.9	2.5	1.8	0.0	0.0
Parks	14	16	0.11	0.11	0.0	16	0.0	0.0	8.3	25
Cemeteries	5.1	6.9	0.0	0.07	3.3	0.0	9.2	1.8	0.0	0.0
Golf Courses	1.0	1.2	0.08	0.08	0.0	0.65	0.0	0.0	0.68	0.0
Vacant	4.1	4.8	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0

Table 4. – *Continued*

Land Use	Storage Paved Connected	Storage Unpaved	Front Landscape	Back Landscape	Large Turf	Undeveloped	Roof Drained to Impervious	Roof Drained to Pervious	Walkway	Grave Area	Total*
High Dens. Residential	0.0	0.0	40	32	0.0	3.9	4.6	8.1	0.0	0.0	100
Med. Dens. Residential (<1960)	0.0	0.0	58	23	0.0	0.0	4.0	5.5	0.0	0.0	100
Med. Dens. Residential (1961-80)	0.0	0.0	53	28	0.0	0.17	2.2	6.6	0.0	0.0	100
Med. Dens. Residential (>1980)	0.0	0.0	51	24	0.0	4.8	6.6	3.2	0.0	0.0	100
Low Dens. Residential	0.0	0.0	33	48	0.0	8.4	0.87	2.9	0.0	0.0	100
Apartments	0.0	0.0	32	23	0.0	3.3	3.6	16	0.0	0.0	100
Multiple Families	0.0	0.0	28	30	0.0	6.9	11	6.7	0.1	0.0	100
Offices	0.0	0.0	24	15	0.0	0.0	17	0.33	0.0	0.0	100
Shopping Centers	0.0	0.0	30	1.8	0.0	0.0	18	3.6	0.0	0.0	100
Schools	0.0	0.0	23	26	14	1.0	6.1	4.8	0.0	0.0	100
Churches	0.0	0.0	21	12	0.0	7.0	10	1.7	0.0	0.0	100
Industrial	16	8.1	27	17	0.0	0.0	5.5	5.4	0.0	0.0	100
Parks	0.0	0.0	1.0	4.3	15	14	0.0	0.0	0.0	0.0	100
Cemeteries	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.98	0.0	70	100
Golf Courses	0.0	0.0	19	0.0	76	0.0	0.0	2.8	0.0	0.0	100
Vacant	0.0	0.0	0.0	0.0	27	67	0.	0.0	0.0	0.0	100

*Total might not add to 100 due to rounding

Fig. 10. Example of Site General View

Fig. 11. Example of Close-up Photograph of the Street Texture

3.3 Description of Land Use

3.3.1 General Land Use Description

A stormwater/watershed study should use the locally available land use data and definitions. The watershed surveys conducted during the field data collection activities revealed the existence of several distinct sub categories of land uses in the Birmingham area. The following briefly explains the land use descriptions used in this research, according to the documentation supplied with WinSLAMM (Pitt and Voorhees 2000). In all cases, all the land surfaces are included in the land uses, such as the streets, building roofs, parking lots, walkways, landscaped areas, undeveloped parcels, etc.

- ***Residential Land Uses***

- High Density Residential: Urban single family housing at a density greater than 6 units/acre. This land use includes the house, driveway, yard, sidewalks, and streets.

- Medium Density Residential: Urban single family housing at a density of 2 -6 units/acre. The same as above, the house, driveway, yard, sidewalks and streets adjacent with the house are included.

- Low Density Residential: Like previous residential areas, except the density is 0.7 – 2 units/acre.

- Multiple Families: Housing of three or more families having 1 to 3 stories in height. Units may be adjoined up-and-down, side-by-side or front-and-rear. This land use includes the streets, buildings, yards, parking lots, and driveways.

- Apartments: Multiple family units of 4 or more stories in height.

- Trailer Parks: A mobile home or trailer park that includes all vehicle homes, the yard, driveways, streets, walkways, and office area.

- ***Commercial Land Uses***

- Strip Commercial: Includes buildings for which the primary function is the sale of goods or services. Some institutional land use such as post offices, fire and police stations, and court houses are also included in this category. The strip commercial land use includes the buildings, parking lots, and streets. This category does not include buildings used for the manufacturing of goods or warehouses, nurseries, tree farms, or lumber yards.

- Shopping Centers: These are commercial areas where the related parking lot is at least 2.5 times the building roof area. The buildings in this category are usually surrounded by parking lots. This land use includes the buildings, parking lots, and the streets, plus any landscaping.

- Office Parks: It is the land use where non-retailed businesses take place. The buildings are usually multi-story buildings surrounded by larger areas of lawn and other landscaping. This land use includes the buildings, the lawn, and streets. Types of establishments usually found in this category may be: insurance offices, government buildings, company headquarters, etc.

- Downtown Central Business District: Highly impervious downtown areas of commercial and institutional land use.

- ***Industrial Land Uses***

- Manufacturing Industrial: Those buildings and premises which are devoted to the manufacture of products, with many of the operations conducted outside, such as power plants, steel mills, and cement plants.

- Medium Industrial: This category includes businesses such as lumber yards, auto salvage yards, junk yards, grain elevators, agricultural coops, oil tank farms, coal and salt storage areas, slaughter houses, and areas for bulk storage of fertilizers.

- Non-Manufacturing: Those buildings which are used for the storage and/or distribution of goods awaiting further processing or sale to retailers. This category mostly includes warehouses and wholesalers where all operations are conducted indoors, but with truck loading and transfer operations conducted outside.

- ***Institutional Land Uses***

- Hospitals: Medical facilities that provide patient overnight care. Includes nursing homes, state, county, or private facilities. This land use includes the buildings, grounds, parking lots, and drives.

- Education (Schools): Includes any public or private primary, secondary, or college educational institutional grounds. The land use consists of the buildings, playgrounds, athletic fields, roads, parking lots, and lawn areas.

- Miscellaneous Institutional: Churches and large areas of institutional property not part of strip commercial and downtown areas.

- ***Open Space Land Uses***

- Cemeteries: Includes cemetery grounds, roads, and buildings located on the grounds.

- Parks: Outdoor recreational areas including municipal playgrounds, botanical gardens, arboretums, golf courses, and natural areas.

- Undeveloped: Lands that are private or publicly owned with no structures and have an almost complete vegetative cover. This includes vacant lots, transformer stations, radio and TV transmission areas, water towers, and railroad rights-of-way (may be part of industrial areas if surrounding areas are such).

- ***Freeway Land Uses***

- Freeways: They are limited access highways and the interchange areas, including any vegetated rights-of-ways.

3.3.2 Little Shades Creek Watershed Land Use Characteristics

The Little Shades Creek Watershed (Figure 12) has an area of almost eight square miles and was about 70% developed at the time of these surveys (mid 1990s). It lies under the jurisdiction of several municipal governments (Hoover, Vestavia Hills, and Cahaba Heights) as well as the county government (Jefferson County), which made land development highly variable and uncoordinated. Many types of land developments are represented, even though the residential areas, mostly as single family residential units, are predominant. Table 5 shows the areas of the local planning agency categories in the watershed.

Table 5. Local Planning Agency Land Use Categories in Little Shades Creek Watershed

Land Use	Total Area (ha)	Total Area (ac)
Single family residential	1,462	3,611
Town homes	49	122
Multifamily residential	32	87
Schools and churches	44	109
Recreation	45	112
Public lands	2	5
Cemeteries	1.2	3
Open space	11	26
Office parks	25	62
Commercial areas	33	82
Industrial areas	4	9
Utility	0.8	2
Vacant land	400	989
Total	**2,112**	**5,218**

Sixteen land uses categories in the watershed were surveyed by investigating about 10 neighborhoods in each area. The predominant land use in the watershed was residential land, subdivided according to the density type, and age. All surveyed residential areas (high density, medium density, low density, apartments, and multi-family complexes) had pitched roofs that drained mainly to pervious surfaces with the only exception being multi-family areas. The soil is represented by sandy loam and silt loam soils, in about equal amounts. The land is mostly flat or with medium slopes. Some landscaping was present near the roads and was mostly lawns and evergreen shrubs. Streets and driveways had asphalt as the most common pavement material and had intermediate texture. The predominant drainage system was composed of concrete curbs and gutters in good or fair condition with a small percentage of grass swales in high and medium density residential areas.

Commercial land use was represented in the watershed by office parks and shopping centers with flat roofs draining mostly to impervious areas. Lawns and evergreen shrubs in excellent condition were found near the roads. The paved parking lots represented the largest connected impervious source areas. The runoff from the roofs drains directly to parking areas and then to the drainage systems that were mostly curbs and gutters in good condition. The streets, driveways and parking area were paved with asphalt having intermediate or smooth texture.

Schools and churches represented the institutional land use category of the watershed. The school roofs were flat and drained slightly more to impervious surfaces than to pervious areas. However, school playgrounds were mostly unpaved. Churches had pitched roofs that drained to impervious areas. Landscape areas had an even distribution of deciduous and evergreen shrubs. Lawns were near the streets. Streets and parking lots were paved with asphalt and had intermediate textures. The drainage systems had both grass swales and curbs and gutters, all in fair condition.

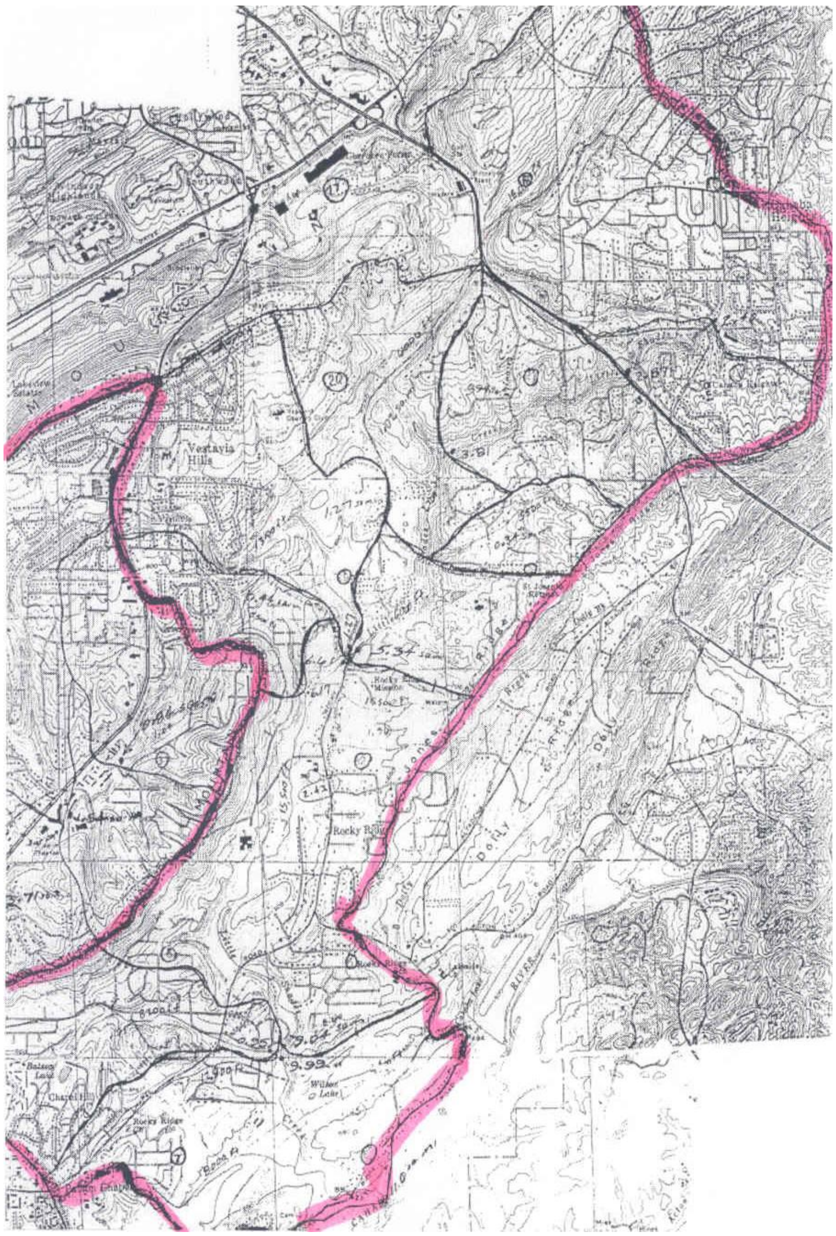


Fig. 12. Map of Lower Portion of the Little Shades Creek Watershed Study Area

The industrial land uses included a lumber manufacturing facility, several equipment storage and office complexes, a public mini-storage facility, a construction supply center, door manufacturer, and an automobile junkyard. The facilities were similar with all buildings being directly connected to the stormwater collection system. All facilities were closely bounded by other developments, roads, steep banks, and for one site, by Little Shade Creek. The industrial sites were relatively small, covering no more than a few acres and they were all dominated by parking and storage areas, and roofs.

The open space land use included parks, cemeteries, a golf course, vacant land, and areas under construction. The few roofs that were found in the vacant land use and golf course areas drained to pervious areas. The parking lots were paved and directly connected to the drainage system. The stormwater drainage system was a combination of curbs and gutters and grass swales.

The drainage system in the freeway land use was comprised of grass swales in the medians and at the shoulders. The pavement was asphalt, with a smooth texture.

3.3.3 Jefferson County Stormwater Permit Monitoring Sites Land Use Description

The sites that were used to re-validate the WinSLAMM model are in Jefferson County, AL, and are being monitored for the counties MS4 (municipal separate storm sewer system) stormwater permit program. This data is incorporated in the National Stormwater Quality Database (NSQD) database (Pitt et al. 2004; Maestre and Pitt 2005). About 10 events have been sampled at each of these areas by the Storm Water Management Authority of Jefferson County since 2001. Manual sampling was used, with composite samples collected during the first three hours of the rains. Each of the five sampling sites is described in the following paragraphs and in Table 6.

• ***Light Industrial (ALJC001)***. Drainage area is 138 ha (341 ac). The sampling location is in a drainage ditch running parallel to the railroad tracks near the 10th Ave. viaduct and 35th St. in Birmingham. The drainage ditch is a western tributary of the Cotton Mill Branch Creek within the Village Creek watershed. This area drains approximately 62% industrial property, 12% commercial land use (shopping centers), a small percentage of high-density residential (8.5%) and open space (6.4%) areas. About 11% of this watershed is represented by freeways.

• ***Heavy Industrial (ALJC002)***. Drainage area is 292 ha (721 ac). The sampling location is in a creek that discharges into Village Creek off Third St. W. in the vicinity of the East Thomas Railroad yards located along Finley Blvd., in Birmingham. Approximately 75% of the drainage area is industrial land use, while 14.5% is high-density residential, and a small percentage (2.5%) is represented by commercial land use and open space (6.7%).

• ***High-Density Residential (ALJC009)***. Drainage area is 42 ha (102 ac). The sampling location is at a 150-mm (60-in.) pipe downstream of a paved channel along Woodland Drive in the Edgewood community of Homewood, Ala. Most of the drainage area is comprised of residential lots 0.25 of an acre or less in size. A small portion of the land use within the basin is institutional (6.7%) and commercial (4.1%), which includes an elementary school, a small church, and a small strip commercial area consisting of small shops, restaurants, and a grocery store. This was found to be typical for many dense residential neighborhoods where small isolated institutional and commercial land uses are not large enough to be assigned separate land use categories.

- ***Low-Density Residential (ALJC010)***. Drainage area is 54 ha (133 ac). The sampling location is in a paved channel along Ponderosa Circle in the Tanglewood subdivision of Vestavia Hills, Ala. The drainage area is almost entirely residential lots greater than a third of an acre (82.5%), except for a small portion of undeveloped land (17.5%) on a steep slope that is wooded with heavy cover. This sampling point is on a designated blue line on the U.S. Geological Survey quad map; however, this was not a perennially flowing stream.

- ***Commercial Mall (ALJC012)***. Drainage area is 92 ha (228 ac). The sampling location is at a large culvert running under Highway 31 just south of where the highway intersects Highway 150, in Hoover, Ala. Most of the drainage basin is composed of strip shopping centers and a fragment of the Riverchase Galleria shopping mall, except for some apartments that make up 25% of the drainage area along with some undeveloped woodland, which is 5% of the drainage area.

3.4 Data Processing

3.4.1 Aerial Photograph Measurements

The second step in this study was the aerial photograph data processing, using GIS Tools and statistical tools (Excel, MINITAB, and SigmaPlot). After the field data description sheets were filled out during each neighborhood survey, the corresponding aerial photographs from TerraServer USA and satellite images provided by Storm Water Management Authority in Birmingham were examined, and the individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc) were measured using GIS Tools (ArcGIS 9.0). The aerial photograph area measurements were tabulated and summarized in Excel spreadsheets. These data were used to build the WinSLAMM files to describe each land use area.

The aerial photograph measurements for Little Shades Creek Watershed were provided by the earlier USDA study. This information was manually measured from the aerial photographs and recorded on "Aerial Photograph Area Measurements" data sheets, one sheet for each site surveyed. An example of this measurement sheet is shown in Figure 13.

The first step in the study of the Jefferson County monitoring watersheds was to procure the satellite imagery taken during 2001 and 2003, plus the watersheds paper maps from SWMA. All images were originally purchased from Space Imaging and acquired by IKONOS Satellite imagery which is a high-resolution satellite operated by Space Imaging LLC. IKONOS produces 1-meter black-and-white (panchromatic) and 4-meter multi-spectral (red, blue, green, near infrared) imagery that can be combined in a variety of ways to accommodate a wide range of high-resolution imagery applications. The satellite was launched on September 24, 1999 and has been delivering commercial data since early 2000. It was the first commercial satellite to deliver photographic high resolution satellite imagery of anywhere in the world. Its applications include both urban and rural mapping of natural resources and of natural disasters, tax mapping, agriculture and forestry analysis, mining, engineering, construction, and change detection. Space Imaging's IKONOS earth imaging satellite has provided a reliable stream of image data that has become the standard for commercial high-resolution satellite data products.

Table 6. Jefferson County AL, MS4 Watersheds: Source Areas by Land Use (Percentages, Unless Otherwise Noted)

High-Density Residential

Watershed ID	Curb mile/ 100ac	Street	Driveways, paved and connected	Driveways, paved and disconnected	Parking, paved and connected	Play-ground, unpaved	Front land-scaped	Back land-scaped	Large turf	Undeve-loped	Roof drained to imper-vious	Roof drained to pervious	Total*
ALJC001	7.8	21	0.0	0.0	0.0	0.0	26	30	0.0	0.0	0.0	23	100
ALJC002	12	24	1.8	1.8	0.23	0.21	17	29	5.9	6.8	3.8	9.9	100
ALJC009	10	20	1.6	1.6	0.0	0.0	25	34	0.0	0.0	6.9	11	100

Medium-Density Residential

Watershed ID	Curb mile/ 100ac	Street gutter	Driveways, paved and connected	Driveways, paved and disconnected	Front landscaped	Back landscaped	Roof drained to impervious	Roof drained to pervious	Other pervious	Total*
ALJC010	11.1	23.3	2.6	2.6	32	24	7.8	7.0	0.0	100

Residential Land Use: Apartments

Watershed ID	Curb mile/ 100ac	Street	Parking, paved and connected	Storage, paved	Large turf	Undeve loped	Roof drained to impervious	Roof drained to pervious	Other pervious	Total*
ALJC012	5.3	12	15	0.0	0.0	0.0	14	0.0	60	100

Commercial Land Use

Watershed ID	Curb mile/ 100ac	Street	Parking, paved and connected	Parking, unpaved	Storage, paved	Front landscaped	Back landscaped	Large turf	Undeve loped	Roof drained to impervious	Roof drained to pervious	Total*
ALJC001	6.8	23	37	0.97	1.3	3.6	2.9	0.0	16	15	0.0	100
ALJC002	12	25	47	0.0	1.6	0.0	0.0	1.7	8.2	16	0.0	100
ALJC009	7.7	31	38	0.0	0.0	0.0	0.0	0.0	0.0	31	0.0	100
ALJC012	4.7	16	36	0.0	5.7	0.0	0.0	28	0.0	14	0.0	100

Table 6. – *Continued6*

Institutional Land Use

Watershed ID	Curb mile/ 100ac	Street	Driveways, paved and connected	Driveways, paved and disconnected	Parking, paved and connected	Play-ground, paved	Play-ground, unpaved	Front land-scaped	Back land-scaped	Large turf	Roof drained to impervious	Total*
ALJC002	9.6	30	0.0	0.0	19	0.0	18	21	0.0	3.5	9.3	100
ALJC009	8.0	14	7.0	7.0	17	12	8.3	3.0	8.1	0.0	23	100

Industrial Land Use

Watershed ID	Curb mile/ 100ac	Street	Parking, paved and connecte d	Parking, unpaved	Storage , paved	Storage, unpaved	Large turf	Undeve - loped	Roof drained to impervious	Roof drained to pervious	Railroa d Tracks	Pond	Other pervi ous	Total*
ALJC001	9.6	25.6	45	3.9	0.0	0.0	0.0	5.3	19	1.3	0.0	0.0	0.0	100
ALJC002	4.9	17	22	16	8.0	4.9	3.6	4.6	15	3.6	3.8	0.47	1.3	100

Open Space/Undeveloped Land Use

Watershed ID	Curb mile/ 100ac	Street	Large turf	Undeveloped	Other pervious	Total*
ALJC001	4.8	14.1	39.5	46.5	0.0	100
ALJC002	7.6	18	30	0.0	52	100
ALJC010	0.0	0.0	0.0	0.0	100	100

Freeway Land Use

Watershed ID	Curb mile/ 100ac	Street	Parking, paved	Parking, unpaved	Large turf	Undeveloped	Other pervious	Total*
ALJC001	0.0	55	0.0	0.0	45	0.0	0.0	100

The second step was the electronic delineation of the five watersheds using the map digitizing technique and GIS tools. The multi-spectral image (“Jefferson.sid”; raster format “MrSID,” number of raster bends: 3) of Jefferson County and the paper maps of the watersheds were used to manually digitized and then cut each one of the five watersheds using ArcGIS 9 (ArcMap). Each watershed was saved separately as a shape file (.SHP) giving the matching name (ALJC001, ALJC002, etc).

The multi-spectral Jefferson.sid image was originally NAPP (National Aerial Photography Program) aerial photos which SWMA further processed. Aerial photography of Jefferson County was obtained during flights in 1999. Film negatives were purchased by SWMA from the USGS and were scanned and saved into digital format, orthorectified and sid’ed into USGS quad arrangements (one singular layer). They were not scanned by a metric scanner (which would have resulted in sharper and more precise output image; this should be considered for further research in this area)

The National Aerial Photography Program was initiated in 1980 and coordinated by USGS. The purpose was to acquire aerial photography of 48 “conterminous” (contiguous) states, every five years. They were acquired at 20,000 feet elevation and centered on 1:24,000 scale USGS maps. They are centered on USGS ¼ quads – eight frames make up one USGS quadrangle map. Each frame represents 32.3-square miles at 2-feet pixel. Final output should be digital ortho quarter quads (DOQQ) and revised approximately every five years. For more information about NAPP see: http://edcwww.cr.usgs.gov/glis/hyper/guide/napp

The next step used the two 1-meter panchromatic satellite images (“Leafoff.img” flown December 2000 and “Leaffon.img”, flown summer 2001; raster format “ERDAS

Little Shades Creek Stormwater Study - Site Characteristics

Site #: 66 Land use: Single-Family Zoning: R-1 Govt: Vest.

Description: High density buildings

Location: Chestnut Road

Total area: 11.6 ha.

Total number of units in area: 31 Density: 2.67 /ha

Streets: Total street length: 992.2 m Street length density: 85.53 m/ha

Average street width: 6.05 m Street area: 6007.8 m^2

Street area density: 517.48 m^2/ha

Grass area between sidewalk and street: width: ____ m length: ____ m

area: ____ m^2 density: X m^2/ha

Sidewalk: width: ____ m length: ____ m area: ____ m^2 density: X m^2/ha

Front landscaping: average per unit 2350 m^2 x 31 # units = 72838 m^2

density: 6279 m^2/ha

Driveways: avg. per unit 78.65 m^2 x 31 # units = 2438.15 m^2 density: 210.19 m^2/ha

100 % paved; 210.19 m^2/ha

0 % unpaved; 0 m^2/ha

Parking areas: ____ m^2 density: X m^2/ha 5429.8

____ % paved; X m^2/ha

____ % unpaved; X m^2/ha

Storage areas: ____ m^2 density: X m^2/ha

____ % paved; X m^2/ha

____ % unpaved; X m^2/ha

Playgrounds: ____ m^2 density: X m^2/ha

____ % paved; X m^2/ha

____ % unpaved; X m^2/ha

Fig. 13. Site 66 Example of "Aerial Photograph Area Measurements" Sheet

IMAGE", number of raster bands: 1) of Jefferson County to overlap and after that cut the corresponding satellite image for each watershed.

These images were purchased by SWMA from Space Imaging and have been assembled into mosaics into PLSS –Township (Public Land Survey System) arrangement. It is complete for the entire county area, but with cloud obstructions in some areas. The overlapping/cutting process made use of GIS Tools: ArcInfo, ArcToolbox and ArcMap 8.9. Each image was saved separately (.IMG extension) having the equivalent name of the watershed.

Appendix B shows the map of Jefferson County and the relative position of those five watersheds, along with their corresponding paper maps and raster images (satellite images). The satellite image measurement process was initially used to describe the different land uses within the watersheds. For residential land uses, the most visible neighborhoods (having minimal tree cover) were selected and their individual elements were electronically measured. However, for industrial, commercial, and institutional areas, it was necessary to take account of all the elements incorporated into the land use due to greater variabilities of the different surface cover areas. The areas of the individual elements were calculated using ArcGIS and stored in the shape file attribute table.

3.4.2 Data Measurements Storage and Processing

The older Little Shades Creek area measurements manually obtained from aerial photographs were recorded on paper sheets and then manually transferred into electronic format (Excel Worksheet). Normalizing of the actual area measurements so they summed

100% was used to account for minor rounding errors. The normalized data (percentages) were then used to build the WinSLAMM files (Table 4).

The individual elements of the five Jefferson County watersheds were measured in square feet units and recorded directly in an electronic format (.dBASE IV). For easier handling of the data, these files were later converted into Excel Worksheet files. Data normalizing was also performed to account for rounding errors. The normalized areas, which were used to build the WinSLAMM files, are presented in Table 6.

3.5 Discussion

Urban stormwater flow discharges to receiving waters are most directly related to watershed imperviousness. It is generally found that stream degradation starts of occur at low levels of imperviousness (about 10 to 15%), where sensitive stream elements are lost from the system. There is a second threshold at around 25 to 30% impervious cover, where most indicators of stream quality change to a poor condition (Schueler 1994).

3.5.1 Surface Covers in the Little Shades Creek Watershed

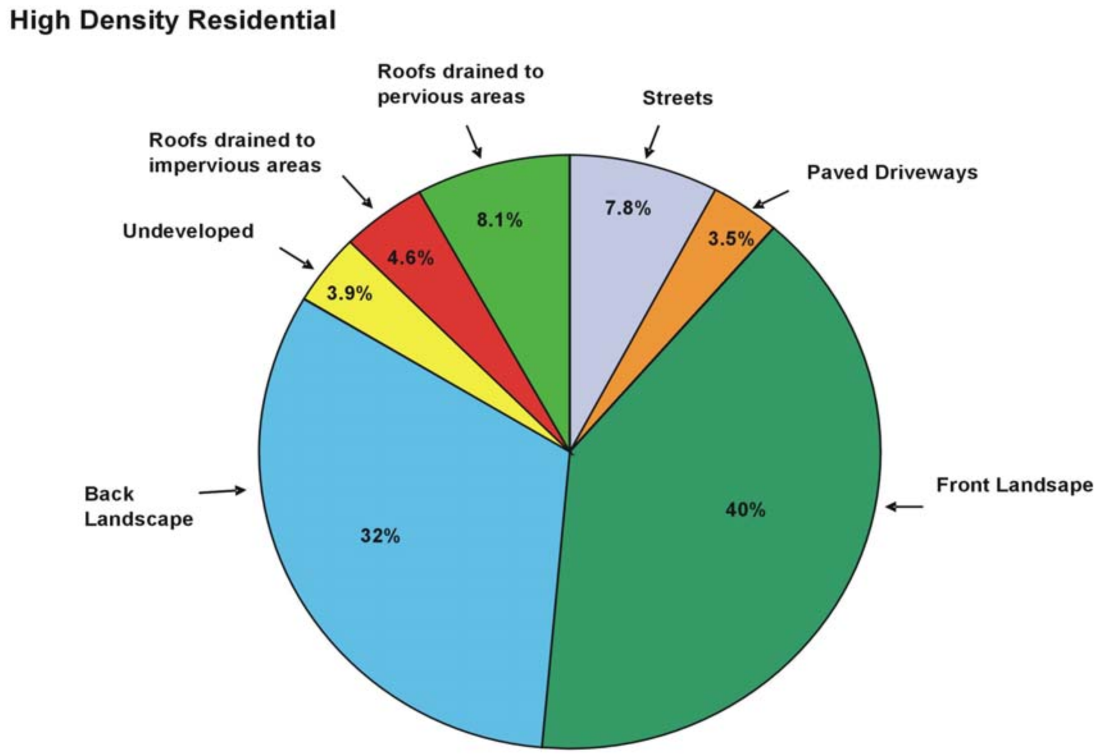
The Little Shades Creek watershed is comprised of 16 major land use categories. More than 125 neighborhoods were surveyed by the USDA Earth Team volunteers in order to determine the surface covers in this watershed, for each land use. Figures 14-18 contains multiple pie charts showing the distribution of the average source area coverage for each land use. There was a similarity observed in the source area distributions for the different residential areas: the main source areas were the landscaped areas- front landscape areas for high and medium density residential areas, and back landscaped areas for low density residential areas. In the case of apartment complexes and multi family housing units, the landscape areas are still the main source areas, but parking lots, streets and roofs comprise larger fractions of the total area than for the other residential areas. In commercial land use areas (strip commercial and office parks), source areas are about equally divided among parking lots, directly connected roofs, streets and front landscaped areas. However, for institutional land use subcategories (schools and churches) there is an evident distinction between the two types of areas. For the school areas, streets and parking areas do not comprise much of the total area; the predominant source area being unpaved playgrounds and large turf area, along with landscaped areas. In contrast, in the church land use area, the dominant impervious surfaces are parking lots and streets, which are slightly larger in area than the total pervious areas. In the light industrial land use area in the Little Shades Creek watershed, the major source areas are the landscaped areas, followed by hard surfaces (such as paved storage areas, parking lots, and streets). In freeways lands use areas the impervious surfaces (street and shoulder areas) make up more than half of the source areas. As expected, in open space land use areas, pervious areas are the predominant surface cover.

Figure 19 shows the variability of the source areas for each land use. For a typical residential area, more than half of the area is covered by landscapes surfaces which will likely be the major runoff source area. The percentage of residential areas covered by front landscape ranges between 20 and 50%. For a typical shopping center land use, the landscape area is expected to range from 0 to 50% of the land use, with an average of 30%, while for office park areas, the landscape areas are expected to be present in a range between 5 and 35% of the total area. In institutional land uses, the expected parking area for schools is between 2 and 8% of the total area, while in the church land use, the paved parking areas are in a range of 20 to 40%. In the industrial land use area, a large variation can be expected in the storage areas (0 to 40%). These large variations are likely to result in large variations in runoff discharges for each individual area. However, most modeling approaches only use an average value when calculating runoff characteristics, ignoring the likely variation inherent in the runoff for different areas represented by the same land use category.

3.5.2 Expected Biological Conditions as a Function of Impervious Areas in Little Shades Creek Watershed

These data show that the Little Shades Creek watershed in Birmingham, Alabama has a watershed impervious cover of about 35%, of which about 25% is directly connected to the drainage system and 10% drains to pervious areas (Table 7). As expected, the land use with the least impervious cover is open space (parks, cemeteries, golf course), and the land uses with the largest impervious covers are commercial areas, followed by industrial areas (Figures 14-18 and 19).

WinSLAMM was used to investigate the relationship between watershed and runoff characteristics for each of the individual 125 neighborhoods investigated. An example evaluation is shown on Figures 20 and 21 which illustrate the relationships between the directly connected impervious area percentages and the calculated volumetric runoff coefficients (Rv) for each land use category (using the average land use characteristics), based on 43 years of local rain data. As expected, there is a strong relationship between these parameters for both sandy and clayey soil conditions.



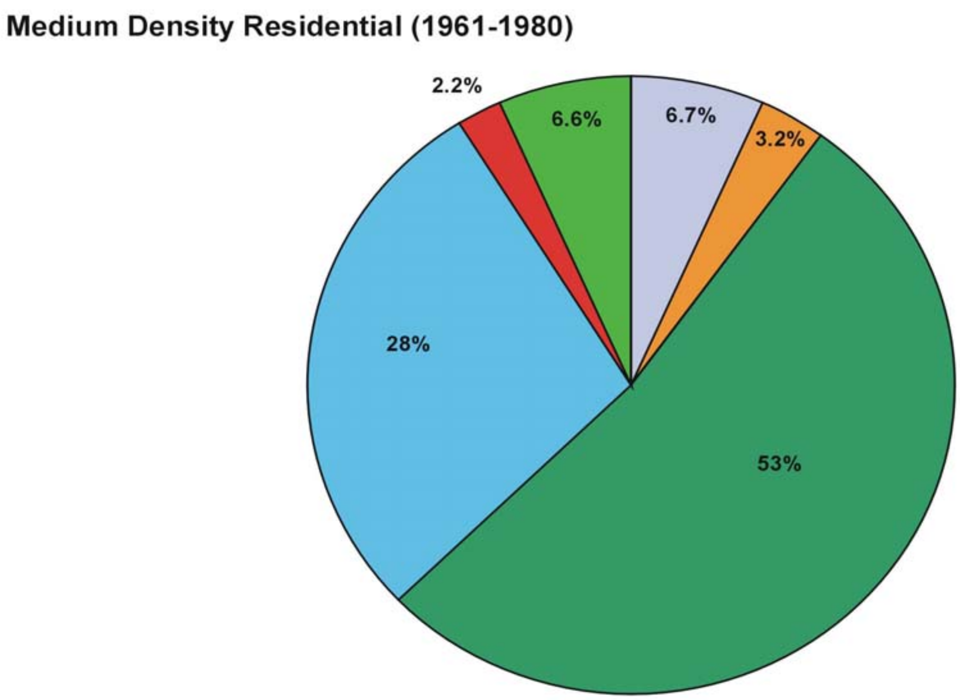
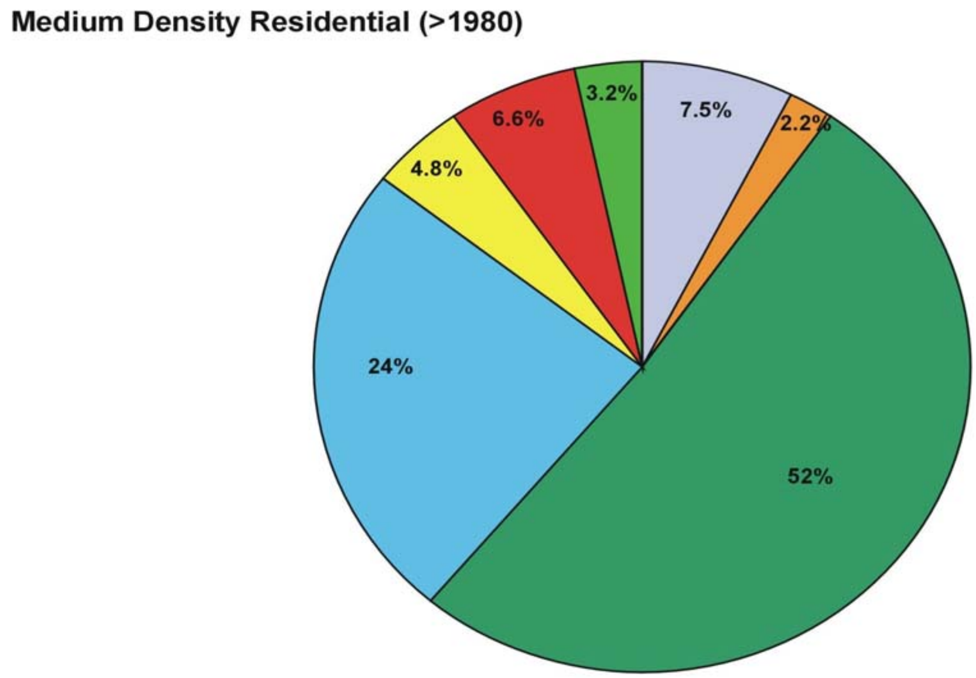


Fig. 14. Little Shades Creek Watershed: Source Area Distribution for Residential Land Use Areas



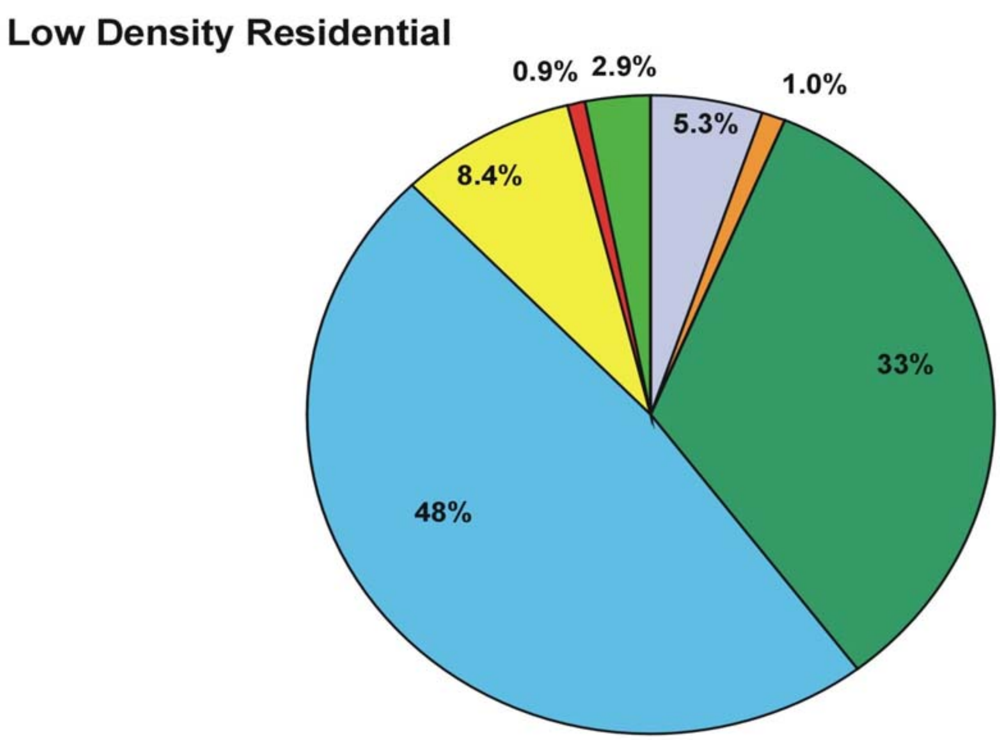
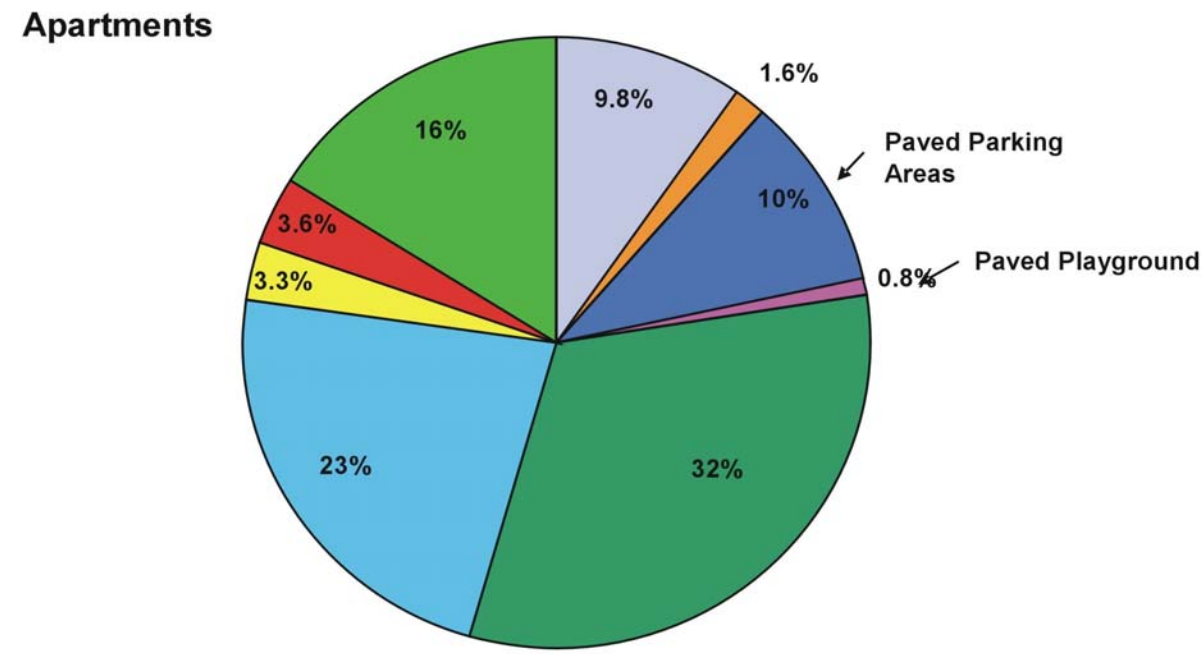
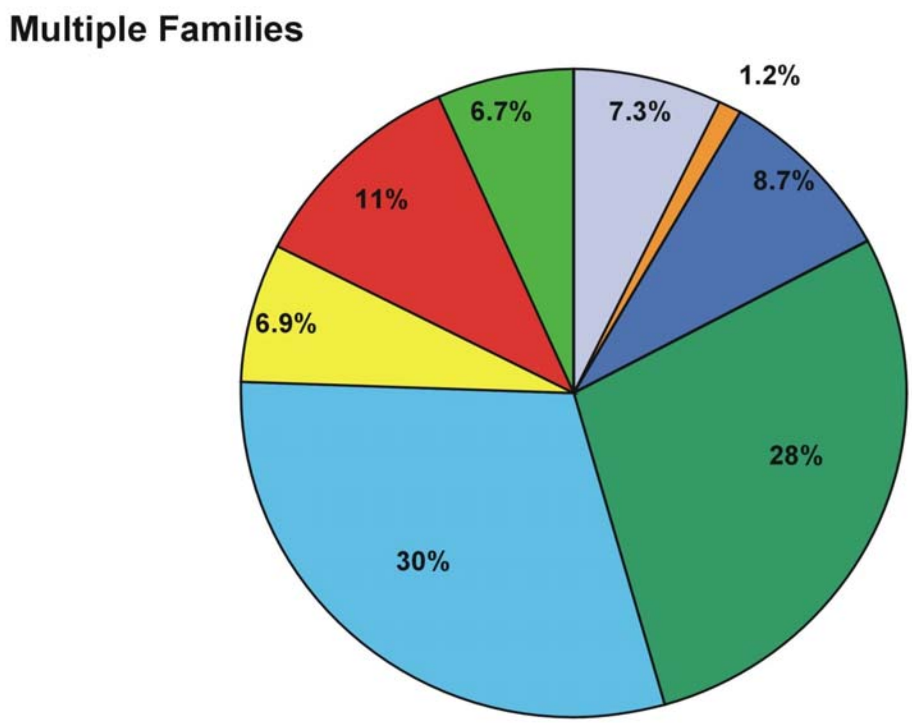


Fig. 14. - *Continued*





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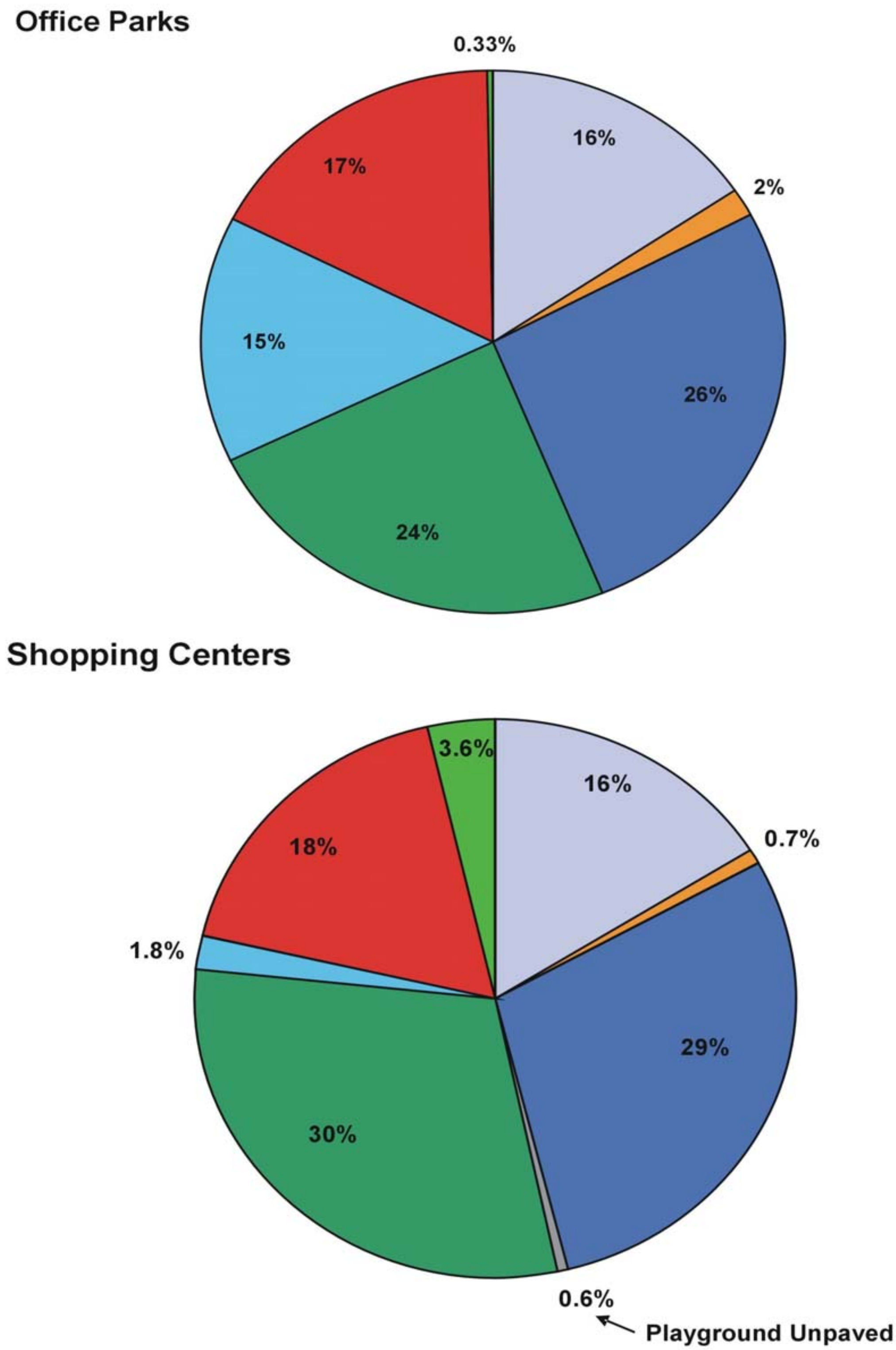


Fig. 15. Little Shades Creek Watershed: Source Area Distribution for Commercial Land Use Areas

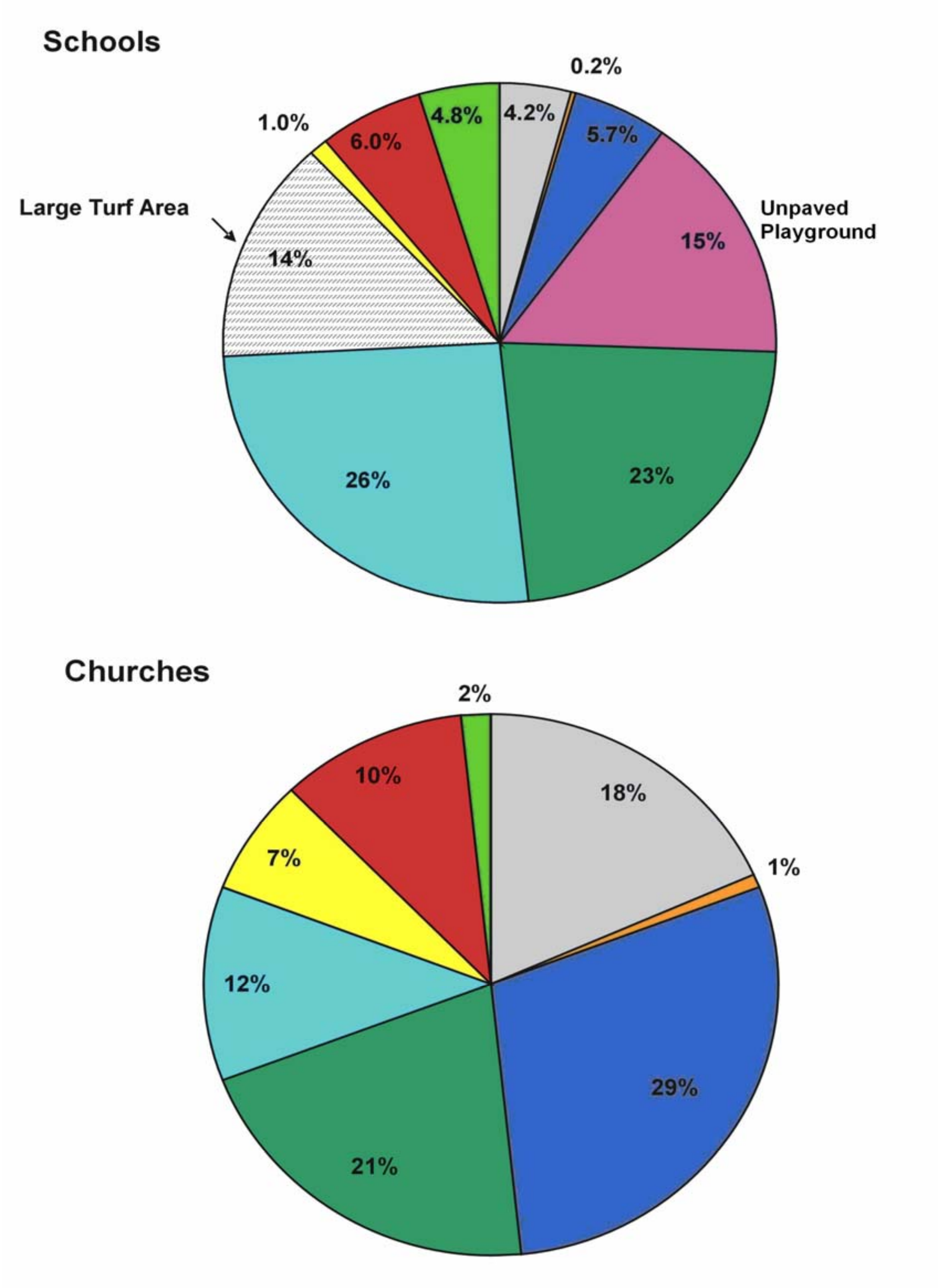
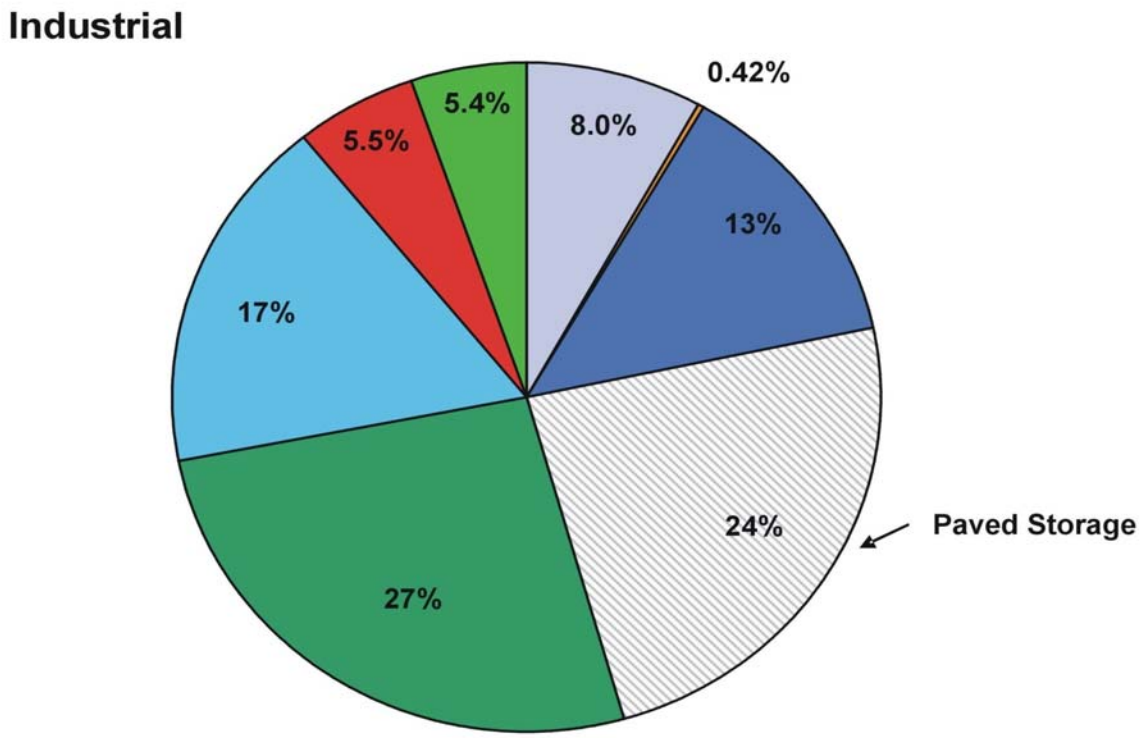


Fig. 16. Little Shades Creek Watershed: Source Area Distribution for Institutional Land Use Areas



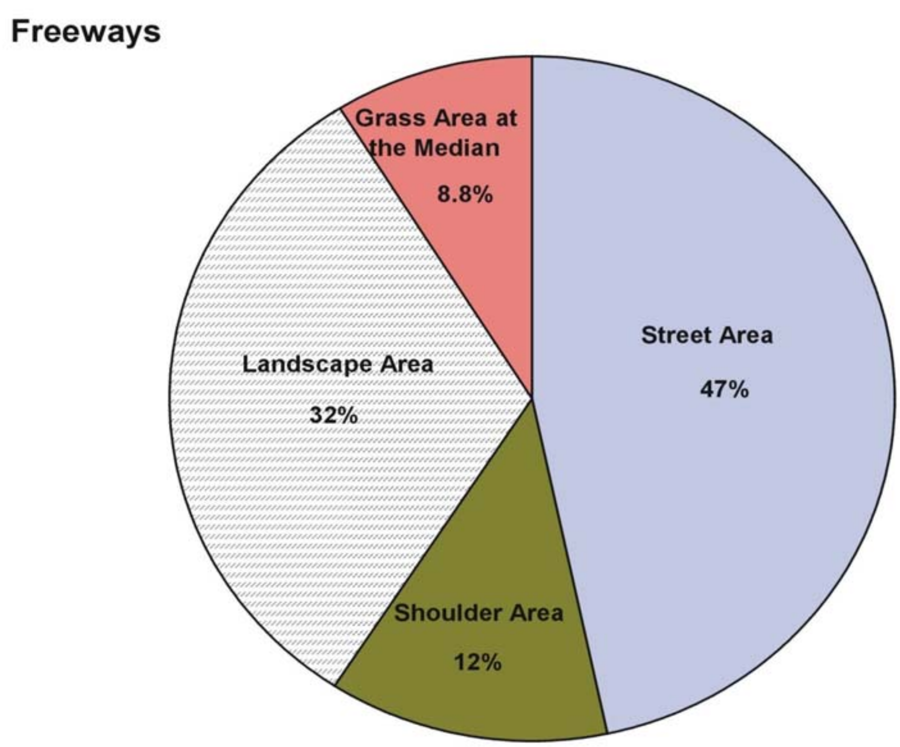


Fig. 17. Little Shades Creek Watershed: Source Area Distribution for Industrial and Freeway Land Use Areas

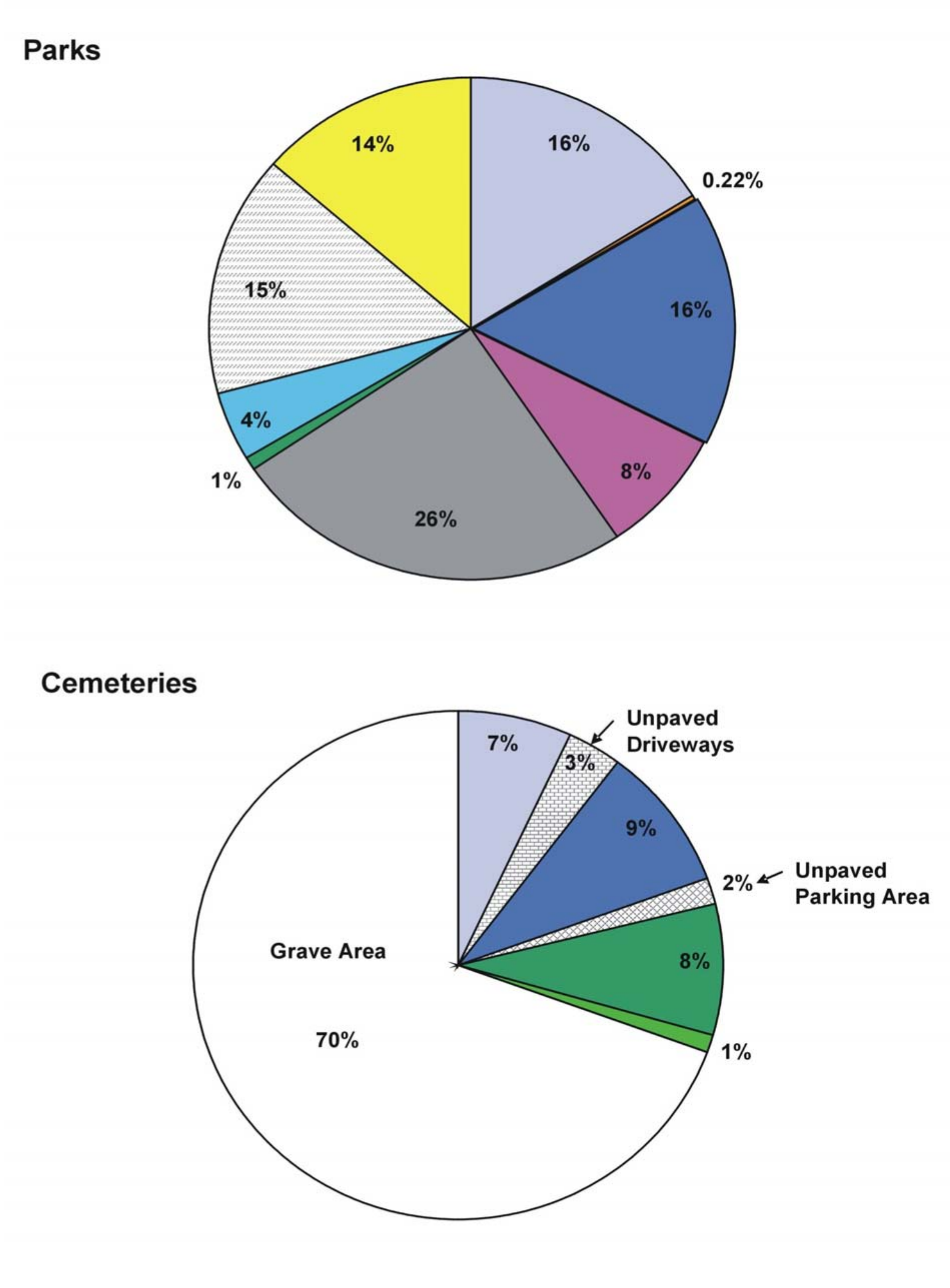


Fig. 18. Little Shades Creek Watershed: Source Area Distribution for Open Space Land Use Areas

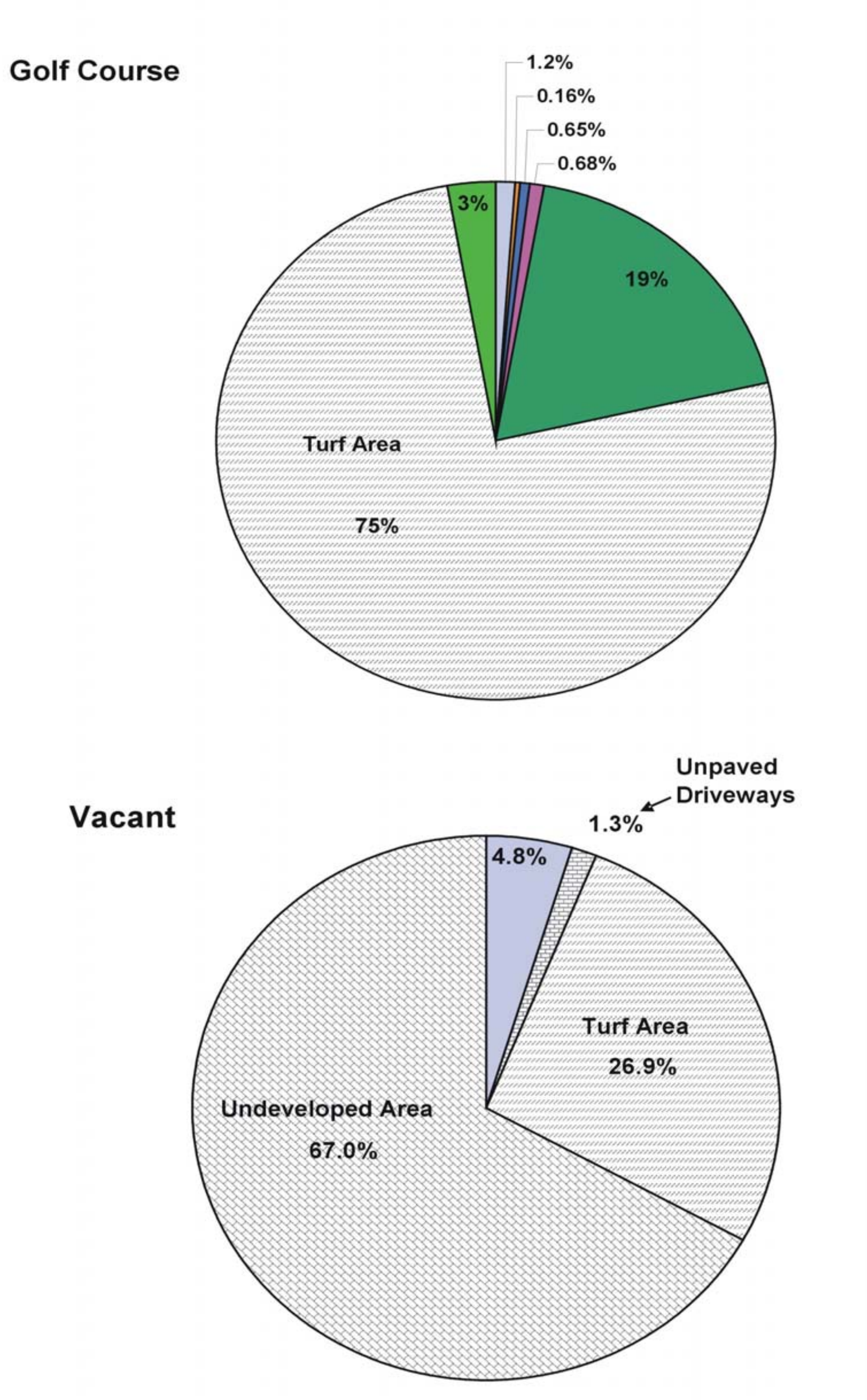
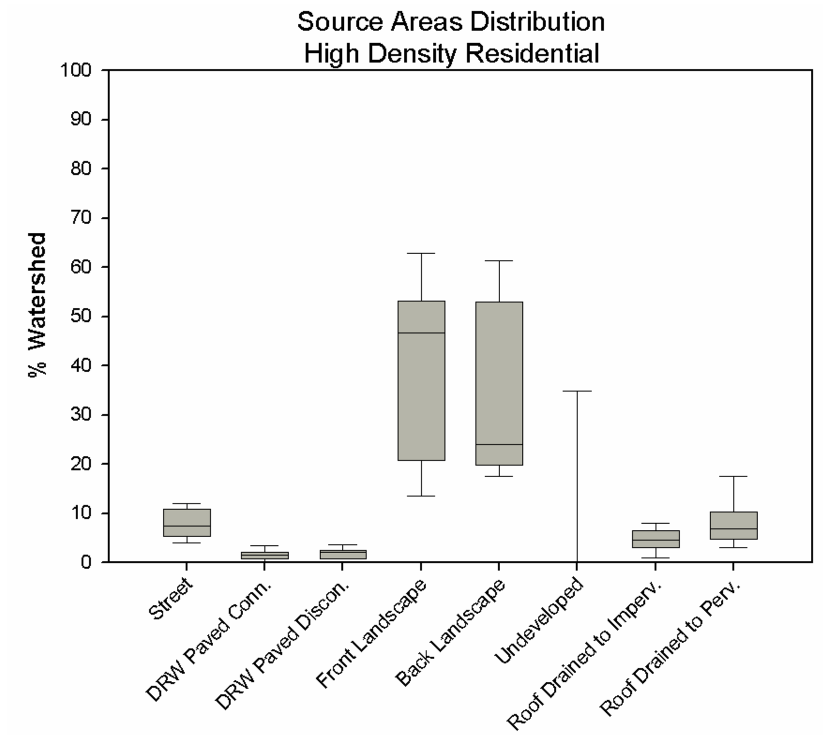


Fig. 18. - *Continued*



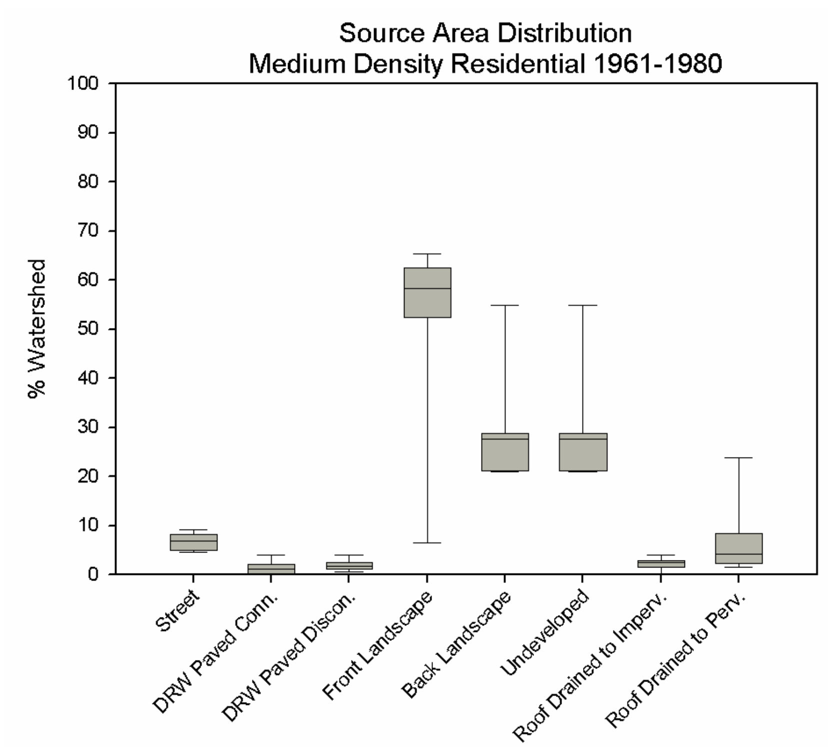
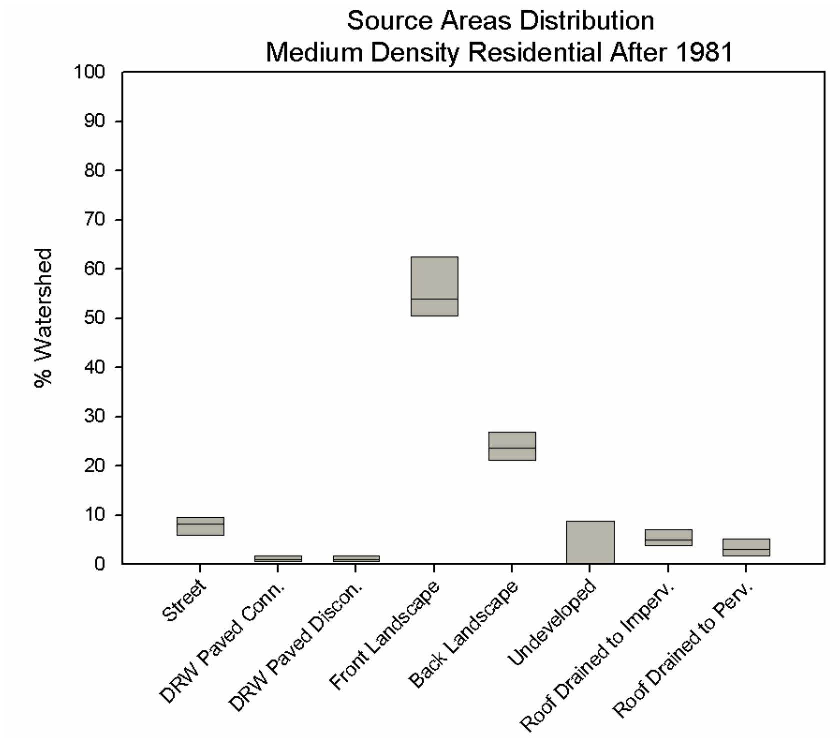
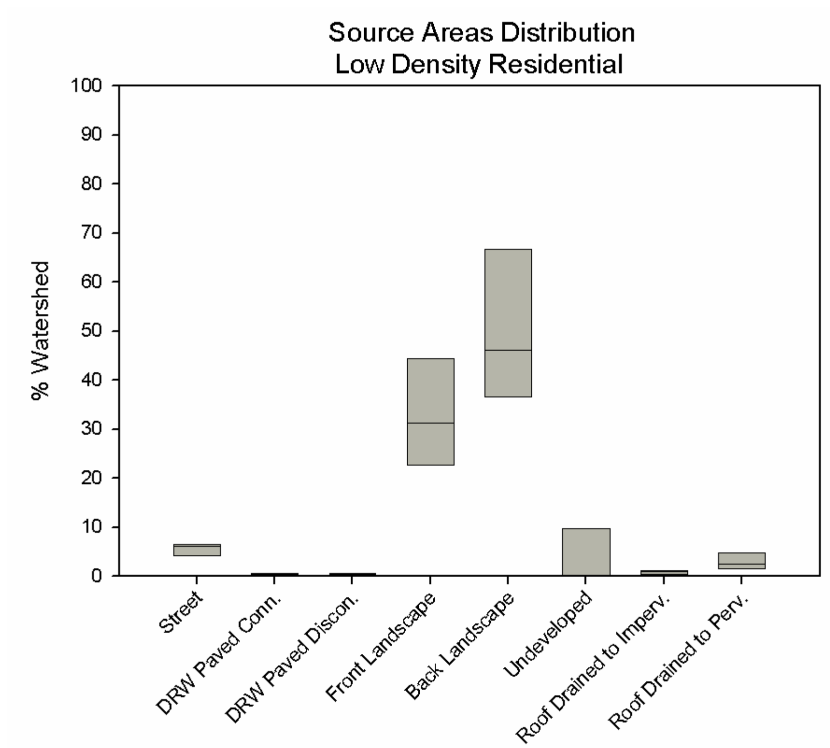


Fig. 19. Little Shades Creek Watershed: Source Area Distribution Variations





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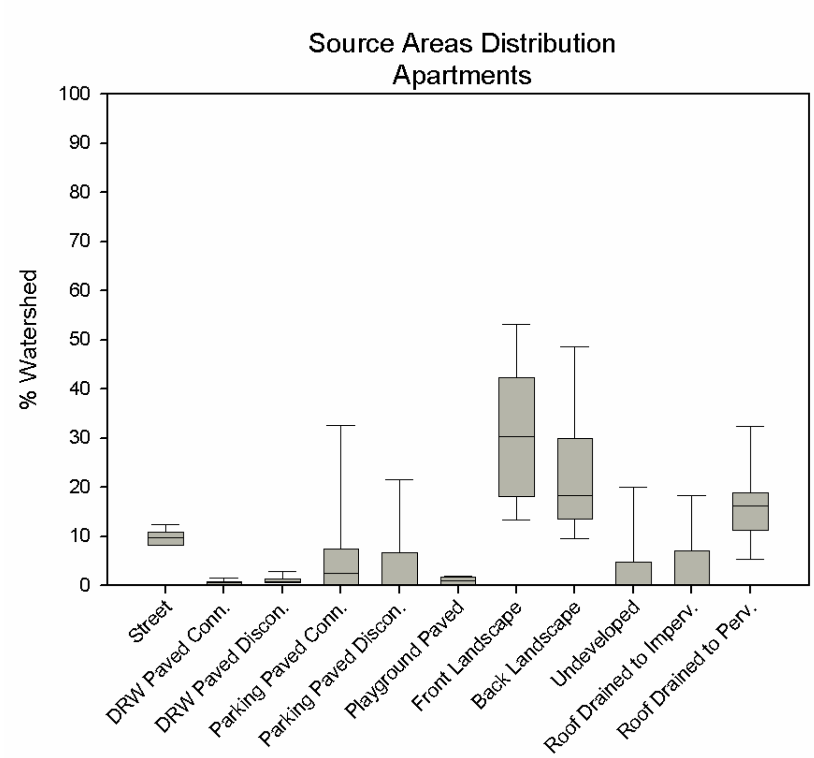

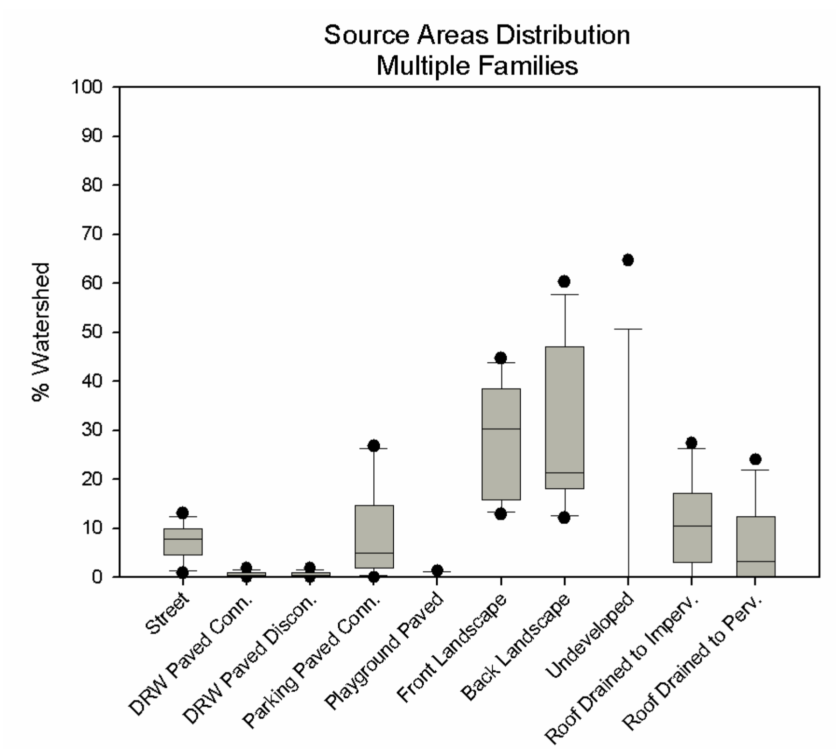

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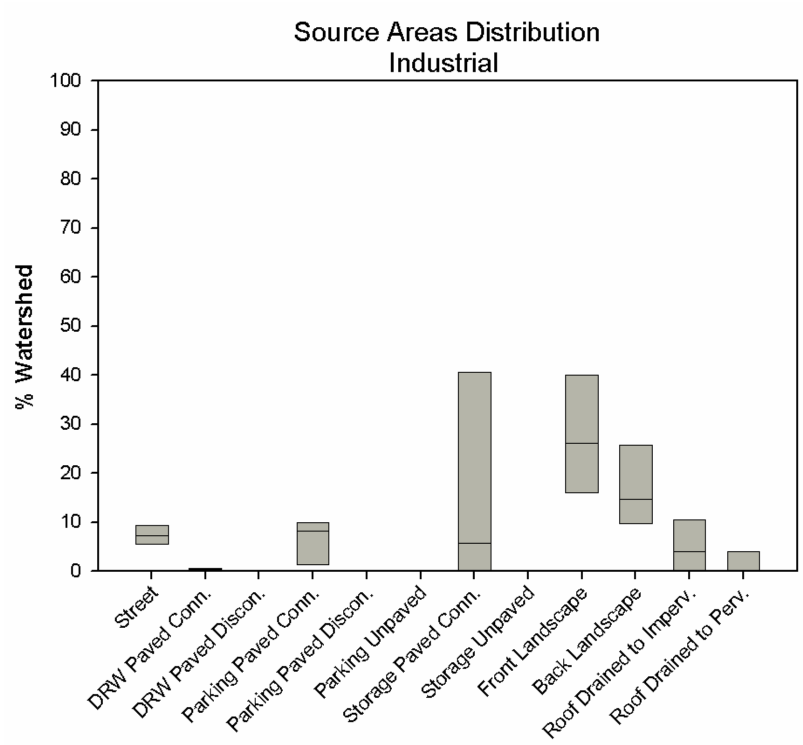

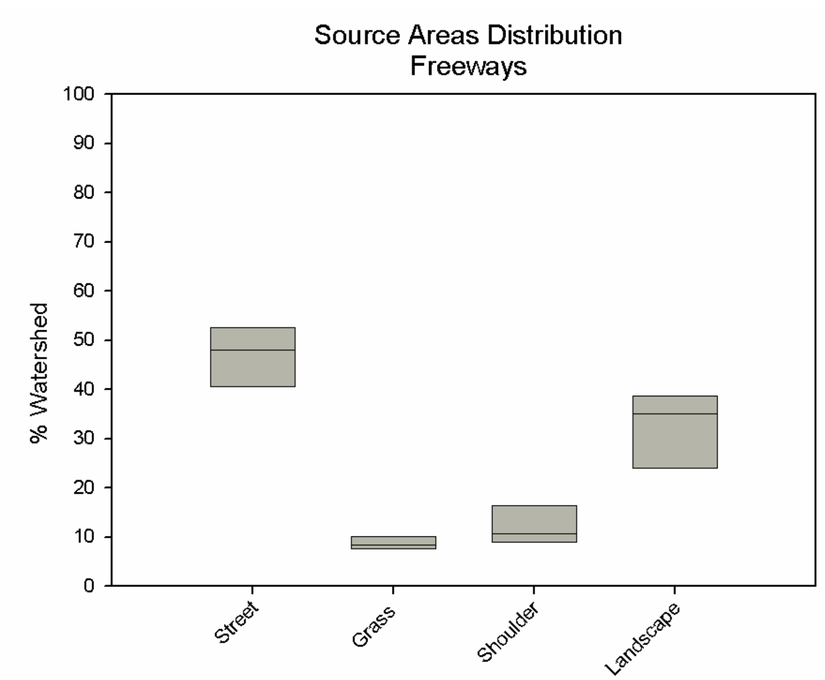

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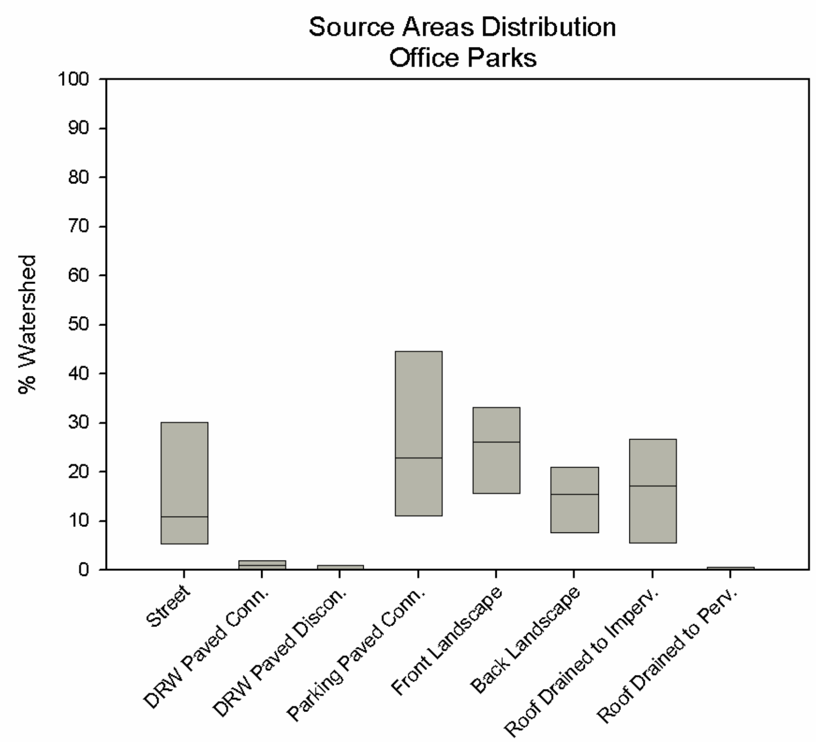

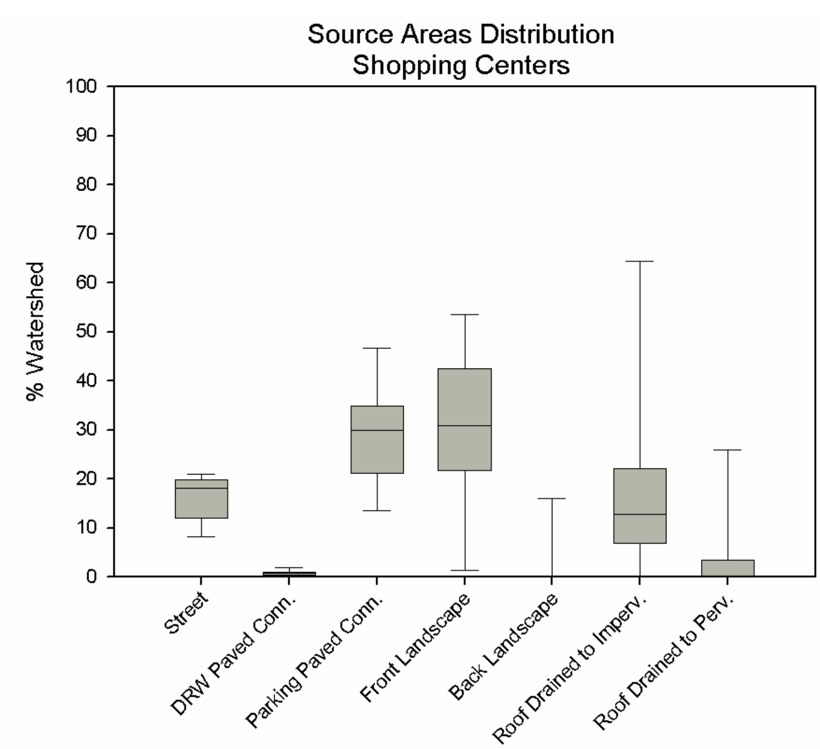

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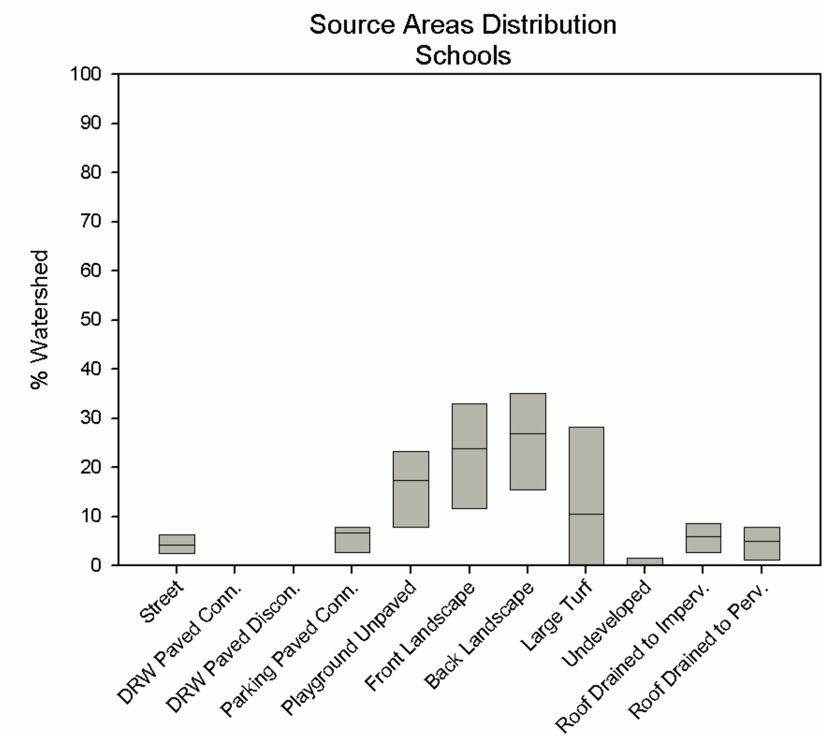

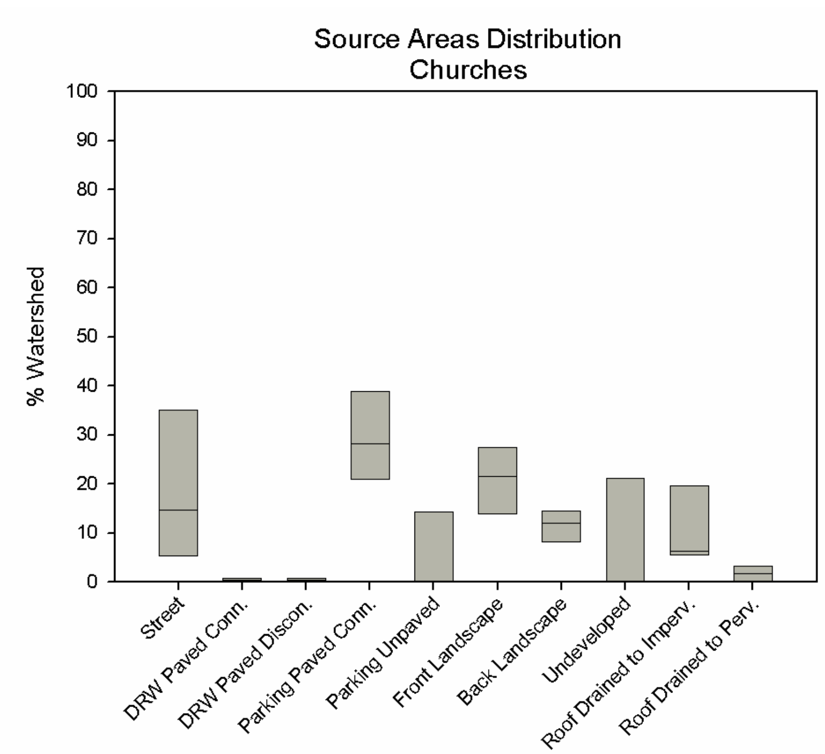

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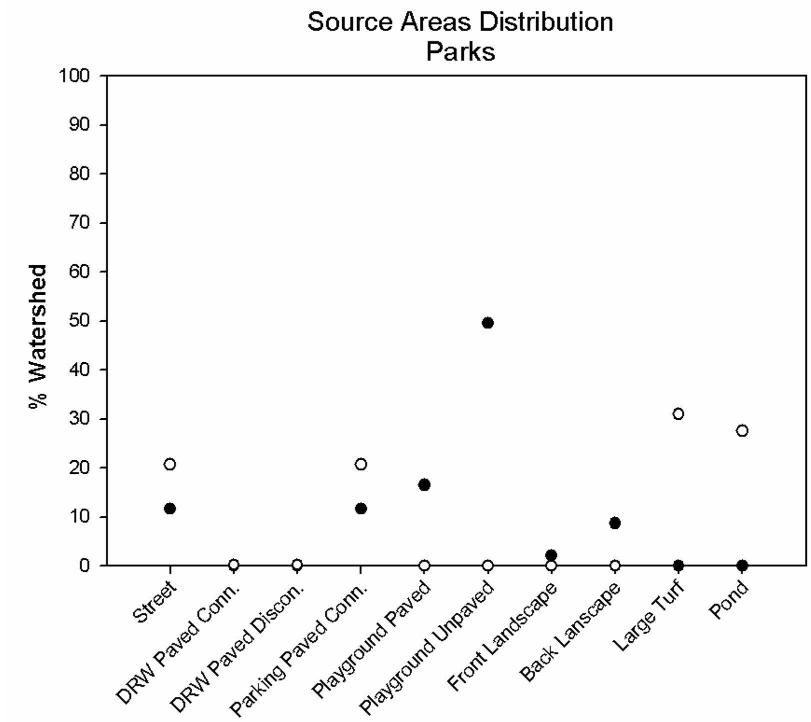

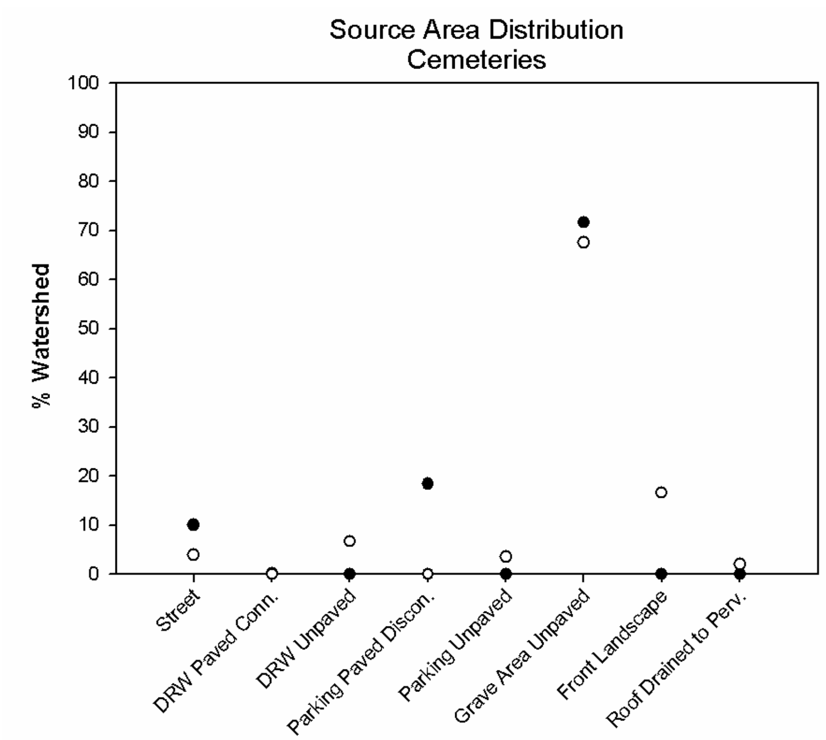

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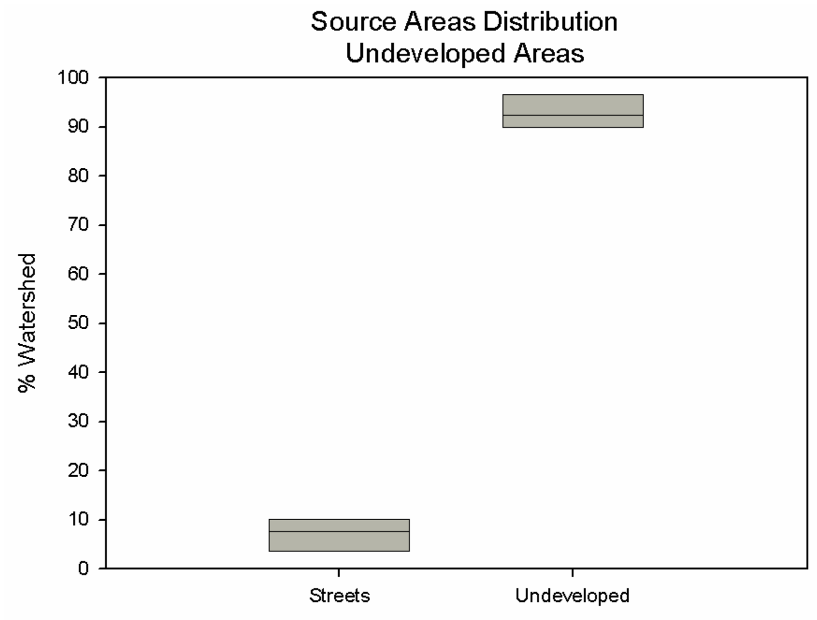


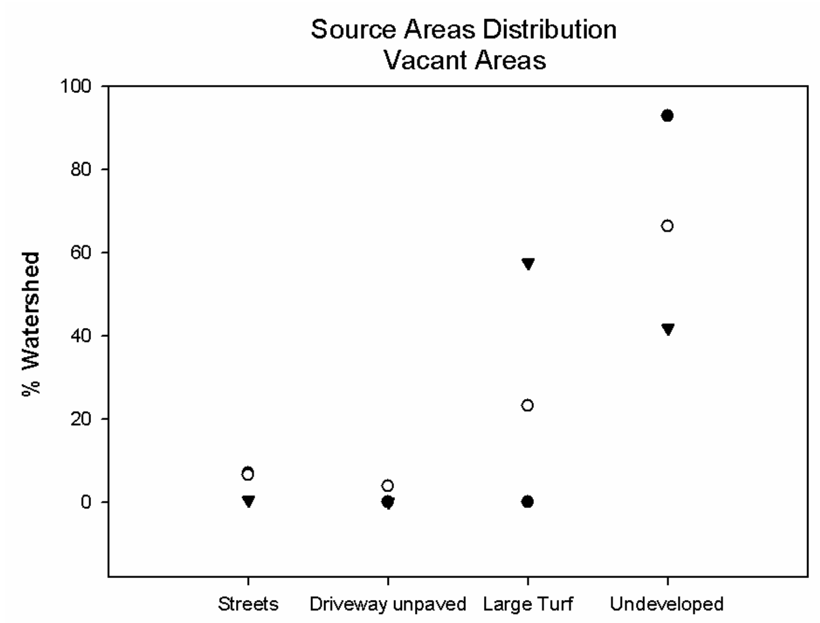


Fig. 19. - Continued

The fitted exponential equations are:

$$\text{Sandy soils:} \quad y = 0.062e^{0.031x} \ (R^2 = 0.83)$$

$$\text{Clayey soils:} \quad y = 0.15e^{0.017x} \ (R^2 = 0.72)$$

Where y is the volumetric runoff coefficients (Rv) and x is the directly connected impervious areas (%) for the areas. It is interesting to note that the Rv is relatively constant until the 10 to 15% directly connected impervious cover values are reached (at Rv values of about 0.07 for sandy soil areas and 0.16 for clayey soil areas), the point where receiving water degradation typically is observed to start. The 25 to 30% directly connected impervious levels (where significant degradation is observed), is associated with Rv values of about 0.14 for sandy soil areas and 0.25 for clayey soil areas, and is where the curves start to greatly increase in slope.

The Storm Water Management Authority of Jefferson County recently conducted biological and habitat surveys in Little Shades Creek in this study area at five locations. These mid summer and early spring surveys were used to verify the assumed relationship between impervious areas and biological conditions for this watershed. They found that the receiving water conditions were already substantially degraded due already to the large amounts of runoff the creek is receiving in all test reaches. WinSLAMM was also modified to track the amounts of directly connected and partially connected impervious areas in modeled areas, along with predicting equivalent directly connected impervious amounts for different stormwater control scenarios. The model calculates outfall flow rates and can present this information in flow-duration probability curves to also assist stormwater managers in predicting receiving water responses to alternative stormwater management programs.

Table 7. Little Shade Creek Watershed, Birmingham, AL Source Area Drainage Connections by Land Use (values are normalized for each land use)

Land Use	Pervious Areas (%)	Directly Connected Impervious Areas (%)	Disconnected Impervious Areas (%) (draining to pervious areas)	Volumetric Runoff Coefficient (Rv) if Sandy Soils	Volumetric Runoff Coefficient (Rv) if Clayey Soils
High Dens. Residential	76	13	11	0.09	0.17
Med. Dens. Residential (<1960)	82	9.1	9.2	0.06	0.14
Med. Dens. Residential (1961-80)	81	8.8	10	0.07	0.15
Med. Dens. Residential (>1980)	82	14	4.3	0.09	0.17
Low Dens. Residential (drained by swales)	90	4.9	5.2	0.05	0.17
Apartments	58	16	26	0.09	0.17
Multi Family	65	27	7.4	0.13	0.14
Offices	39	57	4.6	0.41	0.43
Shopping Centers	33	64	3.6	0.43	0.47
Schools	79	16	4.9	0.12	0.17
Churches	44	54	2.1	n/a	n/a
Strip Commercial	7.9	88	4.3	0.60	0.61
Industrial	54	36	11	0.46	0.49
Parks	59	32	8.4	0.29	0.34
Cemeteries (drained by swales)	83	0.0	17	0.08	0.16
Golf Courses (drained by swales)	95	1.9	3.5	0.04	0.15
Freeways (drained by swales)	41	0.0	59	0.08	0.26
Vacant (drained by swales)	95	0.0	4.8	0.06	0.17

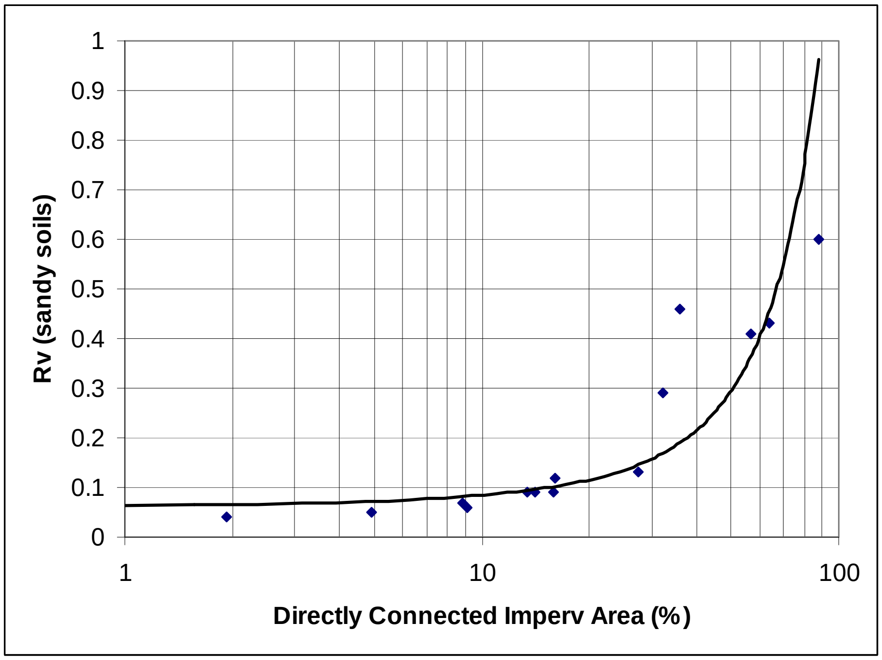


Fig 20. Relationships between the Directly Connected Impervious Area (%) and the Calculated Volumetric Runoff Coefficients for Each Land Use Category (Sandy Soil)

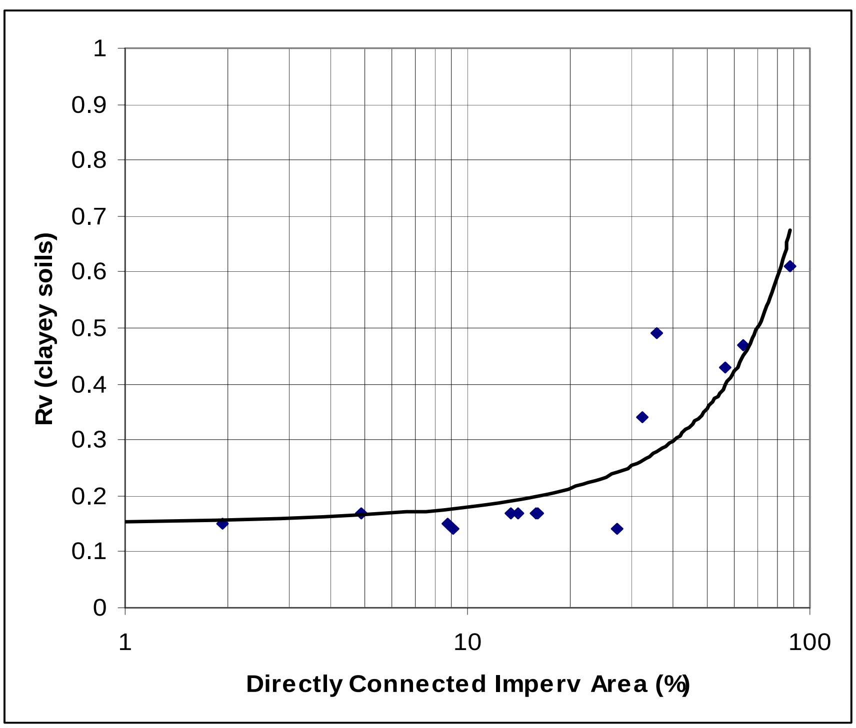


Fig. 21. Relationships between the Directly Connected Impervious Area (%) and the Calculated Volumetric Runoff Coefficients for Each Land Use Category (Clayey Soil)

Table 8 is a summary of the watersheds and their existing land uses that were monitored as part of the Jefferson County MS4 stormwater permit program. The data shows that three watersheds are highly impervious, with more than 50% of watershed being composed of impervious cover. Also, the runoff coefficients indicate that the biological condition in these watersheds is expected to be poor.

Table 8. Jefferson County, AL Source Area Drainage Connections by Land Use (values are normalized for each land use)

Watershed ID	Land Use	Pervious Areas (%)	Directly Connected Impervious Areas (%)	Disconnected Impervious Areas (%) (draining to pervious areas)	Volumetric Runoff Coefficient (Rv)
ALJC001	High Dens. Residential	56	21	23	
	Commercial	24	76	0.0	
	Industrial	11	88	1.3	
	Freeways	45	55	0.0	
	Undeveloped	93	7.2	0.0	
	Open Space	79	21	0.0	
Major Land Use	*INDUSTRIAL*	*25*	*72*	*2.8*	*0.67*
ALJC002	High Dens. Residential	59	30	12	
	Commercial	9.9	90	0.0	
	Institutional	42	58	0.0	
	Industrial	34	59	7.4	
	Open Space	82	18	0.0	
Major Land Use	*INDUSTRIAL*	*40*	*53*	*7.3*	*0.51*
ALJC009	High Dens. Residential	59	28	13	
	Commercial	0.0	100	0.0	
	Institutional	19	74	7.1	
Major Land Use	*HIGH DENS. RES.*	*54*	*34*	*12*	*0.37*
ALJC010	Med. Dens. Residential	57	34	9.5	
	Undeveloped	100	0.0	0.0	
Major Land Use	MED. DENS. RES.	64	28	7.9	*0.30*
ALJC012	Apartments	60	27	14	
	Commercial	28	72	0.0	
Major Land Use	*COMMERCIAL*	*36*	*61*	*3.4*	*0.61*

3.6 Chapter Summary

This chapter described the methods used to collect the field data and processing of the data in order to characterize the surfaces that make up the different land uses in the test watersheds. This information was also used in modeling these watersheds to investigate alternative stormwater control practices. The techniques used to estimate impervious cover in highly urbanized watersheds that were used in this research project were similar to those used by Lee and Heaney (2003), Goetz et al. (2003), and Gregory et al. (2005): site surveying, aerial photographs and satellite remote sensing interpretation and measurements. IKONOS satellite imagery was used, when available, as an alternative to conventional aerial photography. GIS and graphics software (Excel and SigmaPlot) were used to process and present the data.

Schueler (1994) found that the transportation component often exceeds the rooftop component in terms of total impervious areas, a fact clearly observed for the watersheds examined during this research, as shown in Tables 4 and 6. Wells (1995) reported that the transportation-related surfaces made up 63 to 70% of the total impervious cover. These values are quite close to those found at the Jefferson County watersheds: 66 to 78% of the impervious surfaces were transportation related in the commercial areas; 57% of the impervious surfaces were transportation related in the medium residential areas; and 58% of the impervious surfaces were transportation related in the industrial areas (a large part of transportation related surfaces were unpaved streets and parking lots in this area).

The literature review (Chapter 2) reported that curb length in an area is an important factor when predicting the role that streets have in producing pollutant discharges, a common tool in most stormwater quality models. Figure 22 is formatted similar to plots used by others to show the relationship between curb length and percent imperviousness in an area. The detailed information obtained in this study shows that this may not be a useful relationship, even if one also considers the land use category. This figure shows few obvious relationships between curb length and the percentage of imperviousness for the land uses. However, the curb length is more consistent for each land use category, as the block lengths are similar for each area (Table 9 and Figure 23)

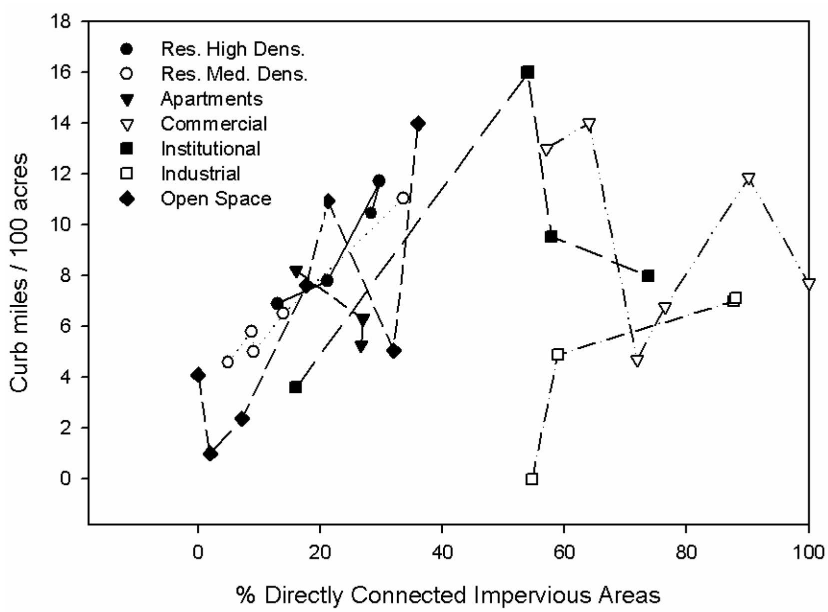


Fig. 22. The Relationship between Curb Length Density and Directly Connected Impervious Areas for Little Shades Creek and Jefferson County, AL Watersheds

Table 9. Curb Length per Watershed Area (curb-miles/acre)

	High Density Resid.	Med Density Resid.	Apartments	Commercial	Institutional	Industrial	Open Space
Minimum	6.9	4.6	5.3	4.7	3.6	0.0	0.0
Maximum	12	11	8.2	14	16	7.1	14
Average	9.2	6.6	6.6	9.7	9.3	4.7	6.4

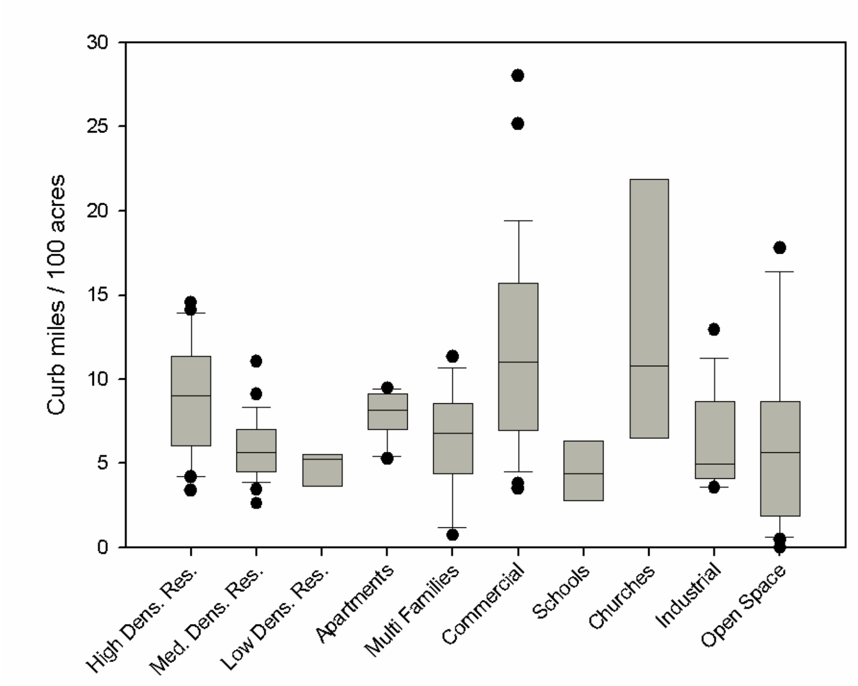


Fig. 23. Curb Length Density by Land Use for Little Shades Creek and Jefferson County, AL Watersheds

Larger variations in curb lengths per unit area are shown among and within the land uses especially for residential, institutional (school and churches) and open space land uses, where the individual block lengths vary more for the specific uses.

Schueler (1994) and Center of Watershed Protection (2003) found that there is a direct relationship between stream quality and watershed imperviousness. Data from Table 7 and 8, and Figure 4 shows that stream quality in the receiving waters is damaged to severely damage for the investigated areas, a fact confirmed by in-stream investigations by the SWMA biologists.

The plot shown on Figure 24 relates the percent directly connected impervious areas (DCIA) to the total impervious areas (TIA) used to create Table 8. This figure and the statistical analysis show that DCIA is a linear function of TIA. In fact, for these watersheds, almost all of the impervious surfaces are directly connected to the drainage system. This finding is not supported by the Alley and Veenhuis (1983) and Sutherland (1995) equations where DCIA is power function of TIA. However, the developed equation is supported by Laenen's (1983) (as cited by Sutherland 1995) findings and equation. Sutherland (1995) reported that the Laenen equation should work properly for values of TIA ranging from 10 to 50% which is approximately our case (subbasins have a TIA below 60%). It is likely that these relationships vary significantly for different regions of the country. In fact, it is likely that they vary within regions as each community may have different standards and requirements concerning drainage connections from parking areas and roofs.

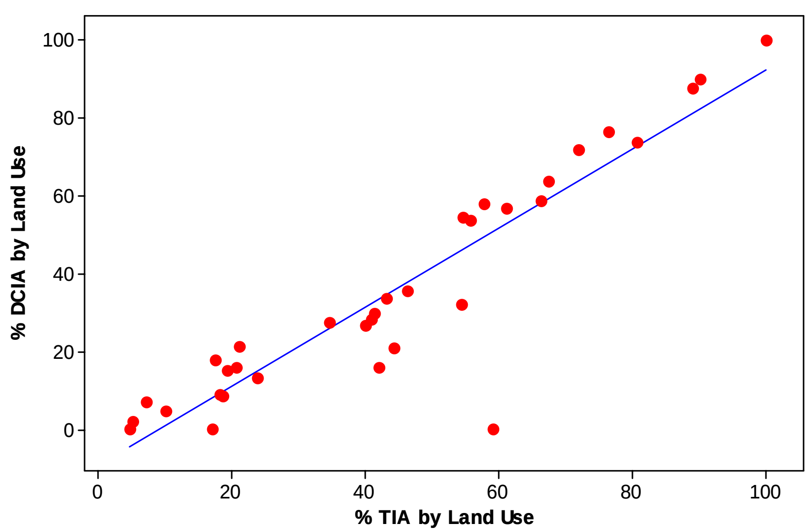


Fig. 24. Empirical Estimation of DCIA based on TIA by Land Use for Little Shades Creek and Jefferson County, AL Watersheds

The directly connected impervious area and total impervious areas data were used to performed regression analysis (Figure 25).

Regression Analysis: % DCIA versus % TIA

The regression equation is
% DCIA = 1.02 (TIA) – 9.29

Predictor	Coef	SE Coef	T	P
Constant	-9.289	3.909	-2.38	**0.024**
TIA	1.016	0.076	13.3	0.000

S = 11.5574   R-Sq = 84.7%   R-Sq (adj) = 84.3%

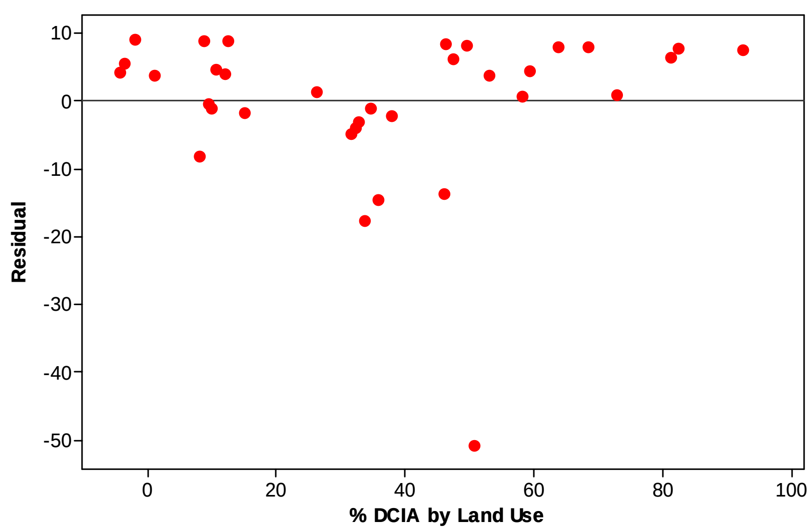


Fig. 25. Residual Plot for Percent DCIA by Land Use

The data from Table 8 is fully supported by the results of the regression analysis. Figures 26 and 27 show that impervious area in Little Shades Creek and Jefferson County watersheds are almost entirely directly connected, and that there is a large variability among and within land uses.

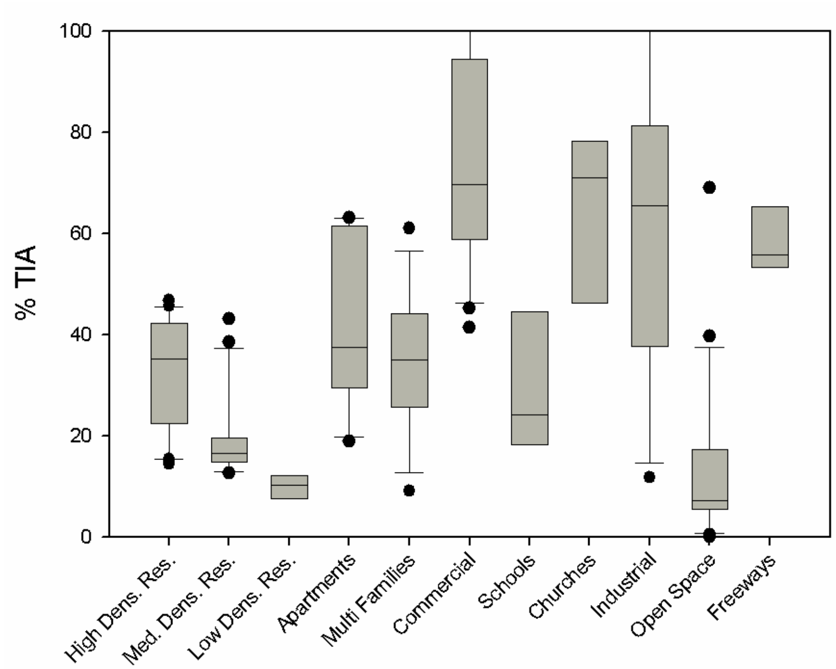


Fig. 26. Percent of Total Impervious Area by Land Use for Little Shades Creek and Jefferson County, AL Watersheds

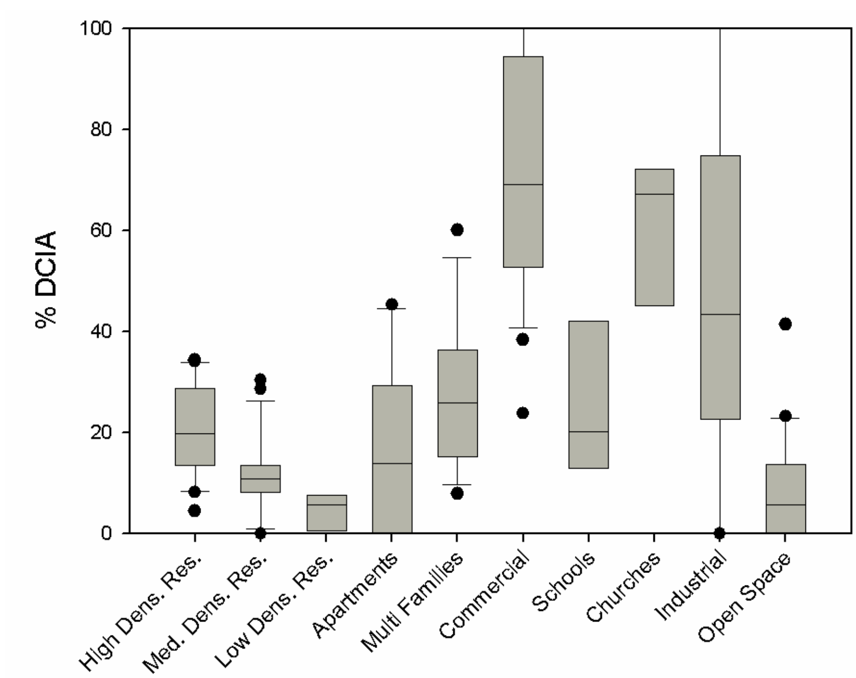


Fig. 27. Percent of Directly Connected Impervious Area by Land Use for Little Shades Creek and Jefferson County, AL Watersheds

Chapter 4
Modeled Flow Duration Variations, Pollutant Discharges, and Costs for Different Stormwater Controls[1]

4.1 Introduction

It is well known that the volume of runoff from a watershed increases with development because of the increase in the amount of impervious areas that are part of land development prevents the infiltration of rainwater. This increased runoff volume, and associated peak flows, is a common cause of increased streambank erosion and other problems in receiving waters. An effective combination of stormwater management and site development practices can be used to reduce peak flows and water volume and pollutant discharges, with subsequent benefits to the receiving waters. Stormwater controls can include such practices as wet detention ponds, bioretention facilities, and grass swales, while development characteristics include such features as the amount of impervious cover and how they are connected to the drainage system. Stormwater controls usually add extra costs to the development. Stormwater control costs must consider their design and construction costs, plus maintenance costs. The magnitude of these costs are dependent on a number of complex factors including local site conditions, site topography, time of year, accessibility to equipment, economies of scale, type of control measure, existing and proposed future land uses, environmental considerations,

[1]Portions of the following were presented as a poster at the *79th Annual Water Environment Federation Technical Exposition and Conference*. Dallas, TX. Oct. 21 –Oct. 25, 2006, as "Modeled Flow Duration Variations, Pollutant Discharges, and Costs for Different Stormwater Controls", by Arvind Narayanan, Celina Bochis and Robert Pitt

government regulations, public preferences, and degree of technical assistance available.

Some of the stormwater controls (those that reduce the peak discharge rates during critical design storms) can also reduce the costs of other components of the conventional drainage system. In addition, the value of the receiving water benefits associated with the stormwater controls are difficult to determine. This chapter will show how runoff flow-duration distributions, pollutant discharges, and costs can be compared for different development scenarios using recent modifications made to the Source Loading and Management Model, WinSLAMM (Pitt 1986; Pitt and Voorhees 2002).

4.2 Jefferson County NPDES Monitoring Watershed Characteristics

A number of local watersheds are being monitored by the Storm Water Management Authority (SWMA) of Jefferson County, AL, as part of their NPDES stormwater permit. Table 10 lists five of these sites and their calculated annual average volumetric runoff coefficients (Rv), total suspended solids concentrations, percent impervious values, and the expected biological conditions of the receiving waters due to expected hydromodifications of the receiving waters from the land development. The expected biological conditions of the receiving waters were calculated by WinSLAMM to be “poor” for the base conditions having no stormwater controls. The highly impervious watersheds (ALJC001 and ALJC012), which have mainly industrial and commercial land uses respectively, have higher values of Rv (about 0.6) but lower values of TSS concentrations, compared to the watersheds dominated by residential land uses (ALJC009 and ALJC010). The residential watersheds are closer to the threshold between fair and poor biological conditions (an Rv of about 0.25) than the industrial and commercial watersheds, as expected. These expected biological conditions in the nearby receiving waters have been verified by biologists from the Jefferson County Storm Water Management Authority during their in-stream investigations. It is therefore possible that stormwater controls that reduce the runoff discharges could be effective in improving receiving water biological conditions in the residential areas, but it would be much more difficult in the industrial and commercial watersheds.

Table 10. Runoff Quantity and Quality for the Five Jefferson Co., AL Monitoring Sites

Site ID	Major Land Use Category	Area (ac)	Percent Total Impervious Areas	Percent Directly Connected Impervious Areas	Calculated Volumetric Runoff Coefficient (Rv)	Calculated TSS Concentration (mg/L)	Expected Biological Conditions of Receiving Waters Due to Hydro Modifications	% Runoff Reductions Needed to Improve the Bio. Conditions
ALJC001	Industrial	341	74.7	71.9	0.67	89	Poor	63 (fair) 85 (good)
ALJC002	Industrial	721	59.9	46.5	0.51	118	Poor	51 (fair) 80 (good)
ALJC009	High Density Residential	102	46.0	34.3	0.37	176	Poor	32 (fair) 73 (good)
ALJC010	Medium Density Residential	133	35.6	27.7	0.30	218	Poor	17 (fair) 67 (good)
ALJC012	Commercial	228	63.9	60.5	0.61	64	Poor	59 (fair) 84 (good)

This chapter discusses Site ALJC012, a 92 ha (228 ac) watershed located in Hoover, AL, in more detail to examine possible benefits associated with different stormwater management options. As noted previously, these sites are being monitored by the Storm Water Management Authority as part of their NPDES stormwater permit. These data have also been used to update the validation of the WinSLAMM model for the region. The sampling location for this watershed is at a large culvert running under Highway 31, just south of where the highway intersects Highway 150, in Hoover, AL.

The drainage basin is comprised mostly of commercial areas (75%) made up of strip shopping centers mixed with offices and banks, and a portion of the very large Riverchase Galleria shopping mall. Apartments make up about 25% of the drainage area, including some undeveloped woodland (about 5%). Table 11 shows the source areas for the two major land uses for the ALJ012 (commercial mall/apartments) watershed.

Table 11. Jefferson County AL, Commercial Mall/Apartments Watershed: Average Source Areas by Land Use (Acres, Unless Otherwise Noted)

Land Use	Curb Miles	Street with Curbs and Gutters	Parking, Paved and Connected	Storage, Paved	Pitched Roof (drained to impervious)	Pitched Roof (drained to pervious)	Flat Roof (drained to impervious)	Large Turf	Other Pervious	Total
Apartments	3.03	6.8	8.5	0	0	7.8	0	0	34	57.4
Commercial	8.03	27	61	9.7	11.95	0	11.95	48	0	171
Total Area	11.1	34.6	69.5	9.7	11.95	7.8	11.95	48	34	228.4

The drainage system serving this area is comprised of concrete curbs and gutters in good condition. The terrain is flat in the central part of watershed (including the large shopping mall area), but there are some areas of hilly topography (11-13% slope), with maximum slopes of about 17% in the northeastern part of the watershed in the residential subarea. All the buildings in the apartment complexes have pitched roofs of composite shingles that are disconnected from the stormwater drainage system, with the water directed onto the surrounding grass (silty loam soil). A large part of this apartment land use (60%) is woodland.

The commercial area is a mixture of shopping centers and a large retail mall having flat and pitched roofs that are also entirely connected to the drainage system. Paved parking lots and roofs are a large part of this land use (49%). However, there are also some landscaped areas (also having a silty loam soil) that comprise about 28% of the commercial land use area.

4.3 Analyses of Source Area Runoff and Pollutant Contributions

Particulate solids and zinc contributions from different source areas in this commercial/apartment watershed were analyzed for various rain depths. These analyses used WinSLAMM with a one year series of typical rainfall data (1976, previously determined to be a representative rain year for this area by Pitt and Durrans 1995). These analyses showed that the site produced a runoff volume of about 120,000 ft^3 /ac-yr (8,500 m^3/ha-yr), which was about 61% of the annual rainfall volume (Rv = 0.61). This runoff quantity is expected to result in poor biological conditions in the receiving waters due to resultant hydromodifications from the runoff energy increases compared to natural conditions. The concentration of total suspended solids was 64 mg/L, and the annual mass discharge of total suspended solids was calculated to be about 40,000 kg (or 440 kg/ha-yr).

Table 12 is a summary of the source area contributions to the total runoff volume discharges (in percent). As expected, almost all (>90%) of the annual runoff volume is expected to come from the directly connected impervious areas, such as the parking lots, streets, and roofs, during this typical rain year.

Table 12. Summary of Source Area Percentage Contributions of Runoff Volume

Land Use	Street with Curbs and Gutters	Parking, Paved and Connected	Storage, Paved	Pitched Roof (drained to impervious)	Pitched Roof (drained to pervious)	Flat Roof (drained to impervious)	Large Turf	Other Pervious	Total*	Avg. Rv
Apartments	3.9	6.0	0	0	0.84	0	0	3.7	14.4	0.35
Commercial	15	43	6.8	8.2	0	7.1	5.1	0	85.6	0.69
Total Area	19	49	6.8	8.2	0.84	7.1	5.1	3.7	100	0.61

* Total might not add to 100 due to rounding

Tables 13 and 14 are summaries of the particulate solids and zinc contributions (in percent) from each of the source areas for this site, for the complete rain year. The directly connected impervious areas are the largest contributors, as expected, but the landscaped areas are also expected to contribute large portions (26%) of the total particulate solids. The parking areas and streets contribute about 41% of the total area zinc discharges. The roofs also contribute a large portion of the zinc (36%), even though they only are expected to contribute about 16% of the runoff volume.

Table 13. Summary of Source Area Percentage Contribution of Particulate Solids

Land Use	Street with Curbs and Gutters	Parking, Paved and Connected	Storage, Paved	Pitched Roof (drained to impervious)	Pitched Roof (drained to pervious)	Flat Roof (drained to impervious)	Large Turf	Other Pervious	Total*
Apartments	4.6	3.5	0	0	0.04	0	0	9.5	17.6
Commercial	10	38	6.0	0.77	0	0.67	26	0	82.4
Total Area	15	42	6.0	0.77	0.04	0.67	26	9.5	100

* Total might not add to 100 due to rounding

Table 14. Summary of Source Area Percentage Contribution of Zinc

Land Use	Street with Curbs and Gutters	Parking, Paved and Connected	Storage, Paved	Pitched Roof (drained to impervious)	Pitched Roof (drained to pervious)	Flat Roof (drained to impervious)	Large Turf	Other Pervious	Total*
Apartments	0.79	1.1	0	0	0.74	0	0	2.9	5.5
Commercial	10	29	4.6	19	0	16	16	0	94.5
Total Area	11	30	4.6	19	0.74	16	16	2.9	100

The most suitable stormwater controls for this area are those that would affect the major sources of the pollutants and flows of interest. As noted above, the greatest quantity of runoff is likely to originate from directly connected impervious areas, as expected. The source areas that first contribute runoff during rains are the directly connected parking lots, paved storage areas, and connected pitched roofs, which start to produce flow during very small rains (0.01 inches). The streets start contributing runoff at about 0.02 inches of rain, followed by flat connected roofs (0.09 inches), and then landscape and disconnected roofs at about 0.12 inches of rain (Figure 28).

Figure 28 shows the percentage of runoff volume originated from the different source areas, for different rain depths for the complete watershed (both land use categories combined). As indicated above, for the smallest rainfall that likely produces runoff, about 85% of runoff comes from the parking areas. Their contribution decreases to approximate 55% at rain depths of 0.5 inches. This decrease in the importance of parking areas as a source of runoff is associated with an increase of streets and directly connected roofs contributions.

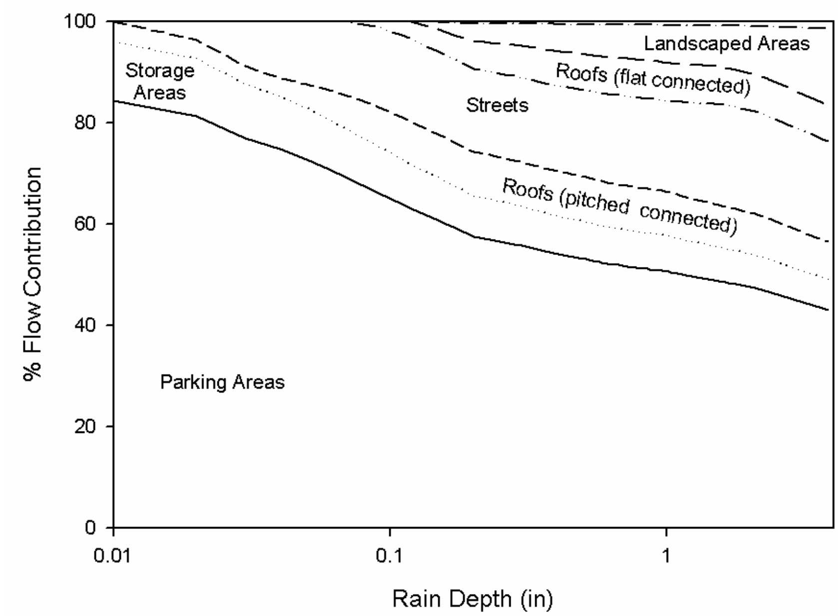


Fig. 28. Runoff Flow Percent Contribution for the Complete ALJC012 Watershed

Figure 29 and 30 represent the runoff percent contribution for residential and respective commercial part of the ALJC012 watershed. They clearly show that the parking areas, roofs, and streets are the predominant flow source in both watersheds. The landscaped areas become important in the residential area only for larger rains (> about 1 inch).

Figures 31 and 34 show the percentage of suspended solids loads and zinc loads discharged from different source areas, as a function of rain depth, for the complete watershed. For small rains, the suspended solids are mostly generated by parking lots (about 87% for 0.01 inch of rain depth), followed by storage areas and streets. Also, the directly connected roofs start generating suspended solids at small depths of the rain (0.02 – 0.09 inches), but their quantity is very small (Figure 33). Landscaped areas are the principal source of suspended solids for large rains.

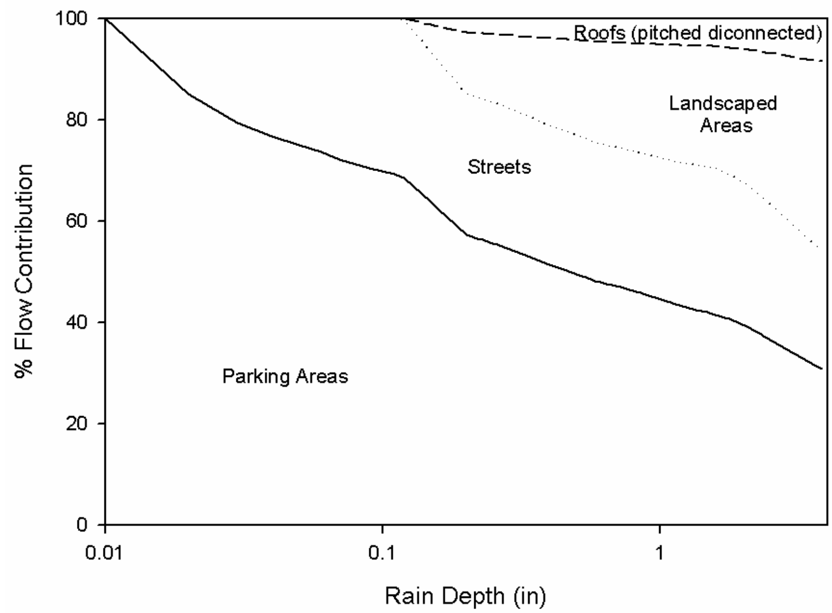


Fig. 29. Runoff Flow Percent Contributions from the Residential Subarea of the ALJC012 Watershed

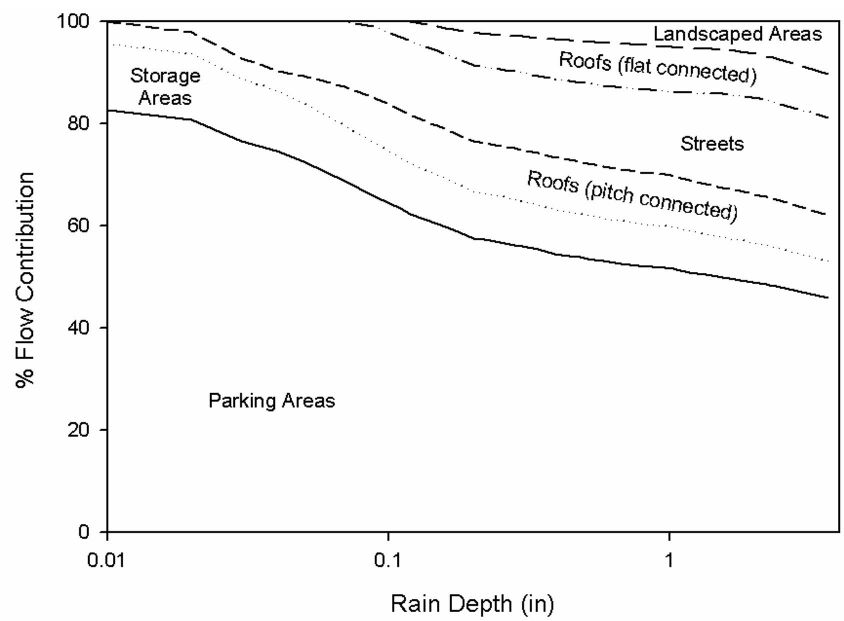


Fig. 30. Runoff Flow Percent Contributions from the Commercial Subarea of the ALJC012 Watershed

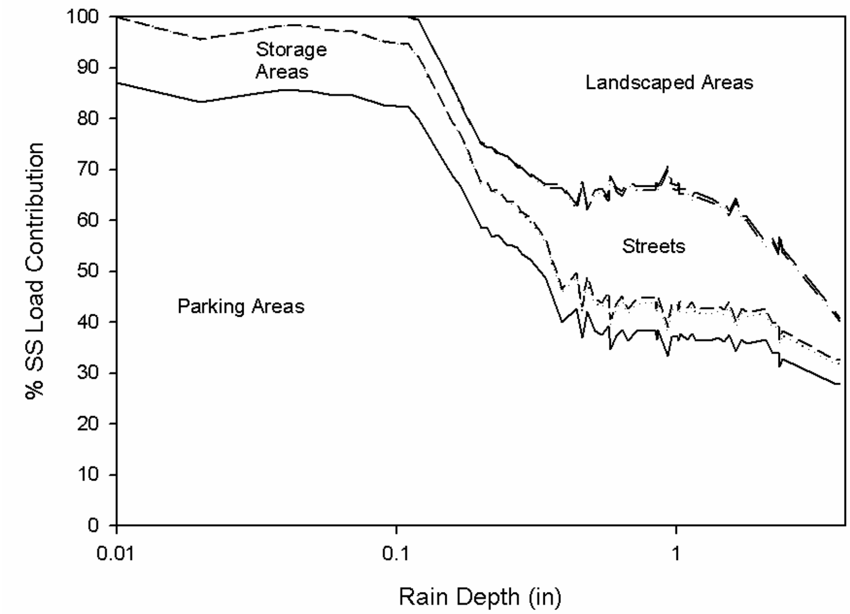


Fig. 31. Particulate Solids Load Percent Contribution for the Complete ALJC012 Watershed

In the residential area (Figure 32), paved parking and streets contribute most of the particulate solids discharges for rains up to about 0.15 inches in depth. For larger rain depths, the landscaped areas contribute the majority of the particulate solids. In the commercial land use area (Figure 33), the landscape areas contribute the majority of particulate solids for rains greater than about 3 inches in depth, with the parking areas and streets contributing most of the particulate solids for smaller rains.

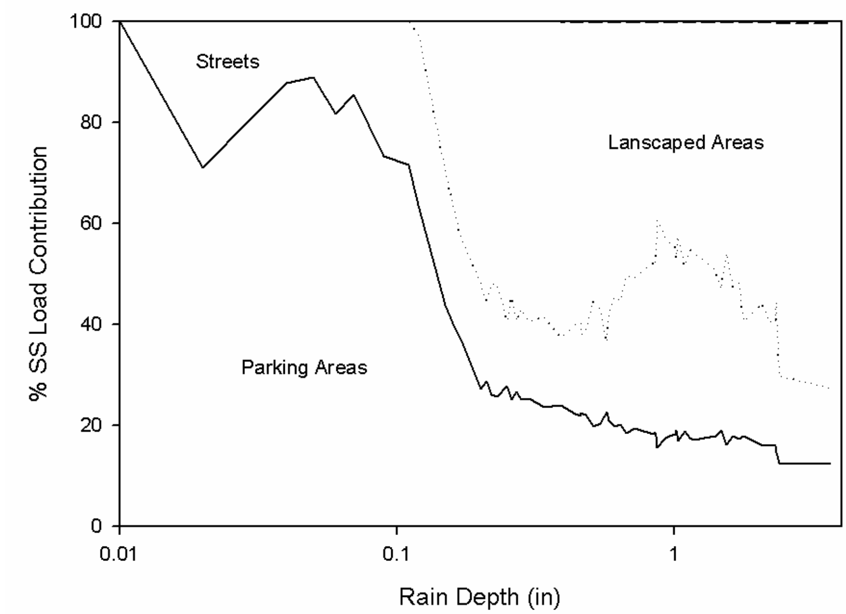


Fig. 32. Particulate Solids Load Percent Contributions for the Residential Subarea of the ALJC012 Watershed

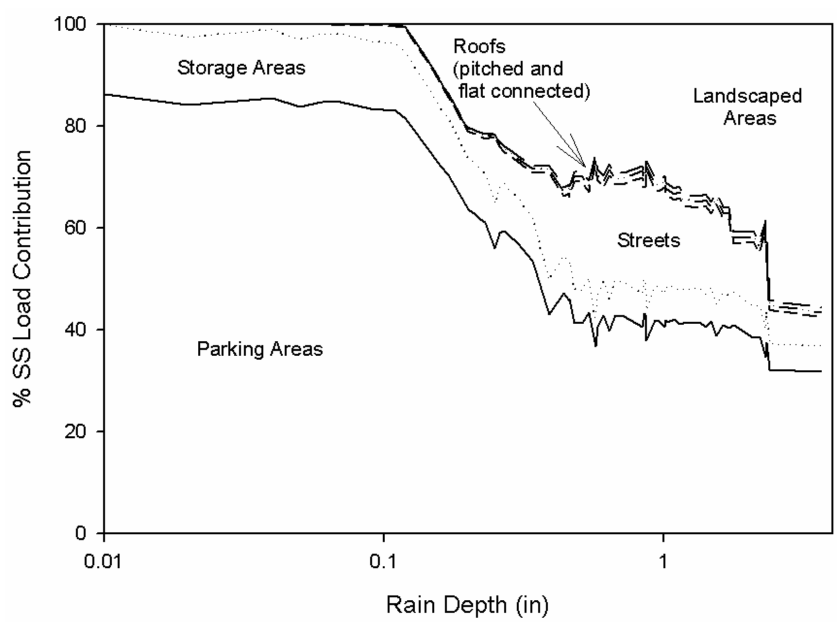


Fig. 33. Particulate Solids Load Percent Contributions for the Commercial Subarea of the ALJC012 Watershed

As shown on Figure 34, zinc discharges at the beginning of rains, and for small rains, mostly originate from parking and storage areas. Pitched roofs directly connected to the drainage system contribute about 4% of zinc loads for the smallest rains (0.01 inch of depth), and then their significance increases dramatically (along with flat, connected roofs) as the rain depths increase. All of the roofs combined contribute the majority of the zinc discharges at about 0.09 inches of rain, and larger.

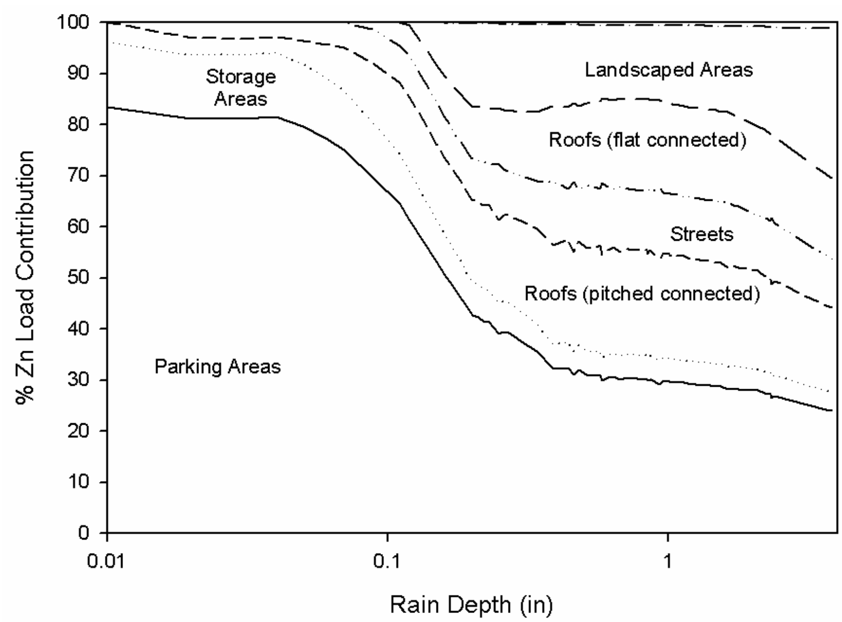


Fig. 34. Zinc Load Percent Contribution for the Complete ALJC012 Watershed

Figures 35 and 36 illustrate the zinc contributions for the residential and commercial portions of the study watershed, clearly illustrating the importance of the parking/storage areas in both subareas for the smallest events and the roofs (for the commercial subarea) and the landscaped areas (for the residential subarea) for the moderate to large events in contributing zinc discharges.

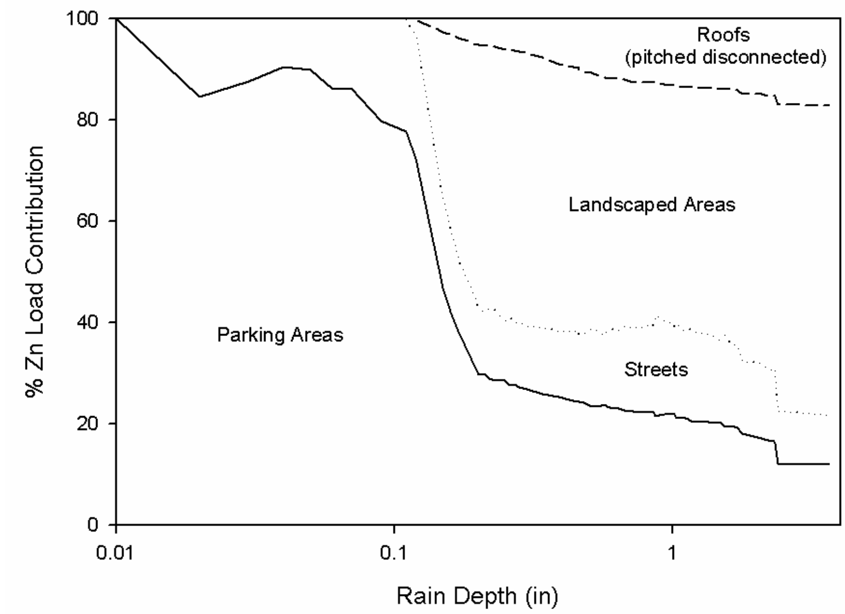


Fig. 35. Zinc Load Percent Contributions for the Residential Subarea of the ALJC012 Watershed

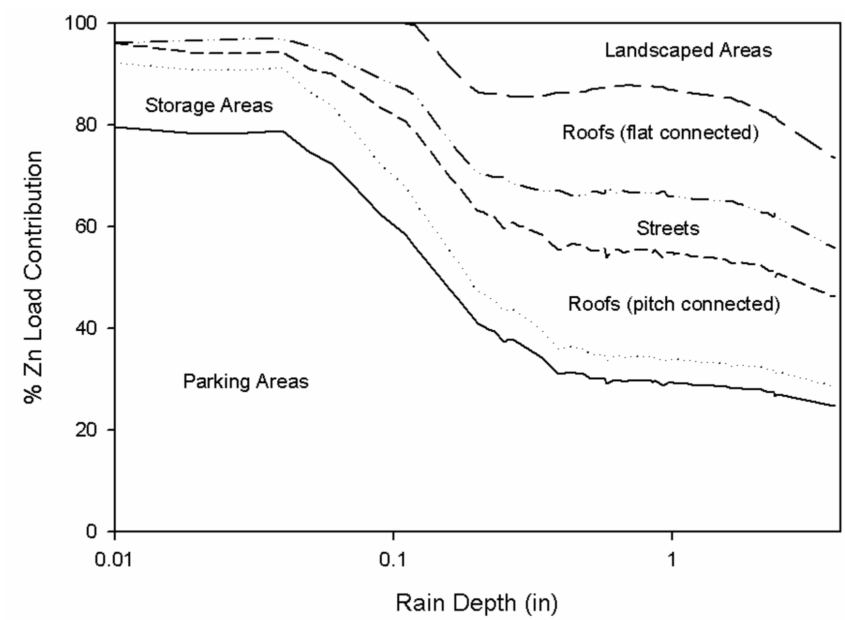


Fig. 36. Zinc Load Percent Contributions for the Commercial Subarea of the ALJC012 Watershed

Based on these source area contribution findings, the source area controls of most potential use will be those that can treat runoff from parking areas and directly connected roofs. Drainage system and outfall controls may also be useful as these can affect flows from all source areas combined.

4.4 Control Practice Characteristics

Wet detention ponds, grass swales, and bioretention devices were considered for this watershed in order to reduce pollutant loadings and runoff discharges. Since this watershed is highly urbanized, retrofitting control practices will be difficult and expensive. As in most areas, the most cost-effective stormwater controls need to be installed at the time of development. The aerial photograph of this watershed (Figure 37) was examined to locate potential stormwater controls. A wet detention pond could potentially be located at the 5.6 acre landscaped area at the junction of Highway 31 and Highway 150. This pond was designed to have a total depth of 9 ft, with a permanent pool of 2.4 acres, and 7.5 feet deep. The pond can treat runoff from the entire 228 acre watershed. This pond has a permanent pool area of only about 1.1% of the watershed area, smaller than what would normally be used for such a highly impervious drainage area (the permanent pool would normally be closer to 3% of the total paved plus roof area in the watershed). However, the available location precluded using a larger pond, and upland controls to reduce the volume of water flowing to the pond, allowing a smaller pond size, were also considered.

Grassed swales can be used along some of the roads in the watershed. Swales having a 5 feet bottom width, 22 feet top width, 2.8 feet deep and 3:1 side slope were selected for this area. The infiltration rates in the soils were assumed to be only 0.15 inches per hour. These swales could be used to replace about half of the conventional curb and gutter drainage system.

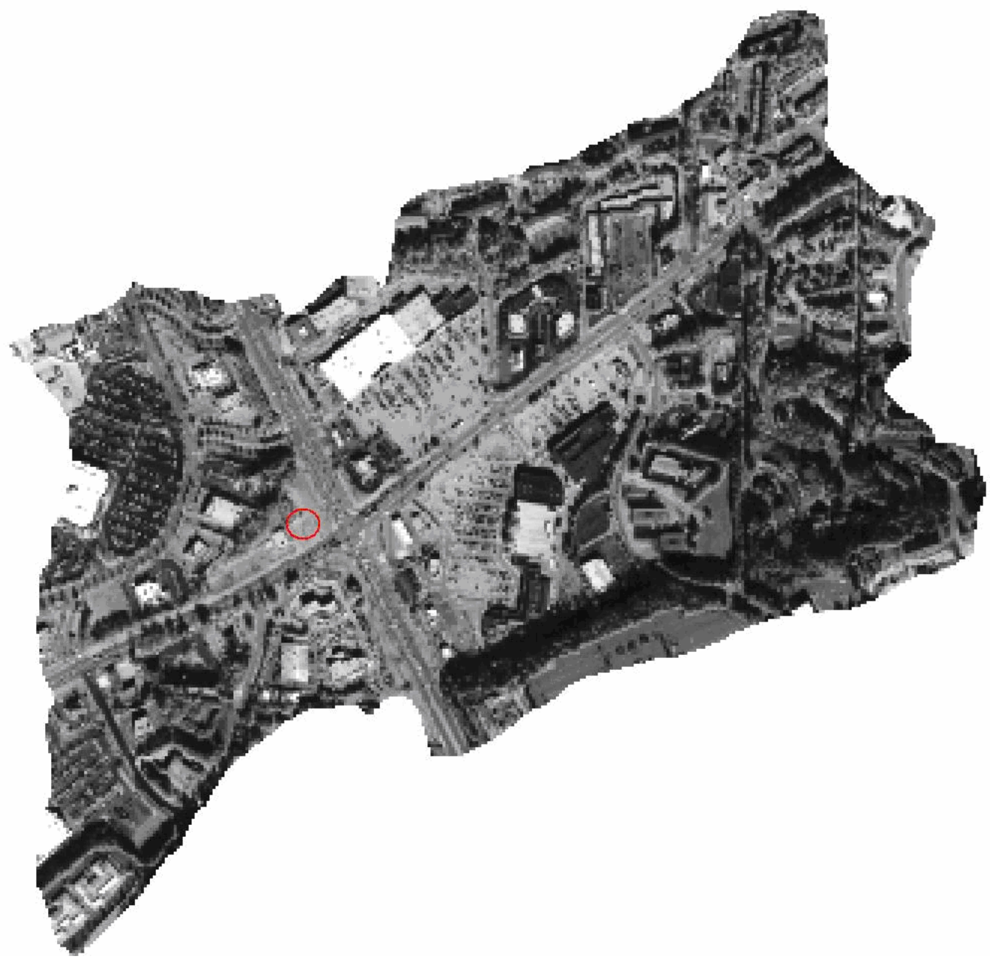


Fig. 37. Aerial Photograph of Commercial/Apartment Watershed, also Showing Location of Wet Detention Pond (Aerial Photograph Courtesy of SWMA)

Bioretention devices retrofitted at landscaped areas can be used to treat roof runoff and as parking lots islands to treat the parking area runoff in both the land use areas. A total of 150 bioretention devices can be used in the residential area. Each was designed to have surface areas of 360 ft^2, with conservative long-term soil infiltration rates of 0.3 inches per hour, which is much lower than would normally be considered for biofiltration devices. A total of 400 bioretention devices can be used in the commercial areas. Each commercial area bioretention device was designed to have 540 ft^2 surface areas. In the residential area, 30 bioretention devices can be used at parking areas and the rest of them can be located in the rear of the buildings to collect runoff form the roof areas. In the commercial areas, 150 bioretention devices can be used in the parking areas to collect runoff from those areas, and 250 additional devices located near the buildings can collect runoff from storage areas and roofs. Construction of the bioretention devices would result in the loss of about 60 parking places in the residential areas and 450 parking places in the commercial areas, if used in areas of existing parking. The actual loss of current parking would be less, as some landscaped islands currently exist that could be converted to bioretention facilities. The total area used for the bioretention devices in the residential area is about 2.2% of the total 54.7 acres of this land use, while the bioretention devices used in the commercial area are about 2.9% of the entire commercial area.

These stormwater controls, in various combinations, were then evaluated by WinSLAMM to calculate the expected reductions in runoff volume, particulate solids and zinc discharges, and the associated costs.

4.5 Results and Discussion

Eight stormwater control combinations were examined that included (i) no controls, (ii) detention pond only, (iii) grass swales only, (iv) site bioretention only, (v) detention pond and swales, (vi) detention pond and site bioretention, (vii) swales and site bioretention, and (viii) detention pond, site bioretention and swales. Table 15 summarizes the costs, total particulate solids, and runoff volume discharges after implementing these different control combinations. The runoff volume reductions are moderate when the swales and bioretention devices are both used together (about 65%), but the expected resulting hydromodifications and biological receiving water impacts are still expected to be significant, with resulting fair conditions. As shown earlier in Table 10, 59% reductions in runoff volume are expected to be needed to result in fair biological conditions in the receiving waters, while 84% reductions would be needed to result in good biological conditions in the receiving waters. Additional reductions in runoff volume are likely needed to improve the expected receiving water conditions to good conditions. As an example, it may be possible to modify the site soils and enhance the designs of the biofiltration devices to be more effectively to result in larger runoff volume reductions. This site contains one of the largest shopping malls in the southeast, and the watershed has a very large amount of impervious surfaces. Although these expected runoff volume reductions are large and the amount of controls and the associated costs are also large, further effort in runoff reductions is still needed to help restore the receiving waters to desirable (good) conditions.

Figure 38 is a plot showing flow-duration curves calculated by WinSLAMM for the watershed discharges that occur for different percentages of time for each control option. The options that contain the wet pond have the greatest benefit on reducing the peak flow rates, reducing the peak discharges by up to about 30-55% for the largest flow rates. The infiltration devices in turn, reduce the total volumes of the discharges by the largest amount.

Table 15. Costs and Particulate Solids Discharges for Different Stormwater Controls

	No Controls	Pond	Swales	Bioretention	Pond and Swales	Pond and Bioretention	Swales and Bioretention	Pond, Swales and Bioretention
Capital Cost ($)	0	248,000	803,147	2,986,378	1,051,156	3,234,387	3,789,526	4,037,535
Annual Maintenance Cost ($/year)	0	6,581	26,387	206,260	32,969	212,842	232,647	239,229
Present Value of All Costs ($)	0	330,031	1,131,992	5,556,838	1,462,023	5,886,869	6,688,830	7,018,861
Annualized Total Costs of Stormwater Controls ($/year)	0	26,482	90,834	445,895	117,316	472,377	536,729	563,211
Total Particulate Solids Concentration Before Drainage System (mg/L)	64	64	64	87.8	64	87.8	87.8	87.8
Total Particulate Solids Concentration After Drainage System (mg/L) (considers source area and drainage system controls)	50.8	51	45.5	80	45.5	80	72.1	72.1
Total Particulate Solids Concentration at Outfall (mg/L) (considers source area, drainage system, and outfall controls)	50.8	12.5	45.5	80	11.4	14.8	72.1	14.0
Total Particulate Discharges at Outfall (lb/year)	87,812	21,370	70,703	58,616	17,464	10,256	44,024	8,050
Percent Reduction of Total Particulates Discharges (compared to no controls)	n/a	**75.7%**	19.5%	33.3%	80.1%	88.3%	49.9%	90.8%
Unit Removal Costs for Total Particulates ($/lb)	n/a	0.40	5.31	15.27	1.67	6.09	12.26	7.06
Total Runoff Volume After Controls (ft^3/year)	27,720,000	27,340,000	24,900,000	11,740,000	24,520,000	11,140,000	9,790,000	9,213,000
Percent Reduction of Total Runoff Volume Discharges (compared to no controls)	n/a	1.4%	10.2%	**57.7%**	11.1%	59.8%	64.7%	66.8%
Unit Removal Costs for Runoff Volume ($/$ft^3$)	n/a	0.07	0.03	0.03	0.04	0.03	0.03	0.03
Runoff Coefficient After Controls (Rv)	0.61	0.60	0.54	0.26	0.54	0.24	0.21	0.20
Expected Biological Conditions in Receiving Waters, if Complete Watershed Developed in this Manner (based on runoff volume)	poor	poor	poor	poor	poor	**fair**	**fair**	**fair**

Figures 39, 40, and 41 plot the cost per unit mass of particulate solids, zinc and runoff volume reduced compared to their maximum percentage reductions for the various combinations of control practices.

The costs of the stormwater controls include capital cost (land cost, construction cost and related site work) and annual operations and maintenance costs (labor, materials, fuel, and equipment for landscape maintenance, structural maintenance, sediment removal from sediment control devices and associated disposal, and litter removal). These costs are calculated in WinSLAMM, based on the thesis prepared by Narayanan (2005). Capital costs generally occur in the first year when the stormwater control is installed in a new development, but they are usually subject to financing costs and are amortized over the life of the project. Operation and maintenance costs are post construction activities and ensure that an installed stormwater control is effective and remains in good conditions. The operational and maintenance costs occur cyclic throughout the life of the stormwater control device.

Wet detention ponds are one of the most effective methods of removing particulate-associated pollutant loadings from stormwater. They are also very suitable for attenuating peak runoff flows. Their cost is mostly a function of storage volume (Narayanan 2005). Conservation design stormwater controls (grass swales, bioretention devices, etc.), include better site layout and decreased use of directly connected paved and roof areas. These practices are almost exclusively part of initial developments, and are difficult to retrofit. Their costs varies from low cost with reasonable maintenance requirements (grass swales), to expensive devices that regular maintenance (bioretention devices) (Narayanan 2005).

The use of the pond and the bioretention devices in combination is expected to reduce particulate solids discharges by about 88%. The combination of the wet detention pond, swales, and bioretention devices are expected to reduce the particulate solids discharges by about 91%, at approximately the same unit cost (per pound of solids). In the case of zinc reductions, the pond also plays a vital role: the wet detention pond results in the most cost-effective reductions in zinc concentrations at the outfall for moderate targeted reductions (up to 41% Zinc reductions). Increasing the zinc reductions to about 45% results in very large increases the unit removal costs (by more than 10 times). The most cost-effective control in reducing the runoff volume at this site is the use of biofiltration devices by themselves (58% reduction), or in combination with grass swales (65% reduction). Soil modifications to increase the infiltration rates would also result in significant increases in performance of both of these stormwater controls and should be considered an important part of the stormwater management plan for this area.

The combination of the wet detention pond, grass swales, and bioretention devices together, will provide the largest reductions in runoff, particulate solids, and zinc in this watershed. The installation of the bioretention devices and replacing half of the curb and gutters with grass swales not only reduces the runoff volume and pollutant discharges, but also decreases the costs of the conventional drainage system (if done at the time of initial development), as the grass swales serves to convey stormwater instead of the usual curb and gutter and pipe systems, and the upland bioretention devices provide some reduction in the runoff volume during critical drainage design storms. Therefore, any decrease in pipe diameter or length of pipe can result in significant decreases in the cost of the entire system. These additional cost savings are not included in these analyses. Of course, if these practices are retrofitted in this area, these capital cost savings would not be realized, and additional costs associated with their removal must be added to these calculated costs.

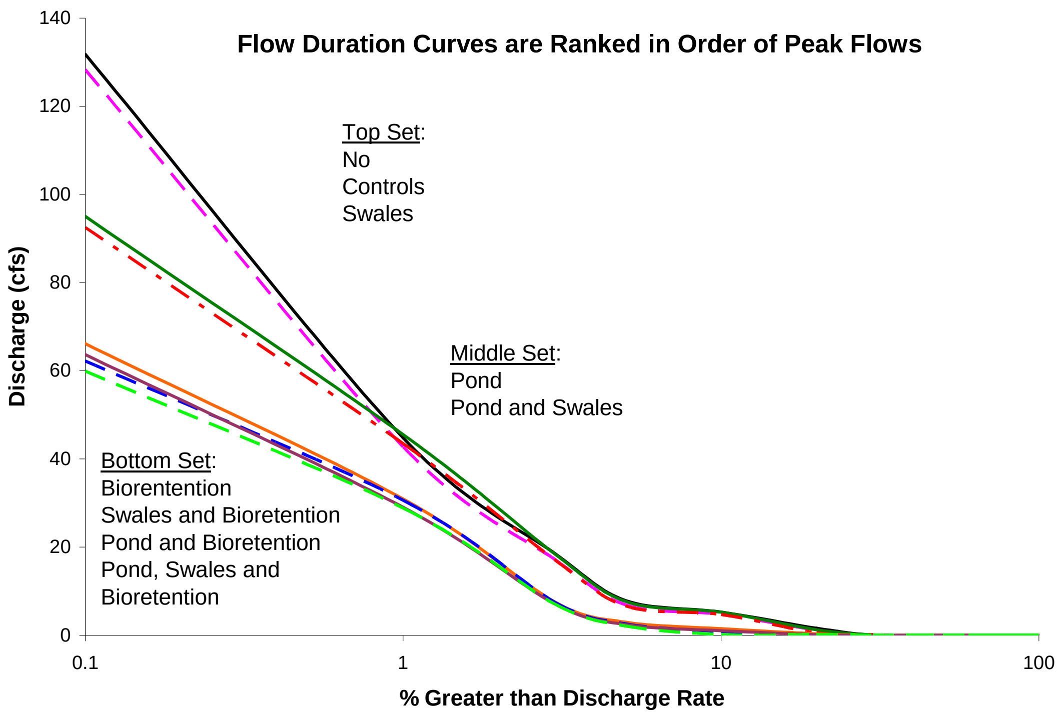


Fig. 38. Flow-Duration Curves for Different Stormwater Conservation Design Practices

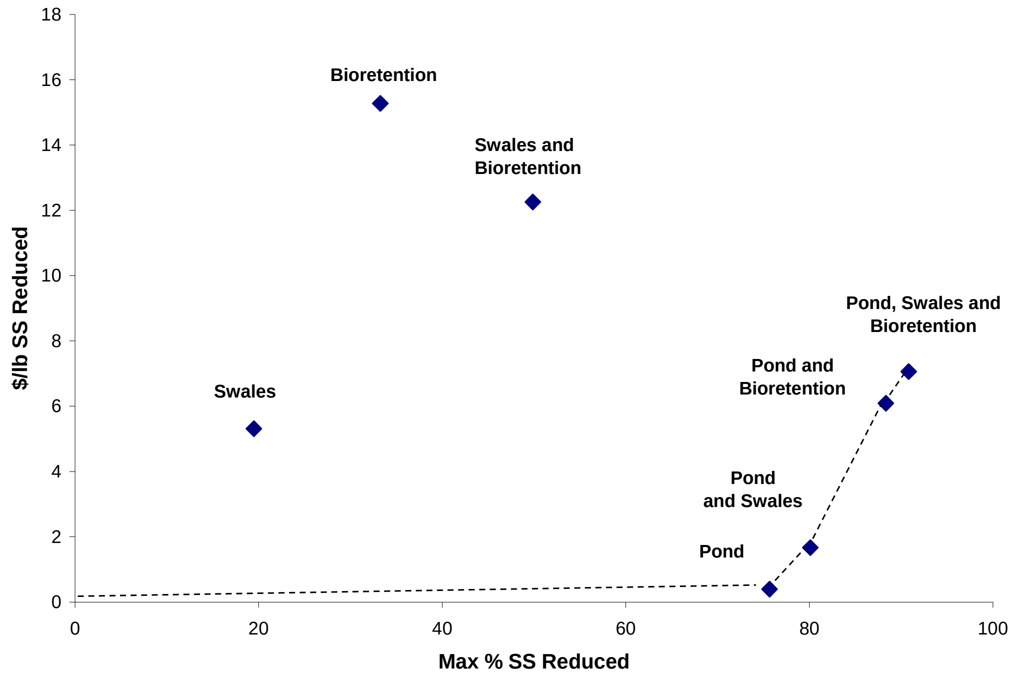


Fig. 39. Cost Effectiveness of Stormwater Control Practices for Particulate Solids Reductions

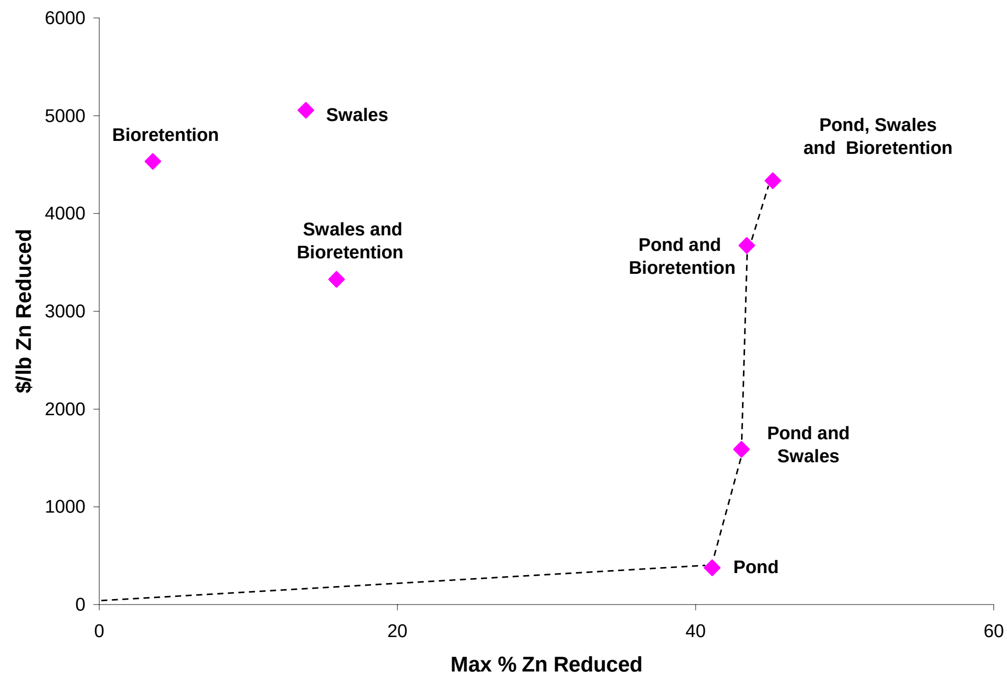


Fig. 40. Cost Effectiveness of Stormwater Control Practices for Zinc Reductions

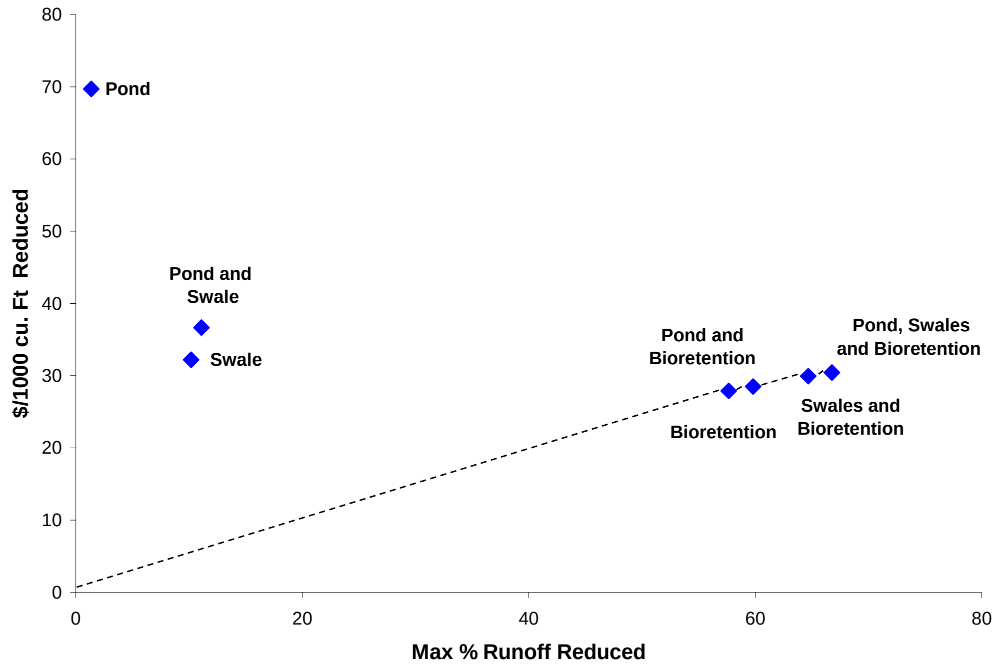


Fig. 41. Cost Effectiveness of Stormwater Control Practices for Runoff Volume Reductions

4.6 Chapter Summary

Runoff volume and pollutant discharges increase with development, with associated detrimental receiving water effects. These increases can be partially controlled by installing stormwater control practices, such as wet detention ponds at outfalls, using conservation design controls such as grass swales and bioretention devices, and by improved development practices that reduce the amounts of impervious areas. It would be rare for a single stormwater control to be effective by itself in meeting a broad range of receiving water objectives. The volume of runoff and the pollutants associated with the different source areas within a watershed can be used to identify the most likely suitable stormwater controls for the area. The reductions in runoff volume and pollutant discharges, and the costs associated with installing these control practices, are presented in this chapter for an example 228 acre watershed located in Jefferson County, AL. This site consists of 75% commercial lands and 25% residential lands. The Source Loading and Management Model for Windows (WinSLAMM) was used to calculate the reduction of these pollutants and runoff volume, the associated durations of different flows, and the costs involved with retrofitting different combinations of a wet detention pond, grass swales, and bioretention devices in the example watershed.

It was found that the wet detention pond is the best option in reducing the peak flow rates, while the infiltration devices best reduce the total volumes of the discharges. As expected, a combination of the wet detention pond, grass swales, and bioretention devices provides the best reductions in runoff, particulate solids, and zinc in this watershed.

References

Arnold, Chester, and James Gibbons. 1996. Impervious Surface Coverage. The Emergency of a Key Environmental Indicator. *Journal of the American Planning Association* 62: 243-58.

Bannerman, Roger, K. Baun, M. Bohn, P.E. Hughes, and David Graczyk. 1983. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin* 1. Grant No.P005432-01-5, PB 84-114164. U.S. Environmental Protection Agency, Water Planning Division.

Bannerman, Roger, Andrew Legg, and Steven Greb. 1996. *Quality of Wisconsin Stormwater,1989-1994*. U.S. Geological Survey. Open Files Report 96-458. Madison, WI. 26 pgs.

Bochis-Micu, Celina, and Robert Pitt. 2005. Impervious Surfaces in Urban Watersheds, *Proceedings of the 78thAnnual Water Environment Federation Technical Exposition and Conference* in Washington, D.C., Oct. 29 – Nov. 2, 2005.

Booth, Derek.1991.Urbanization and the Natural Drainage System–Impacts, Solutions and Prognoses. *Northwest Environment Journal* 7(1): 93–118.

Booth, Derek. 2000. *Forest Cover, Impervious-Surface Area, and the Mitigation of Urbanization Impacts in King County, Washington*. Center for Urban Water Resources Management, Seattle, WA, USA. Unpublished (URL as 03/14/2007) http://www.metrokc.gov/ddes/cao/PDFs04ExecProp/BAS-AppendixB-04.pdf

Booth, Derek, and Lorin Reinelt. 1993. Consequences of Urbanization on Aquatic Systems Measured Effects, Degradation Thresholds, and Corrective Strategies. *Proceedings of the Watershed 1993- A National Conference on Watershed Management* in Alexandria, VA, 545 – 550, March 21–24, 1993.

Brattebo, Benjamin, and Derek Booth. 2003. Long Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. *Water Research* 37: 4369–4376.

Burton, Allen, and Robert Pitt.2000. *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers*. Boca Raton, FL: CRC Press, Inc. ISBN 0-87371-924-7.

City of Olympia. 1995. *Impervious Surface Reduction Study: Final Report*. City of Olympia Public Works Department, Water Resources Program, Olympia, WA.

Center for Watershed Protection. 2003. *The Impervious Cover Model*. Internet Available http://www.stormwatercenter.net/monitoring%20and%20assessment/imp%20cover/impercovr%20model.htm (accessed March 21, 2007)

Davis, Mackenzie, and David Cornwell. 1998. *Introduction to Environmental Engineering*. WCB/ McGraw-Hill Companies Inc.: 154-155 ISBN 0-07-015918-1.

Driver, Nancy, Martha Mustard, Bret Rhinesmith, and Robert Middleburg. 1985. *U.S. Geological Survey Urban Stormwater Database for 22 Metropolitan Areas throughout the United States*. U.S. Geological Survey Open File Report 85-337. Denver, CO.

Evett, Jack, Margaret Love, and James Gordon. 1994. *Effects of Urbanization and Land Use Changes on Low Stream Flow*. Report No. 284. North Carolina Water Resources Research Institute. 66 pgs.

Frazer, Lance. 2005. Paving Paradise: The Peril of Impervious Surfaces. *Environmental Health Perspective*113 (7): A456–A462.

Gesford, Alan, and John Anderson. 2006. *Environmentally Sensitive Maintenance for Dirt and Gravel Roads*. *Chapter 4*.Manual Sponsored by Pennsylvania Department of Transportation and U.S. Environmental Protection Agency. Grant No. PA-2006-001/CP-83043501-0, Harrisburg, PA. Internet Available http://www.epa.gov/owow/nps/sensitive/chap4.pdf (accessed March 21, 2007)

Goetz, Scott, Robb Wright, Andrew Smith, Elizabeth Zinecker, and Erika Schaub. 2003. IKONOS Imagery for Resource Management: Tree Cover, Impervious Surfaces, and Riparian Buffer Analyses in the Mid-Atlantic Region. *Remote Sensing of Environment* 88:195–208.

Gregory, Michael, John Aldrich, Amy Holtshouse, and Kyle Dreyfuss-Wells.2005. Evaluation of Imperviousness Impacts in Large, Developing Watersheds. In: *Efficient Modeling for Urban Water Systems, Monograph 14.* (Edited by W. James, E.A. McBean, R.E. Pitt, and S.J. Wright). CH I Guelph, ON, Canada: 115-150.

Heaney, James. 2000. Principles of Integrated Urban Water Management. In: *Innovative Urban Wet-Weather Flow Management Systems*. Lancaster, PA: Technomic Publishing Company, Inc.: 36- 73.

Lee, Joong, and James Heaney. 2003. Estimation of Urban Imperviousness and Its Impacts on Storm Water Systems. *Journal of Water Resources Planning and Management* 129 (5): 419-426.

Legg, Andrew, Roger Bannerman, and J. Panuska. 1996. *Variation in the Relation of Rainfall to Runoff from Residential Lawns in Madison, Wisconsin, July and August 1995*. Report 96-4194. U.S. Geological Survey. Water-Resources Investigations. Madison, Wisconsin. 11 pgs.

Maestre, Alexander, and Robert Pitt. 2005. *The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information*. U.S. Environmental Protection Agency. Water Planning Division. Washington, D.C.

Narayanan Arvind. 2005. Costs of Urban Stormwater Control Practices. Master Thesis. The University of Alabama at Tuscaloosa.

National Climatic Data Center (NCDC). Birmingham Airport Weather Station. Birmingham, AL. Internet Available (accessed March 21, 2007) http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20000236

Pitt, Robert.1979. *Demonstration of Nonpoint Pollution Abatement through Improved Street Cleaning Practices*. Grant No. EPA-600/2-79-161, U.S. Environmental Protection Agency. Office of Research and Development. Cincinnati, OH. 270 pgs.

Pitt, Robert.1984. *Characterization, Sources, and Control of Urban Runoff by Street and Sewerage Cleaning*. Grant No. R-80597012. U.S. Environmental Protection Agency. Office of Research and Development. Cincinnati, OH.

Pitt, Robert. 1986. The Incorporation of Urban Runoff Controls in the Wisconsin Priority Watershed Program. In: *Advanced Topics in Urban Runoff Research*, (Edited by B. Urbonas and L.A. Roesner). Engineering Foundation and ASCE. New York: 290-313.

Pitt, Robert. 1987. Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges. Ph.D. Dissertation. University of Wisconsin at Madison.

Pitt, Robert. 2000. Principles of Integrated Urban Water Management. In*: Innovative Urban Wet-Weather Flow Management Systems.* Lancaster, PA: Technomic Publishing Company, Inc.

Pitt, Robert, Alexander Maestre, and Renee Morquecho. 2004. Stormwater Characteristics as Contained in the Nationwide MS4 Stormwater Phase 1 Database. *Proceeding in the Water World and Environmental Resources*

Conference 2004, Environmental and Water Resources Institute of the American Society of Civil Engineers, Salt Lake City, UT. July 27 – August 1, 2004.

Pitt, Robert, and G. Shawley. 1982. *A Demonstration of Nonpoint Source Pollution Management on Castro Valley Creek*. Alameda County Flood Control and Water Conservation District (Hayward, CA) and the U.S. Environmental Protection Agency, Water Planning Division (Nationwide Urban Runoff Program). Washington, D.C.

Pitt, Robert, Janice Lantrip, Robert Harrison, Charles Henry, and Dongsen Xue.1999. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. Grant No. EPA 600/R-00/016. U.S. Environmental Protection Agency. National Risk Management Research Laboratory. Office of Research and Development. Cincinnati, OH. 231 pgs.

Pitt, Robert, and J. McLean. 1986.*Toronto Area Watershed Management Strategy Study – Humber River Pilot Watershed Project*. Ontario Ministry of the Environment, Toronto, ON, Canada, 483 pgs.

Pitt, Robert, and John Voorhees. 1995. Source Loading and Management Model (SLAMM). *Seminar Publication: National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels*. March 30 – April 2, 1993. Grant No. EPA/625/R-95/003. U.S. Environmental Protection Agency. Center for Environmental Research Information. Cincinnati, OH: 225-243

Pitt, Robert, and John Voorhees. 2002. SLAMM, the Source Loading and Management Model. In: *Wet-Weather Flow in the Urban Watershed: Technology and Management* (Edited by Richard Field and Daniel Sullivan). Boca Raton, FL: CRC Press, Lewis Publishers: 103- 139.

Pitt, Robert, and Martin Bozeman. 1982. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek.* Grant No. EPA-600/S2-82-090, PB83-111-021. U.S. Environmental Protection Agency, Office of Research and Development Cincinnati, OH. 142 pgs.

Pitt, Robert, and Pam Bissonnette. 1984. *Bellevue Urban Runoff Program Summary Report*. Grant No. PB84 237213. U.S. Environmental Protection Agency. Water Planning Division. Washington, D.C. 173 pgs.

Pitt, Robert, Richard Field, Melinda Lalor, and M. Brown. 1995. Urban Stormwater Toxic Pollutants: Assessment, Sources and Treatability. *Water Environment Research* 67 (3): 260-275. Discussion and closure 68 (4): 953-955.

Pitt, Robert, and Rocky Durrans.1995. Drainage of Water from Pavement Structures. *Alabama Department of Transportation*. 253 pgs.

Pitt, Robert, Derek Williamson, and John Voorhees. 2005c. Review of Historical Street Dust and Dirt Accumulation and Washoff Data. In: *Effective Modeling of Urban Water Systems*, *Monograph 13*. (Edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, ON: 203 – 246.

Pitt, Robert, Roger Bannerman, Shirly Clark, and Derek Williamson. 2005a. Sources of Pollutants in Urban Areas (Part 1) – Older Monitoring Projects. In: *Effective Modeling of Urban Water Systems*, *Monograph 13*. (Edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, ON: 465 – 484 and 507 – 530.

Pitt, Robert, Roger Bannerman, Shirly Clark, and Derek Williamson. 2005b.Sources of Pollutants in Urban Areas (Part 2) – Recent Sheetflow Monitoring Results. In: *Effective Modeling of Urban Water Systems*, *Monograph 13*. (Edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, ON: 485 – 530.

Reilly, James, Patricia Maggio, and Steven Karp. 2004. A Model to Predict Impervious Surface for Regional and Municipal Land Use Planning Purposes. *Environmental Impact Assessment Review* (24):363-82

Sartor, J. D., and G. B. Boyd. 1972. Water Pollution Aspects of Street Surface Contaminants. Grant No. EPA-R2-72-081. Environmental Protection Agency. Washington D.C.

Schueler, Thomas. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*. Center for Watershed Protection 1(3): 100-111

SCS (U.S. Soil Conservation Service, now Natural Resources Conservation Service).1986. *Urban Hydrology for Small Watersheds*. U.S. Department of Agriculture Techical Release No. 55.

Smullen, Jim, and Kelly Cave. 2002. National Stormwater Runoff Pollution Database. In: *Wet-Weather Flow in the Urban Watershed* (Edited by Richard Field and Daniel Sullivan). Boca Raton, FL: CRC Press, Lewis Publishers.

Stone, Brian. 2004. Paving over Paradise: How Land Use Regulations Promote Residential Imperviousness. *Landscape and Urban Planning* (69): 101-13.

Storm Water Management Authority Inc. (SWMA). Internet Available http://www.swma.com/ (accessed March 21, 2007)

Sutherland, Roger. 1993. *Portland Stormwater Quality using SIMPTM*. Draft report. Lake Oswego, OR: OTAK, Inc.

Sutherland, Roger. 1995. Methods for Estimating the Effective Impervious Are of Urban Watersheds. *Watershed Protection Techniques.* Center for Watershed Protection. 2 (1): 282-284.

Southeastern Wisconsin Regional Planning Commission (SEWRPC).1991. *Costs of Urban Nonpoint Source Water Pollution Control Measure.* Waukesha, WI.

University of Wisconsin and The Wisconsin Department of Natural Resources.1997. Polluted Urban Runoff- A Source of Concern. DNR WT 483-97.

US Census Bureau.2000. Census 2000 Urban and Rural Classification. Internet Available http://www.census.gov/geo/www/ua/ua2k.html (accessed March 21, 2007)

U. S. Environmental Protection Agency. Urbanization and Streams: Studies of Hydrologic Impacts. Internet Available http://www.epa.gov/owow/nps/urbanize/report.html (accessed March 21, 2007)

U. S. Environmental Protection Agency. 1983. *Results of the Nationwide Urban Runoff Program*. Grant No. PB 84-185552. Water Planning Division.

Wells, Cedar.1995. Skinny Streets and One-sided Sidewalks: A Strategy for Not Paving Paradise. *Watershed Protection Techniques*. Center for Watershed Protection 1(3): 135-137

Appendix A
WinSLAMM Re-Calibration

A1. WinSLAMM Data Files

Data from the NSQD (National Stormwater Quality Database) MS4 (municipal separate storm sewer system) database (Maestre and Pitt 2005) for Jefferson County, Alabama, was used to conduct a re-validation of the WinSLAMM model before it was used to calculate the expected runoff conditions for the case study discussed in Chapter 3.

In order to construct WinSLAMM files, several types of information about the site is needed, such as describing the drainage system (grass swales, curb and gutter in good/fair/poor condition, undeveloped roadside) and the fraction of each type of drainage system serving the study area; the soil type (sandy, silty, clayey); site development characteristics (such as the roof type, street texture, etc.); and measurements of the different source areas. Except for the soil type, all of the other information was obtained during field surveys, or during the aerial photograph measurements.

A separate evaluation was performed to determine the site's general soil type. Field maps showing the exact site locations were used in conjunction with Alabama topographic maps (scale 1:24000, published by US Geological Survey in 1988) and the *Soil Survey of Jefferson County*, Alabama, maps (scale 1:24000, published by US Department of Agriculture Soil Conservation Service in 1975) to identify the site locations on the county soil maps.

The information necessary to perform a WinSLAMM model run is stored in a WinSLAMM data file and its associated parameter files. This information includes a description of land uses and source areas, the time period and corresponding rainfall events, the pollutant control devices applied to the site, and the pollutants to be analyzed

Several parameter files are needed when conducting a WinSLAMM analysis. The most important file used with the model is the rain file (*.RAN) which describes the rain series during the study period. To better evaluate the conditions in the five different Jefferson County drainage areas, a separate rain file was created for each area based on the nearest rain gage data. Each file described the rains that occurred during the field sampling, including several rains before and after the sampling period started and ended. Separate rain files were used for each watershed in order to best represent the actual rains that occurred at each site, as there was substantial variability in the rain characteristics (depth and duration) over the entire area. The rain files contain the start and end dates and times for each rain, and the total rain depth for the rain. A six hour dry period separated each rain event. The model calculated the antecedent rain period before each event, and the average rain intensity.

For the Little Shades Creek watershed analyses, the typical Birmingham area rain file (BHAM76.RAN) was used. This file includes the rains for the entire 1976 year which has been previously determined to be a representative rain year for the area, based on comparisons with long term (about 45 year) rain records. Birmingham's rains are reasonably well distributed throughout the year. However, some of the wetter winter months, plus March and July, have twice the rainfall of October, the driest month.

Summer rainfall is almost entirely from scattered afternoon and early evening thunderstorms. Serious droughts are rare and most dry spells are not severe.

There are mandatory and optional parameter files required to run WinSLAMM. The runoff file (*.RSV), a required file, contains volumetric runoff coefficients for each surface type that generates surface runoff for the rains. For this study, the RUNOFF.RSV file supplied with the model was used for all runs. The file was developed based on extensive monitoring data collected in Toronto and Milwaukee (as reported by Pitt 1987). It has been verified using additional independent data representing a wide range of land development and rain conditions. The current NSQD MS4 database for Jefferson County Alabama does not include runoff data, so it was not possible to re-verify this file for local conditions.

Four additional files were previously created based on Birmingham area regional research and include:

1 particulate solids concentration file (BHAM.PSC) that describes the particulate residue (particulate solids) concentrations for each source area (except for roads) and land use, for several rain categories;

2. particulate residue reduction file (DELIVERY.PRR) that accounts for the deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls (the delivery file is calibrated for swales, curb and gutters, undeveloped roadsides, or combinations of drainage conditions);

3. the pollutant file (BHAM.PPD) is needed when examining pollutants besides particulate solids, and is used to describe the particulate pollutant strengths related to particulate residue (in units such as mg pollutant / kg

particulate solids) and the filterable pollutant concentrations (in units such as mg/L) for each source area for each land use (this file also contains the coefficient of variation (COV) values for each pollutant for Monte Carlo simulations in WinSLAMM in order to account for the random nature of stormwater pollutants); and

4. the street delivery file (STREET.STD) is used to define the limits of the street dirt washoff routines in the model based on rain characteristics (energy limitations).

These four files (*.PSC, *.PRR, *.PPD, *.STD) were re-validated using the NSQD MS4 monitoring information for Jefferson County prior to their use in examining the Little Shades Creek data. The Jefferson County MS4 data were not affected by any stormwater source area or outfall control measures.

A.2 Rain File Construction

The first step in the construction of the rain files was the collection of hourly rainfall data for the Birmingham, AL, area. The local rain data for the Birmingham Municipal Airport Weather Observation Station was obtained through its internet site maintained by NCDC (National Climatic Data Center). http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20000236. The hourly precipitation data (measured in hundredths of inches, stored and observed to the same accuracy) from January 01, 2001 to April 11, 2005 were downloaded as a text file (.TXT) and used to create the MASTER.RAN file, covering the same time period as the local MS4 data collection.

This rain file, which served as the basic rain file for all of the five individual rain files for each of the five monitoring locations, had some missing data. Periods of missing data were added manually and labeled “no record” for the start/end date and time of the rain and rain depth. The “no record” rain depth values were replaced using estimated values obtained by averaging the values obtained from four Birmingham Water Works (BWW) Rainfall Stations (Lake Purdy, Putnam, Shades and Western) for that particular day. Carson and Inland Lake stations (also part of the BWW network) were not used due to their remote location from the study watersheds. The BHAMSRCE.RAN rain file, supplied with WinSLAMM, was used as a reference to estimate the durations of the rain events. BHAMSRCE.RAN was created using long-term rainfall records. It includes 12 rain events from 0.01 to 4 inches and corresponding typical rain durations.

A rain file was created for each MS4 station using this master rain file. The rain files include the start/end date and time of the rain event, along with the total rain depth. The final individual rain files start and end approximately 1 month before and after the monitoring dates.

A.3 WinSLAMM Re-Calibration Process

The verification and calibration procedures for WinSLAMM are the same as for any other stormwater quality model: local data has to be collected to check the accuracy of the calculated results produced by the model. The data that is needed include outfall quality and quantity measurements and watershed information.

A good approach to calibrate a model is to collect all the necessary information from one watershed and to use that data to adjust the necessary parameters to obtain the best agreement between the calculated and observed conditions. Verification then uses independent data from another watershed to compare the calculated and observed conditions. Another common method used to calibrate and verify a model is to collect information for a series of events and use that data for adjusting the model parameters to obtain the best fit. Verification is then accomplished using additional data from the same watershed. During this re-calibration and re-verification of WinSLAMM, we used the first approach due to the fact that we had monitoring data from five independent drainage areas.

The process of calibrating WinSLAMM for this project used the following order:

- Runoff quantity (*.rsv file)
- Particulate solids loading (*psc and delivery files)
- Total pollutant loading (*.ppd file)

The runoff quantity file has to be calibrated before any of the additional parameter files are examined. After this file is calibrated, the particulate solids files must be calibrated, followed by the other pollutants. It is very important to be completely satisfied with the calibration at each step before proceeding to the next one. As already mentioned, the NSQD MS4 Jefferson County monitoring information does not include runoff data, so the RUNOFF.RSV could not be re-validated, therefore the re-calibration process started with particulate solids and delivery files.

Data from five drainage areas are available for the re-calibration and verification process. Therefore, the calibration process started with data from the simplest and most uniform drainage area (one that has only a single land use); these areas were calibrated first before moving on to more complex areas, such as areas having a mixture of land uses and areas having both connected and disconnected roofs.

One single data file (*.dat) that stores the information necessary to perform a WinSLAMM model run was created for each drainage area based on the field data and the surface areas measured from the aerial photographs. Each data file was modeled twice, once using the rain file for the specific monitoring event), and again using the BHAMSRCE rain file. The model output included the percentage contribution of runoff volume and pollutants of interest for each rain and for each source area, indicating the main source areas that generate runoff for the different rain depths. The use of BHAMSRCE rain file (containing only 12 sorted rains) was important because it revealed the rain depth at which each source area generated runoff and pollutants, and helped focus on certain areas that needed to have their parameters modified. The monitored rain events covered a smaller range of rain depths.

A.3.1 Re-validation of particulate solids concentration (.PSC) file*

WinSLAMM uses the mandatory PARTICULATE.PSC file to describe particulate solids concentrations for each source area (except for streets) and all land uses (except freeway), for several rain categories. The model also uses the DELIVERY.PRR file to adjust the source predictions for outfall conditions because the larger particulates will accumulate in the storm drainage system during the smaller rains. This file is used for swales, curb and gutters, undeveloped roadsides, or combinations of drainage components.

The washoff of particulates from streets is directly calculated using explicit accumulation and washoff algorithms based on land use, street texture, and rain conditions. Freeway paved lane and shoulder areas are also directly predicted and have explicit algorithms that calculates the washoff of particulate solids based on traffic volumes and rain conditions. The street and highway predictions for particulate solids are modified by the STREET.STD file to account for reduced rainfall energy during the smaller rains. Concentrations of particulate solids at the beginning of the rains at some source area (especially paved parking areas) are much greater than later in the same rain ("first flush" conditions). This variation is highly dependent on rain energy and WinSLAMM uses a similar relationship to describe particulate solids variations for different rain depths.

The re-calibration process was started by running the WinSLAMM files for the monitored drainage areas using their own rain file, and the delivery, street and particulate files without any additional pollutants selected. The predicted and observed particulate solids concentrations for the monitored events were compared by creating a double probability plot of observed and predicted values (Figure A1). The data is plotted using a log- normal distribution so that the points should form approximately a straight line. Departures from this straight line indicate departures from the specified normal distribution. The desired pattern for the observed and predicted particulate solids concentration plots is to have two overlapping lines of points with minimal deviation. The desired pattern for the residual error plot is an even, narrow band over the range of observed rain depths, centered on the zero residual error horizontal line (Figure A2). Also, the sum of the observed and predicted particulate solids concentration (mg/L) for all monitored events has to be calculated. The percentage difference in the sum of concentrations should be small indicating small changes needed. It is likely that the largest difference in the particulate solids concentrations are associated with small rain depths (WinSLAMM will probably over-estimates the concentrations, unless the delivery files are correctly used), while the differences for the larger rains will be smaller. WinSLAMM calibration for particulate solids concentrations and loadings was accomplished by modifying the DELIVERY.PRR, STREET.STD and BHAM.PSC files.

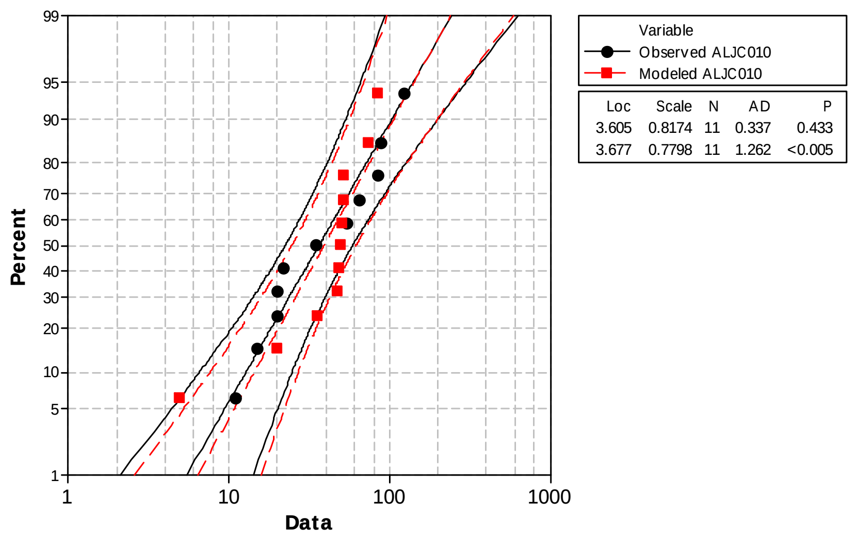


Fig. A1. Example of Log-Normal Probability Plot for Site ALJC010 (Residential Land Use)

The *.PRR file adjusts the delivery of the particulate solids for the whole watershed (based on the drainage system type) and usually has a greater effect on small rains, with minimum effects on large rains. The DELIVERY.PRR file data was smoothened by modifying almost all of the delivery fractions by the same amount (Figure

A3). Grass swales, undeveloped roadsides, and flat curbs and gutters have slow runoff velocities and lower carrying capacities of sediment than flows in steeper areas or smoother gutters.

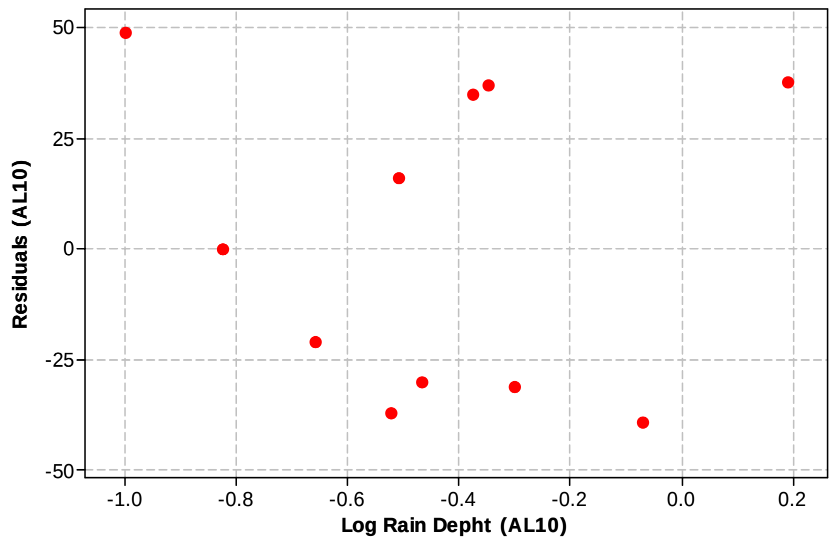


Fig. A2. Example of Residual Plot for Site ALJC010 (Residential Land Use)

The differences are the most pronounced for the smaller rains than for larger rains where the velocities are all much greater, corresponding too much greater sediment carrying capacities.

The street delivery file (*.STD) only affects solids originating from the street areas, and was the next file to be calibrated. Separate street delivery files were created for each land use (Figure A4).

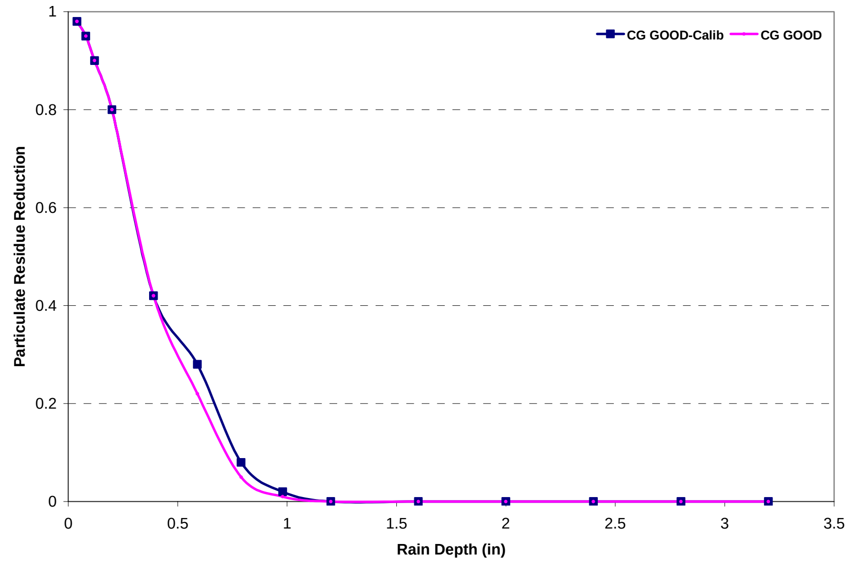


Fig. A3. Example of Smoothed Delivery File (for Curbs and Gutters in Good Conditions or Very Steep Drainage System)

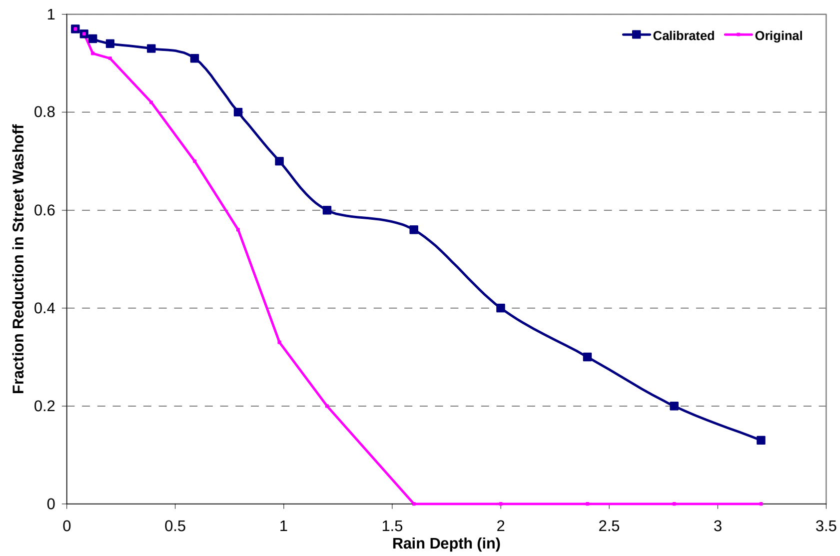


Fig. A4. Example of Street Delivery File (for Residential Land Uses)

The *.PSC file describes the particulate solids concentrations (mg/L) for each rain for each source area, showing where WinSLAMM is generating the particulate solids for different rain depths. The calibration process for the *.PSC file began by first focusing on the larger storms, trying to bring the medians of the observed and calculated values close together. For some land uses, we ended up increasing and decreasing the PSC values more for the larger storms than for the smaller storms (Figure A5 and A6).

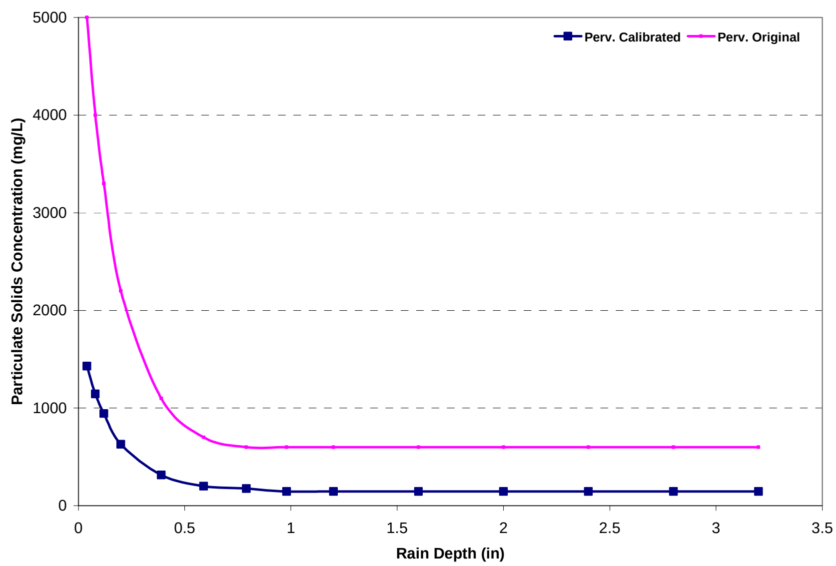


Fig. A5. Example of Particulate Solids Concentration File for Residential Land Use - Pervious Surfaces

After each change was made, the program was re-run using the new parameter file and the results were reviewed. It was necessary to repeat this process a few times to become satisfied that no further improvements were possible.

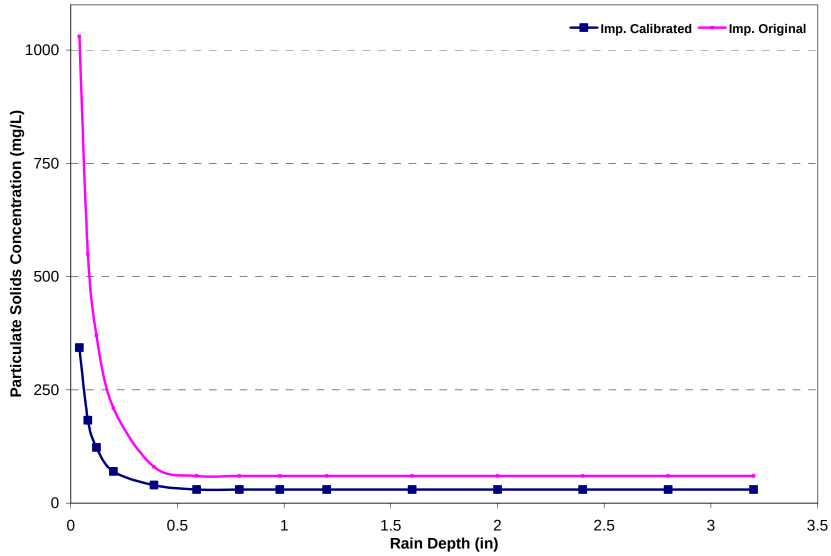


Fig. A6. Example of Particulate Solids Concentration File for Residential Land Use - Impervious Surfaces

A.3.2 Re-validation of pollutants concentration (.PPD) file*

The pollutant file BHAM.PPD describes the particulate pollutant strengths associated with the particulate solids (mg pollutant/kg particulate solids) and the filterable pollutant concentrations (mg/L) for each land use for each source area. This file is not needed if the watershed analysis includes only runoff volume and particulate solids calculations. This file also contains the COV values for each pollutant for Monte Carlo simulations in WinSLAMM, an option which is turned off by the default (seed of -42).

For this study, only phosphorus, COD, copper, and zinc from the pollutants list were calibrated. The procedure for calibrating the total pollutants followed the same pattern as for calibrating the *.PSC file, with one exception: the total pollutant value is the sum of the particulate and filterable pollutant values. Therefore, the calibration was performed for particulate and filterable pollutants by increasing and decreasing the values by the same amount for one particular pollutant (Figure A7 and A8).

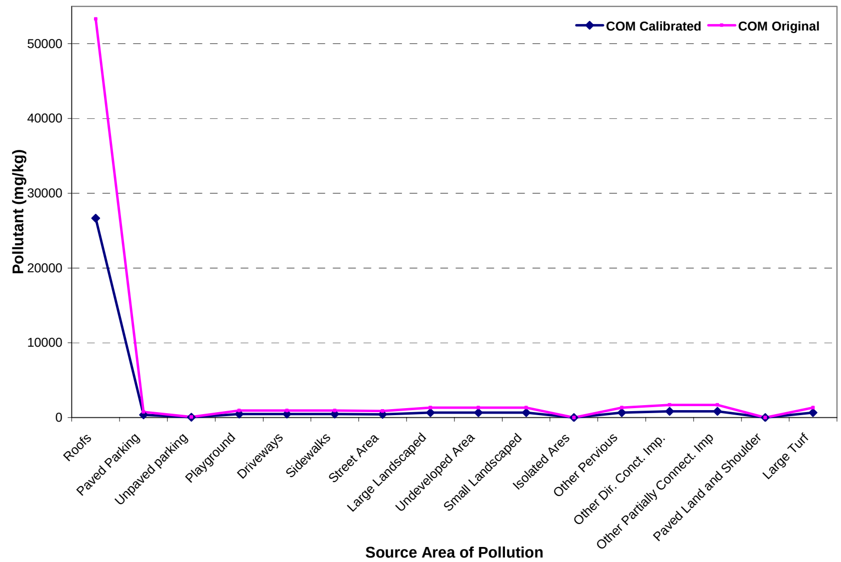


Fig. A7. Example of Particulate Zinc for Commercial Land Use

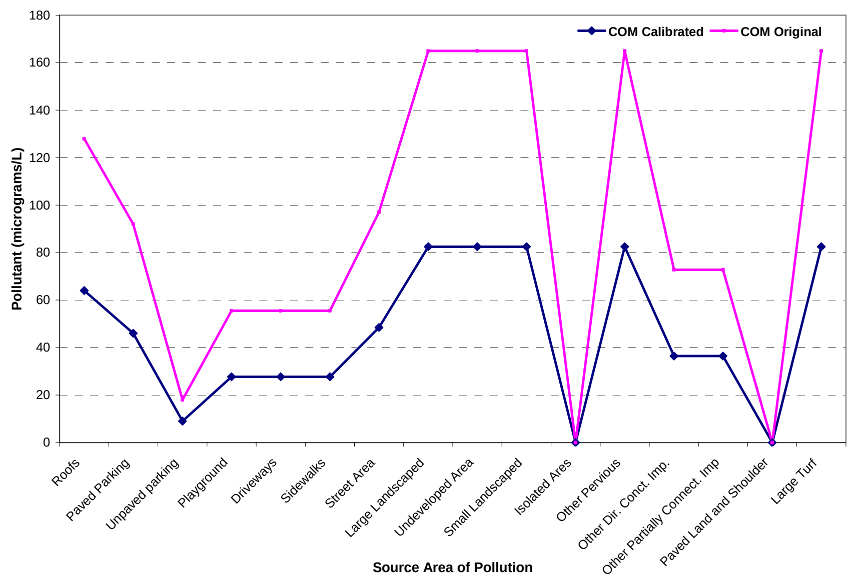


Fig. A8. Example of Filterable Zinc Concentration for Commercial Land Use

Once again, after each change was made to the pollutant file, the program was re-run using the new *.PPD parameter file and the already calibrated particulate solids concentrations files. The results were reviewed and the process was repeated multiple times until satisfied that no further improvements were possible.

Appendix B
Jefferson County Stormwater Permit Monitoring Sites and Data

B1. Introduction

Jefferson County is located in north central Alabama (Figure B1) at the foothills of the Appalachian Mountains. The city of Birmingham is the county seat. The population of Jefferson County in 2005 was estimated at 657,229, whereas the Birmingham population was 231,483 (US Census 2005). The Jefferson County area experiences four distinct seasons. The annual average temperature ranges from a high of 72.7 F to a low of 51.3 F. On a typical mid-summer day, the temperature is nearly 70 F at daybreak, approaches 90 F at noon, and level off in the low 90s during the afternoon (NCDC website). The rainfall is abundant and quite well distributed throughout the year. The stormiest time of the year with the greatest risk of severe thunderstorms and tornadoes are the months of March and April, while October is the driest month (NCDC website).

On November 16, 1990, the U.S. Environmental Protection Agency published NPDES stormwater permit regulations for Phase 1 communities (those having more than 100,000 in population). Jefferson County, the City of Birmingham, along with 22 other county municipalities were required to comply with these regulations. In order to gain the required legal authority, reduce redundancy and cost, a Storm Water Management Act was introduced to the legislature in July 1995. This Act gave the twenty-three cities and

Jefferson County the ability to form a Public Corporation - The Storm Water Management Authority (SWMA), Inc.

The mission of this corporation is to procure water samples in the authority jurisdiction (Jefferson, part of Shelby and part of St. Clair counties) in both wet and dry weather conditions, to analyze them using appropriate laboratory testing to determine the quality of water flows in the minor streams and creeks, and to educate the public about non-point source pollution and the types of practices that contribute to pollution (SWMA website). SWMA samples 150 sites and inspects approximately 3500 outfalls per year within the jurisdiction to check for illicit connections to the system.

Fig. B1. Alabama State and Jefferson County Map Location

B2. Sampling Stations

For this thesis, five SWMA drainage areas and associated data were examined and used to re-verify the WinSLAMM model. One of the drainage areas was also used as a case study to consider the stormwater quality and quantity effects of combinations of stormwater control devices.

According to the sampling guidance (40 CFR 122.21) for the permit application, each community was required to sample at least a residential, a commercial and an industrial watershed. According to the activity performed in the watershed, each site was classified as residential, commercial, industrial, open space, freeway, or mixed. When a single activity was not identified for the watershed, then the site was considered mixed, with a predominant land use. Table B1 shows the drainage areas (acres) and the associated land use components (percentages) for each outfall, highlighting the main land use in each drainage area.

Table B1. Land Use (percent) and Drainage Area (acres) for Each Sampling Stations

	ALJC 001	ALJC 002	ALJC 009	ALJC 010	ALJC 012
Residential	8.5	14.5	**89.3**	**82.5**	25.2
Institutional	0.6	0.8	6.7	0.0	0.0
Commercial	11.9	2.5	4.1	0.0	**74.8**
Industrial	**61.8**	**75.5**	0.0	0.0	0.0
Open Space	5.8	6.7	0.0	17.5	0.0
Freeway	11.4	0.0	0.0	0.0	0.0
Drainage Area	**341**	**721**	**102**	**133**	**228**

The runoff samples used in this research to re-calibrate the WinSLAMM model for local conditions were collected by SWMA during various rain conditions. At least three samples need to be collected every year at each outfall location and each storm has to be at least one month apart and have at least a 3 days antecedent dry period to meet the conditions of their permit. Only samples from rain events greater than 0.1 inches, and close to the annual mean conditions, were considered valid for the. A composite sample based on sub-samples collected during the first three hours of the event was collected for each storm. An additional grab sample was required during the first 30 minutes of the event to evaluate the “first flush” effect. Because the sample collection process was driven by the rain occurrence and distribution over the Jefferson County area, the SWMA team in charge with sample collection was constantly receiving weather reports from Birmingham Airport Weather Station in order to capture the beginning of the rain and to sample the “first flush.”

The samples used for this research were all collected manually as composites over a 3-hour period, using a dipper and a container for stormwater storage. The precipitation depth was also measured using a portable rain gauge. The samples were use for composite analysis following the Methods for Chemical Analysis (1994). The quality control and quality assurance (QA/QC) of the data were performed by SWMA employees and by Maestre and Pitt (2005) when compiling the NSQD version 1.1 database. The data was reviewed by rows (corresponding to individual runoff events) and then by columns (corresponding to measured constituents), at least once and compared to information contained in the original report. For each constituent, probability plots, box and whisker plots, and time series plots were used to identify possible errors mainly associated with the transcription of the information, or as typographical errors in the original report (Maestre and Pitt 2005).

The values of the detection limits and their frequencies vary among the different constituents and monitoring locations. The most common locally non-detected observations were for total copper and total zinc analyses, mainly in mixed residential and mixed commercial land uses. The detection limits (<20 µg/L for copper and <30 µg/L for zinc) imply that copper and zinc may have been detected in the stormwater samples, but their values were at least smaller than the measured detection limit values.

The precipitation depths and the constituent concentration measurements (TSS, COD, P, and Zn) for the monitored events are shown in Tables B3 to B7. These values are also included in the NSQD database version 1.1 (Maestre and Pitt 2005). This version of the NSQD contains 3,765 stormwater events collected during the 1992-2002 period, representing sites throughout the US, for most land uses and for many constituents, and is the most comprehensive stormwater quality database currently available. Approximate 60% of the NSQD data is located in the Mid-Atlantic and southeastern states, with about 2% of the data collected in Alabama from the Birmingham and Huntsville areas. About one third of the sites included in the database correspond to residential areas, another third is shared by commercial and industrial land uses. The remaining third correspond to freeways, open space, institutional and all the mixed land uses. Several schools were identified in the sites, however only one site was considered 100% institutional (Table B2) (Maestre and Pitt 2005).

Table B2.Total Number of Sites by Land Use Included in the NSQD version 1.1 Database

Land Use	Number of Sites	Percentage
Residential	111	30.8
Mixed Residential	44	12.2
Commercial	51	14.2
Mixed Commercial	29	8.1
Industrial	54	15.0
Mixed Industrial	22	6.1
Institutional	1	0.3
Open Space	10	2.8
Mixed Open Space	13	3.6
Freeways	22	6.1
Mixed Freeways	3	0.8

Source: Maestre, Alexander, and Robert Pitt. 2005. *The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information*. U.S. Environmental Protection Agency, Water Planning Division. Washington D.C.

Data from Table B8 is from the NSQD, version 1.1, database which is used as a benchmark for comparison with locally collected data. Locally observed median copper and dissolved phosphorus concentrations are higher than the national median values for all land uses, with a much higher concentration of phosphorus in mixed industrial drainage areas (0.17 mg/L compared to 0.08 mg/L) (Tables B3 through B8).

The coefficients of variations for the locally collected data are in general below or close to 1 for all constituents (exception being dissolved phosphorus), showing typically large variations in the measured concentrations. In contrast, the national's data coefficients of variations sometimes exceeds values of 3, showing a larger variability among the constituents' values for all land uses, most likely because the national data represent a much greater variety of conditions affecting stormwater quality.

Table B3. The Precipitation Depth and the Constituents Measurements Used in Model Calibration for Drainage Area ALJC 001 (Mixed Industrial Land Use, Drainage Area 341 acres)

Location ID	Precipitation Depth (in)	Start Date (mm/dd/yy)	Start Time (hh:mm)	End Date (mm/dd/yy)	End Time (hh:mm	TSS (mg/L)	COD (mg/L)	Phosphorous Dissolved (mg/L)	Copper Total (μg/L)	Zinc Total (μg/L)
ALJC 001	0.2	11/27/2001	14:45	11/27/2001	17:45	60	48	0.13	50	230
ALJC 001	1.6	1/19/2002	7:45	1/19/2002	10:45	158	66	0.08	<20	250
ALJC 001	0.17	4/22/2002	8:00	4/22/2002	11:00	36	120	0.44	50	170
ALJC 001	0.32	8/9/2002	14:00	8/9/2002	17:00	173	181	0.45	20	300
ALJC 001	0.6	5/5/2003	8:45	5/5/2003	11:45	268	*	0.11	60	270
ALJC 001	0.4	6/27/2003	12:00	6/27/2003	15:00	57	*	0.19	<20	80
ALJC 001	0.45	12/23/2003	13:20	12/23/2003	16:20	124	*	1.3	40	250
ALJC 001	*	6/7/2004	9:00	6/7/2004	12:00	23	*	0.17	<20	50
ALJC 001	0.4	9/7/2004	8:00	9/7/2004	11:00	28	*	0.16	30	60
ALJC 001	0.38	12/22/2004	9:20	12/22/2004	12:20	74	*	0.34	<20	130
ALJC 001	1.3	3/7/2005	15:00	3/7/2005	18:00	58	*	0.21	<20	110
ALJC 001	0.4	4/6/2005	14:55	4/6/2005	17:55	102	*	0.2	30	120
Number of Observations	**11**	**-**	**-**	**-**	**-**	**12**	**4**	**12**	**12**	**12**
% of Samples Above Detection	**91.7**	**-**	**-**	**-**	**-**	**100**	**33.3**	**100**	**58.3**	**100**
Median	**0.40**	**-**	**-**	**-**	**-**	**67**	**93**	**0.20**	**40**	**150**
Coefficient of Variation	**0.81**	**-**	**-**	**-**	**-**	**0.75**	**0.58**	**1.06**	**0.35**	**0.52**

* Missing Data

Table B4. The Precipitation Depth and the Constituents Measurements Used in Model Calibration for Drainage Area ALJC 002 (Mixed Industrial Land Use, Drainage Area 721 acres)

Location ID	Precipitation Depth (in)	Start Date (mm/dd/yy)	Start Time (hh:mm)	End Date (mm/dd/yy)	End Time (hh:mm	TSS (mg/L)	COD (mg/L)	Phosphorous Dissolved (mg/L)	Copper Total (µg/L)	Zinc Total (µg/L)
ALJC 002	0.23	11/27/2001	14:30	11/27/2001	17:30	22	51	0.11	80	700
ALJC 002	0.22	3/20/2002	11:30	3/20/2002	14:30	31	79	0.09	40	1810
ALJC 002	0.35	5/9/2002	16:00	5/9/2002	19:00	43	42	0.11	50	550
ALJC 002	0.3	8/28/2002	9:30	8/28/2002	12:30	53	*	0.14	<20	290
ALJC 002	0.5	6/11/2003	15:00	6/11/2003	18:00	85	*	0.14	50	430
ALJC 002	0.65	7/22/2003	11:15	7/22/2003	14:15	96	*	0.18	60	330
ALJC 002	0.39	12/23/2003	13:20	12/23/2003	16:20	108	*	0.23	110	630
ALJC 002	*	6/7/2004	9:10	6/7/2004	13:10	17	*	0.09	50	310
ALJC 002	0.32	9/7/2004	9:20	9/7/2004	13:20	18	*	0.27	40	120
ALJC 002	0.62	3/22/2005	9:55	3/22/2005	12:55	390	*	0.2	70	240
Number of Observations	**10**	**-**	**-**	**-**	**-**	**11**	**3**	**11**	**11**	**11**
% of Samples Above Detection	**90.9**	**-**	**-**	**-**	**-**	**100**	**27.3**	**100**	**90.9**	**100**
Median	**0.37**	**-**	**-**	**-**	**-**	**53**	**51**	**0.14**	**55**	**430**
Coefficient of Variation	**0.57**	**-**	**-**	**-**	**-**	**1.24**	**0.34**	**0.43**	**0.42**	**0.84**

* Missing Data

Table B5. The Precipitation Depth and the Constituents Measurements Used in Model Calibration for Drainage Area ALJC 009 (Mixed Residential Land Use, Drainage Area 102 acres)

Location ID	Precipitation Depth (in)	Start Date (mm/dd/yy)	Start Time (hh:mm)	End Date (mm/dd/yy)	End Time (hh:mm	TSS (mg/L)	COD (mg/L)	Phosphorous Dissolved (mg/L)	Copper Total (µg/L)	Zinc Total (µg/L)
ALJC 009	0.3	8/31/2001	10:50	8/31/2001	13:50	18	<10	0.17	<20	<30
ALJC 009	0.12	3/9/2002	12:30	3/9/2002	15:30	23	50	0.14	<20	40
ALJC 009	0.23	9/13/2002	16:30	9/13/2002	19:30	44	*	0.15	20	50
ALJC 009	0.65	6/27/2003	11:45	6/27/2003	14:45	25	*	0.27	<20	50
ALJC 009	0.23	8/12/2003	15:30	8/12/2003	18:30	8	*	0.18	<20	<30
ALJC 009	0.15	10/10/2003	7:45	10/10/2003	10:45	17	*	0.25	<20	<30
ALJC 009	2.1	6/7/2004	9:15	6/7/2004	12:30	6	*	19.3	60	50
ALJC 009	0.5	9/7/2004	7:00	9/7/2004	9:45	18	*	0.25	<20	<30
ALJC 009	0.19	10/19/2004	8:15	10/19/2004	11:45	17	*	0.29	90	40
ALJC 009	0.6	1/13/2005	10:45	1/13/2005	13:45	42	*	0.07	<20	<30
Number of Observations	**10**	**-**	**-**	**-**	**-**	**10**	**2**	**10**	**10**	**10**
% of Samples Above Detection	**100**	**-**	**-**	**-**	**-**	**100**	**10**	**100**	**30**	**50**
Median	**0.27**	**-**	**-**	**-**	**-**	**18**	**50**	**0.22**	**60**	**50**
Coefficient of Variation	**1.17**	**-**	**-**	**-**	**-**	**0.58**	**n/a**	**2.87**	**0.62**	**0.12**

* Missing Data

Table B6. The Precipitation Depth and the Constituents Measurements Used in Model Calibration for Drainage Area ALJC 010 (Mixed Residential Land Use, Drainage Area 133 acres)

Location ID	Precipitation Depth (in)	Start Date (mm/dd/yy)	Start Time (hh:mm)	End Date (mm/dd/yy)	End Time (hh:mm	TSS (mg/L)	COD (mg/L)	Phosphorous Dissolved (mg/L)	Copper Total (μg/L)	Zinc Total (μg/L)
ALJC 010	0.1	8/31/2001	9:30	8/31/2001	13:30	54	15	0.15	<20	<30
ALJC 010	0.15	3/9/2002	13:15	3/9/2002	15:15	20	24	0.05	<20	<30
ALJC 010	1.55	5/29/2002	9:40	5/29/2002	12:40	123	44	0.1	20	50
ALJC 010	0.31	9/13/2002	15:30	9/13/2002	18:30	65	*	0.15	<20	<30
ALJC 010	0.42	6/11/2003	15:00	6/11/2003	18:00	85	*	0.07	20	30
ALJC 010	0.22	10/17/2003	11:00	10/17/2003	14:00	15	*	0.16	30	<30
ALJC 010	0.3	6/14/2004	15:15	6/14/2004	18:15	11	*	0.11	<20	<30
ALJC 010	0.34	9/7/2004	7:00	9/7/2004	10:15	22	*	0.14	<20	<30
ALJC 010	0.5	12/5/2004	15:15	12/5/2004	18:00	20	*	0.17	<20	<30
ALJC 010	0.85	1/13/2005	10:45	1/13/2005	13:45	35	*	0.14	<20	<30
ALJC 010	0.45	4/6/2005	14:45	4/6/2005	17:45	89	*	0.11	<20	<30
Number of Observations	**11**	**-**	**-**	**-**	**-**	**11**	**3**	**11**	**11**	**11**
% of Samples Above Detection	**100**	**-**	**-**	**-**	**-**	**100**	**27.3**	**100**	**27.3**	**18.2**
Median	**0.34**	**-**	**-**	**-**	**-**	**35**	**24**	**0.14**	**20**	**40**
Coefficient of Variation	**0.87**	**-**	**-**	**-**	**-**	**0.76**	**0.54**	**0.31**	**0.25**	**0.35**

* Missing Data

Table B7. The Precipitation Depth and the Constituents Measurements Used in Model Calibration for Drainage Area ALJC 012 (Mixed Commercial Land Use, Drainage Area 228 acres)

Location ID	Precipitation Depth (in)	Start Date (mm/dd/yy)	Start Time (hh:mm)	End Date (mm/dd/yy)	End Time (hh:mm	TSS (mg/L)	COD (mg/L)	Phosphorous Dissolved (mg/L)	Copper Total (µg/L)	Zinc Total (µg/L)
ALJC 012	0.32	12/17/2001	10:15	12/17/2001	13:15	45	24	0.06	<20	50
ALJC 012	1.8	5/29/2002	9:40	5/29/2002	12:40	82	45	0.07	<20	80
ALJC 012	0.55	9/25/2002	6:15	9/25/2002	9:15	27	*	0.15	<20	<30
ALJC 012	0.5	6/11/2003	15:00	6/11/2003	18:00	50	*	0.18	<20	120
ALJC 012	0.15	7/31/2003	11:00	7/31/2003	14:00	30	*	0.2	<20	70
ALJC 012	0.3	12/13/2003	14:30	12/13/2003	17:30	23	*	0.16	<20	100
ALJC 012	0.15	6/14/2004	16:10	6/14/2004	19:10	7	*	0.18	<20	70
ALJC 012	1.2	3/22/2005	9:30	3/22/2005	12:30	100	*	0.13	<20	80
Number of Observations	**8**	**-**	**-**	**-**	**-**	**8**	**2**	**8**	**8**	**8**
% of Samples Above Detection	**100**	**-**	**-**	**-**	**-**	**100**	**25**	**100**	**0**	**87.5**
Median	**0.41**	**-**	**-**	**-**	**-**	**37.5**	**34.5**	**0.16**	**n/a**	**80**
Coefficient of Variation	**0.94**	**-**	**-**	**-**	**-**	**0.69**	**0.43**	**0.37**	**n/a**	**0.28**

* Missing Data

Table B8. Summary of Available Stormwater Data Included in NSQD1.1 Compared to Locally Obtained Data

Land Use	Precipitation Depth (in)		TSS (mg/L)		COD (mg/L)		Phosphorous Dissolved (mg/L)		Copper Total (µg/L)		Zinc Total (µg/L)	
	NSQD vs 1.1	Jefferson County	NSQD vs 1.1	Jefferson County	NSQD vs 1.1	Jefferson County	NSQD vs 1.1	Jefferson County	NSQD vs 1.1	Jefferson County	NSQD vs 1.1	Jefferson County
Mixed Residential												
Number of Observations	491	21	582	21	465	4	430	21	432	21	515	21
% of Samples Above Detection	100	100	98.3	100	99.6	19.0	83.3	100	83.8	28.6	92.6	33.3
Median	0.53	0.31	66	22	43	34	0.13	0.15	16	25	95	50
Coefficient of Variation	0.8	1.01	1.6	0.86	1.2	0.50	1.1	3.91	1.2	0.72	0.9	0.18
Mixed Commercial												
Number of Observations	305	8	297	8	267	2	221	8	191	8	243	8
% of Samples Above Detection	100	100	99.7	100	99.6	25	93.7	100	93.2	0	98.8	87.5
Median	0.47	0.41	54.5	37.5	60	34.5	0.12	0.16	17.5	n/a	131.4	80
Coefficient of Variation	1.0	0.94	1.3	0.69	1.0	0.43	2.1	0.37	3.0	n/a	1.7	0.28
Mixed Industrial												
Number of Observations	193	21	207	23	175	7	179	23	150	23	212	23
% of Samples Above Detection	100	91	100	100	98.9	30	84.4	100	90.0	74	98.6	100
Median	0.45	0.40	82	60	39.9	66	0.08	0.17	23	50	172	250
Coefficient of Variation	0.9	0.72	1.4	0.97	1.2	0.60	2.3	1.08	0.8	0.48	3.1	1.06

Source: Maestre, Alexander, and Robert Pitt. 2005. *The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information*. U.S. Environmental Protection Agency. Water Planning Division. Washington D.C.

The following figures (Figures B2 through B22) show the locations of the Jefferson County Stormwater Permit Monitoring sites and outfalls in the Birmingham area. Each map is accompanied by two pictures of the outfalls and surrounding area, and by a satellite image of the monitoring site. The outfall photos, and the material used to process the maps and to compile the satellite images contained in this Appendix were provided by the Storm Water Management Authority Inc. (2004).

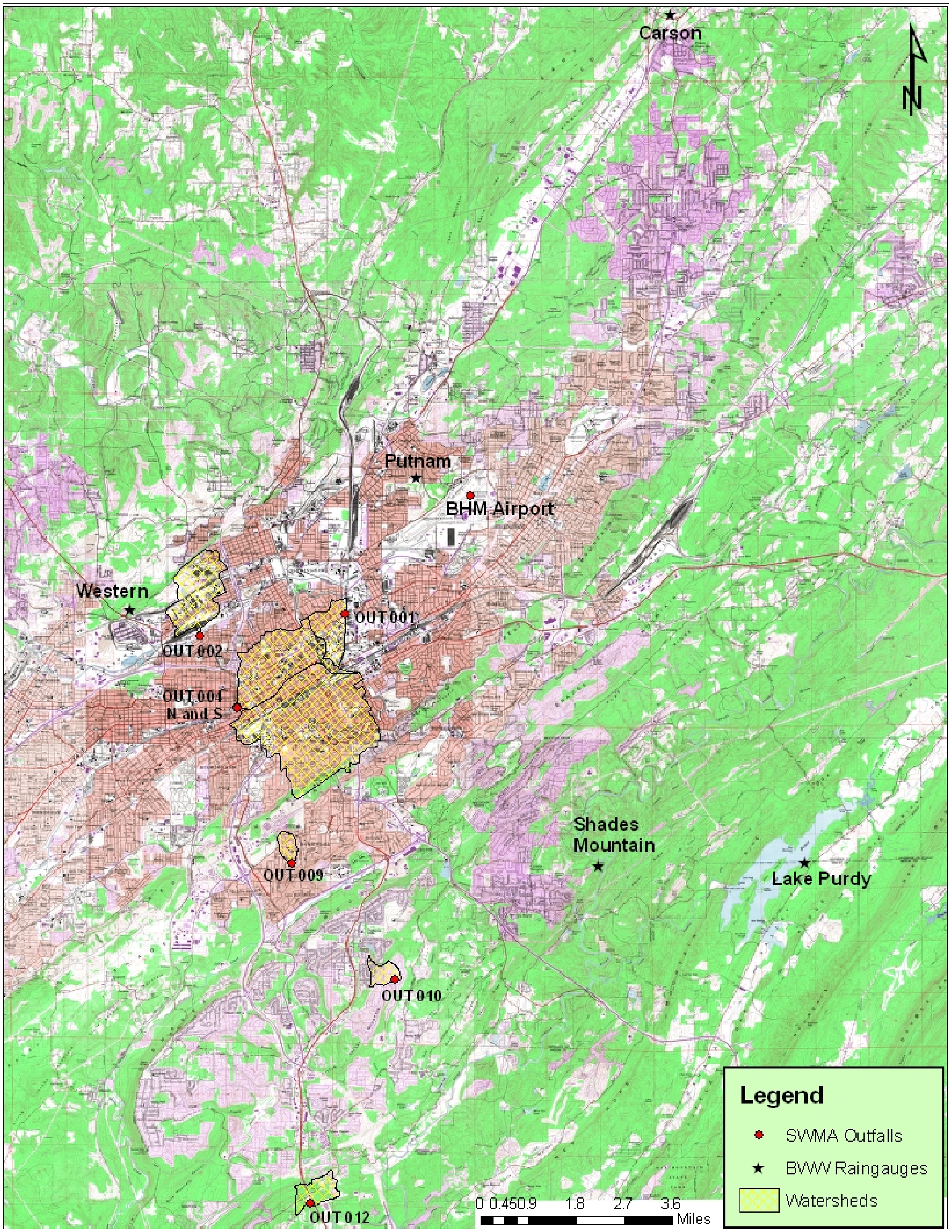
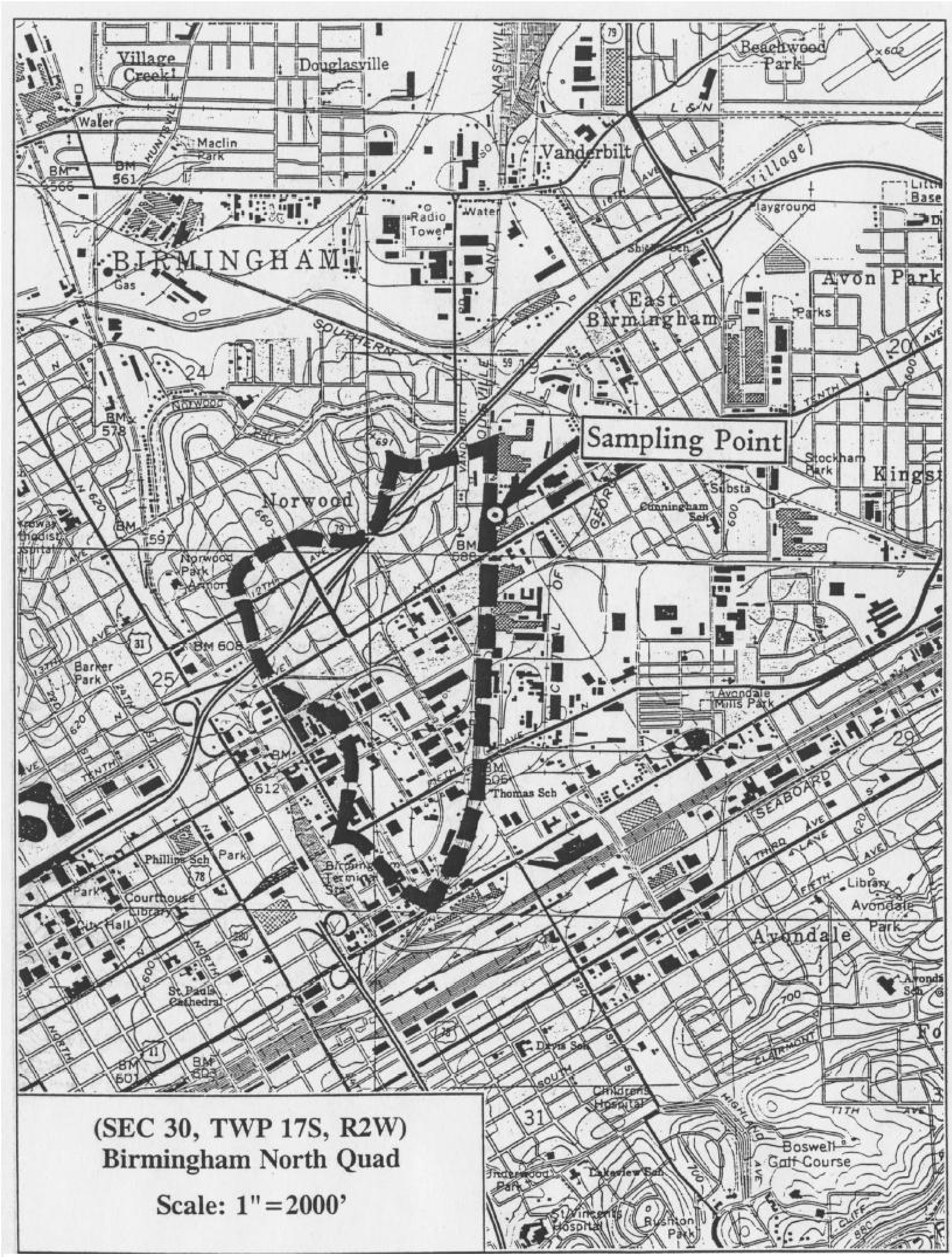


Fig. B2. General Map Showing the Relative Location of Jefferson County Stormwater Permit Monitoring Sites (ALJC), near Birmingham, AL



ALJC001: LIGHT INDUSTRIAL- VILLAGE CREEK BASIN

Fig. B3. ALJC001 Drainage Area and Outfall Location (341 acres)

Fig. B4. Outfall 001 Surrounding Area

Fig. B5. Outfall 001 General View

Fig. B6. ALJC001 Mixed Light Industrial Area - Site Satellite Image

ALJC002: HEAVY INDUSTRIAL-VILLAGE CREEK BASIN

Fig. B7. ALJC002 Drainage Area and Outfall Location (721 acres)

Fig. B8. Outfall 002 Surrounding Area

Fig. B9. Outfall 002 General View

Fig. B10. ALJC002 Mixed Heavy Industrial Area - Site Satellite Image

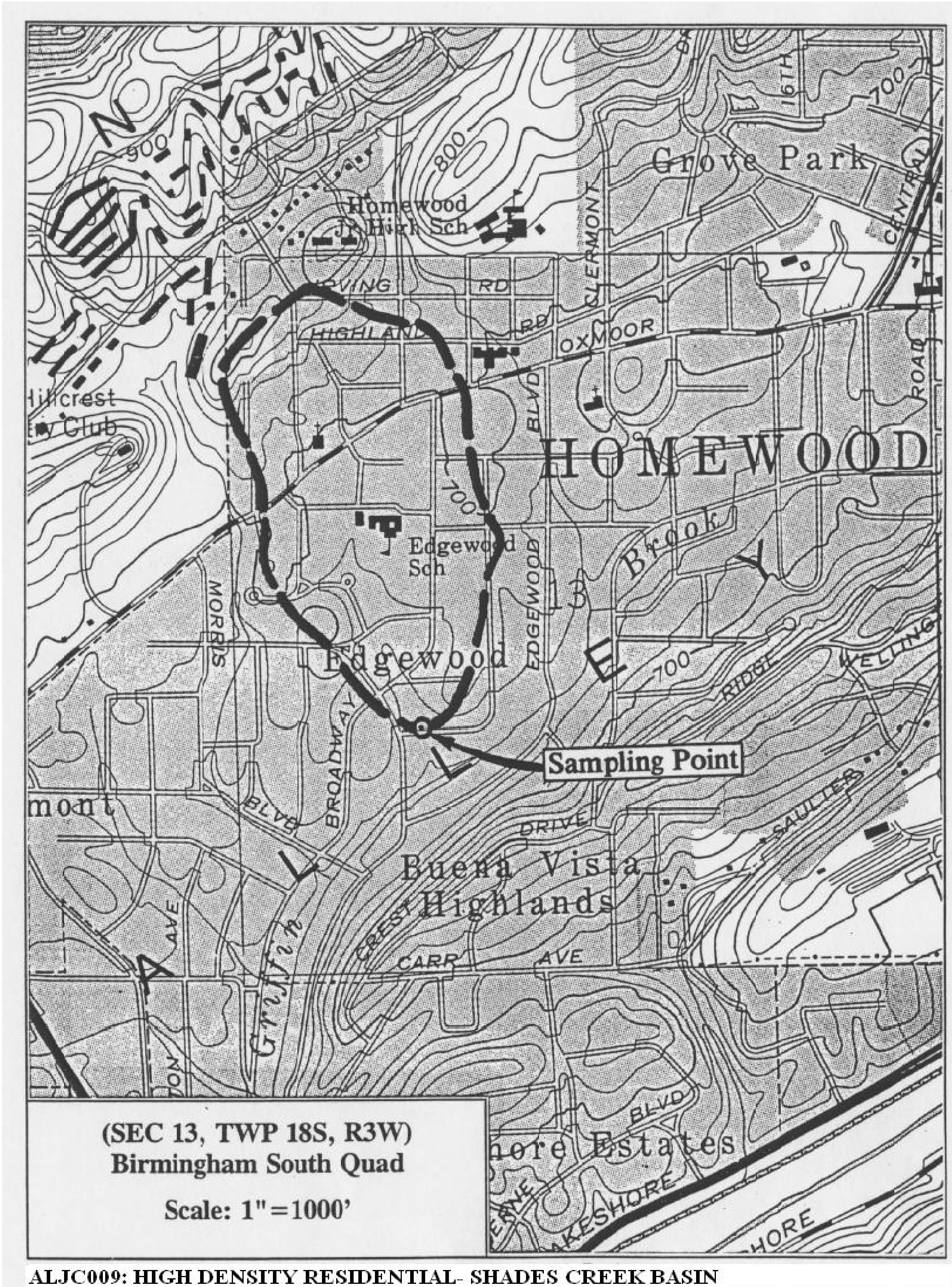


Fig. B11. ALJC009 Drainage Area and Outfall Location (102 acres)

Fig. B12. Outfall 009 Surrounding Area

Fig. B13. Outfall 009 General View

Fig. B14. ALJC009 Mixed High Density Residential Area - Site Satellite Image

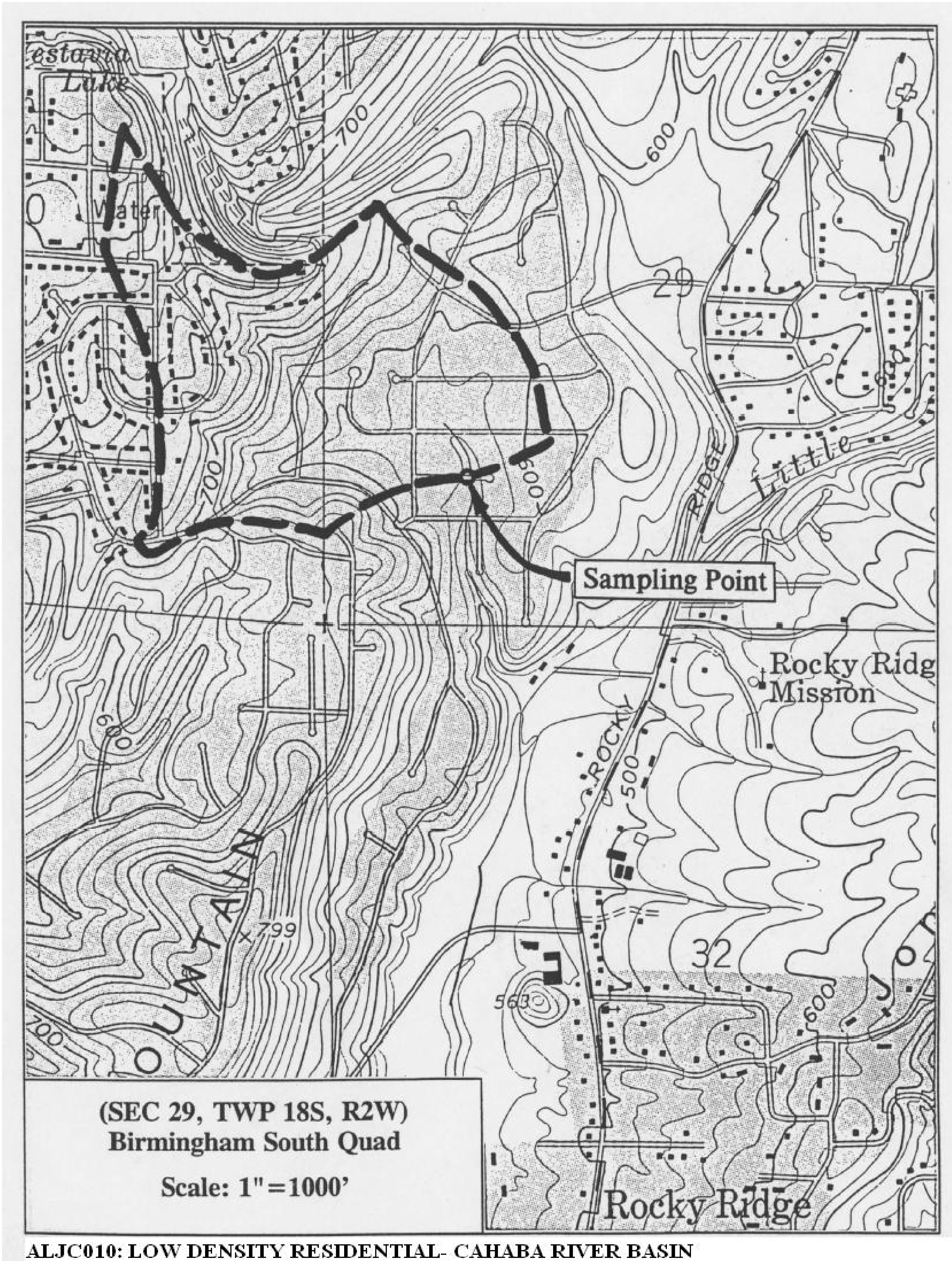


Fig. B15. ALJC010 Drainage Area and Outfall Location (133 acres)

Fig. B16. Outfall 010 Surrounding Area

Fig. B17. Outfall 010 General View

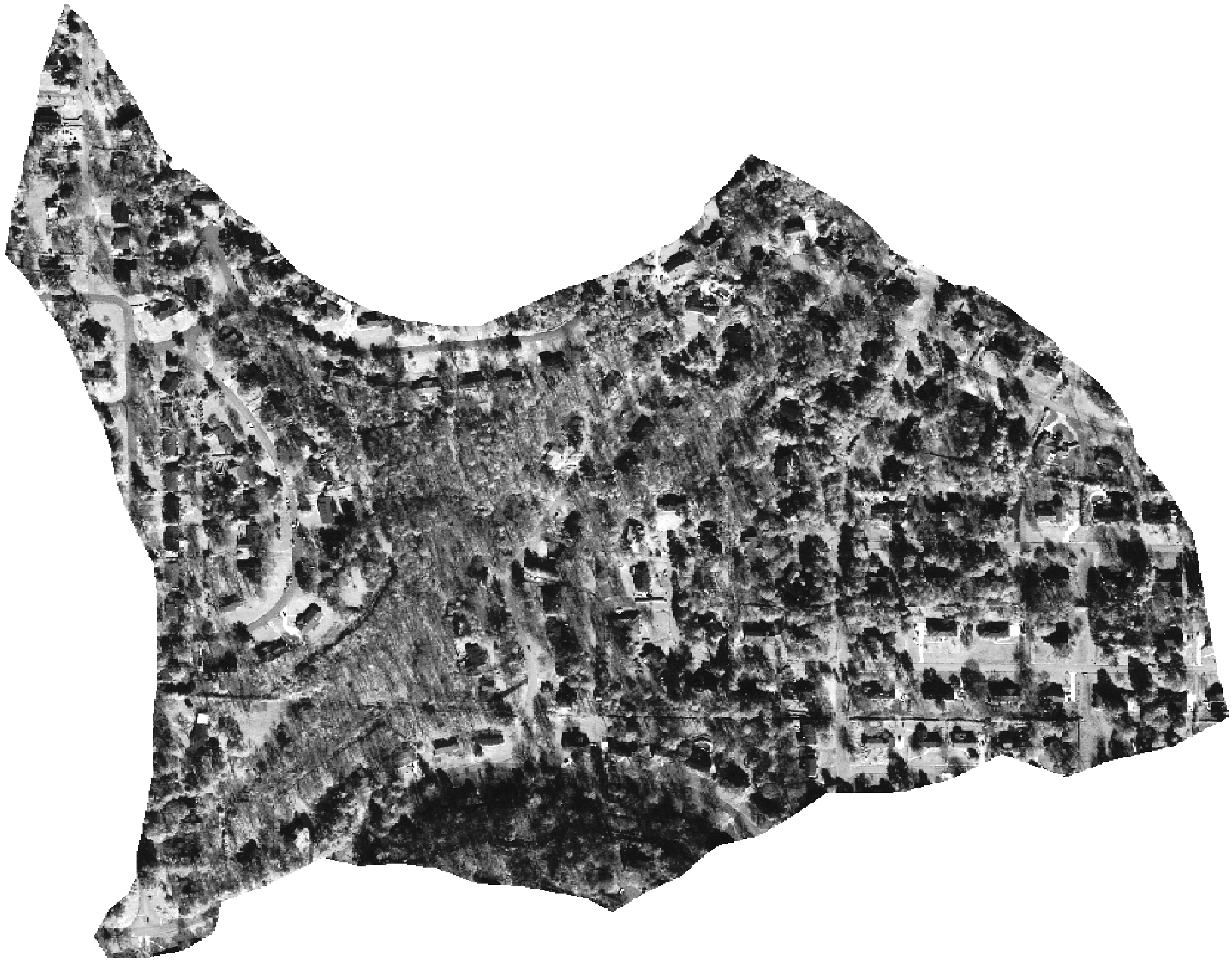


Fig. B18. ALJC010 Mixed Low Density Residential Area - Site Satellite Image

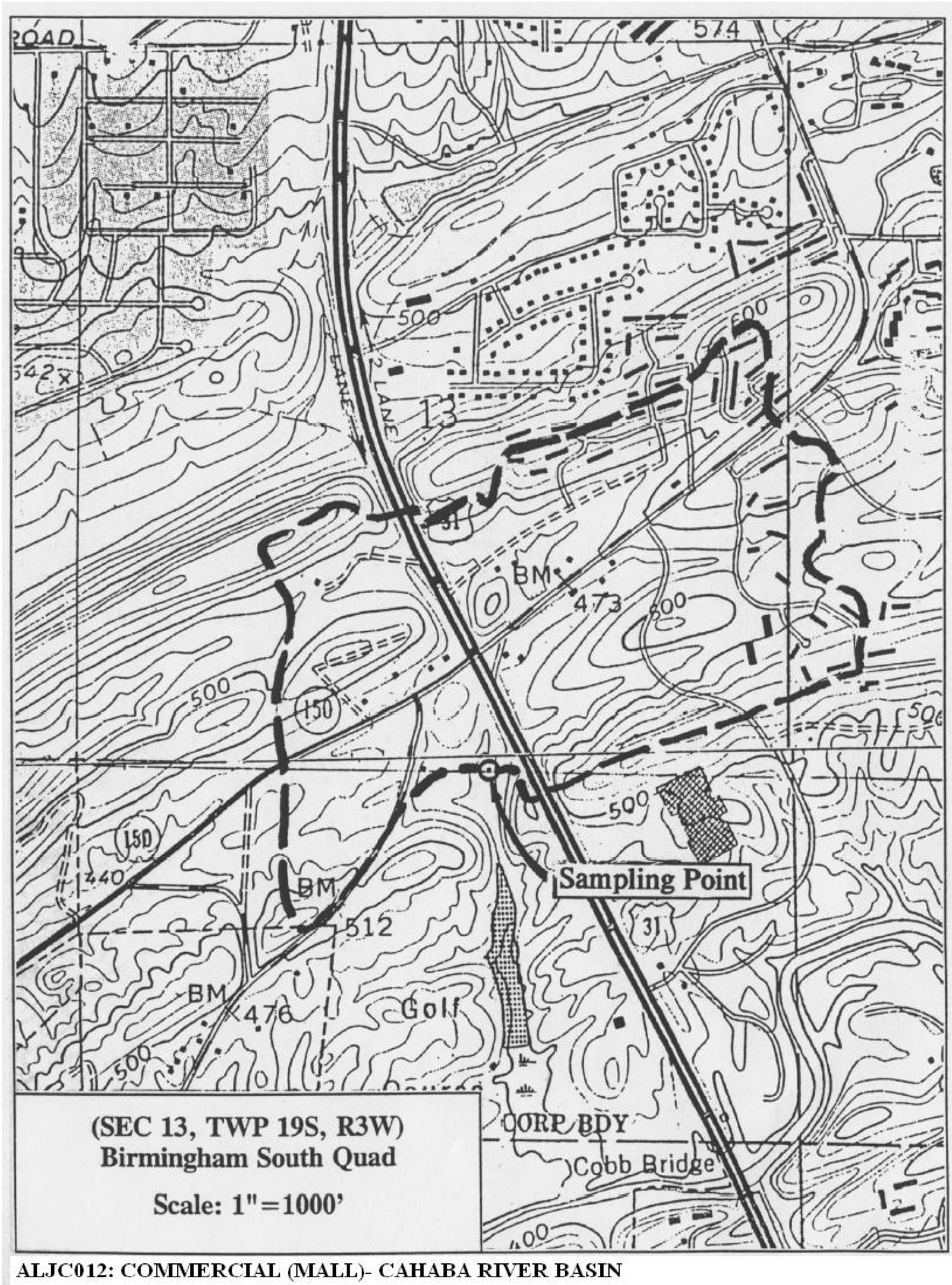


Fig. B19. ALJC012 Drainage Area and Outfall Location (228 acres)

Fig. B 20. Outfall 012 Surrounding Area

Fig. B 21. Outfall 012 General View

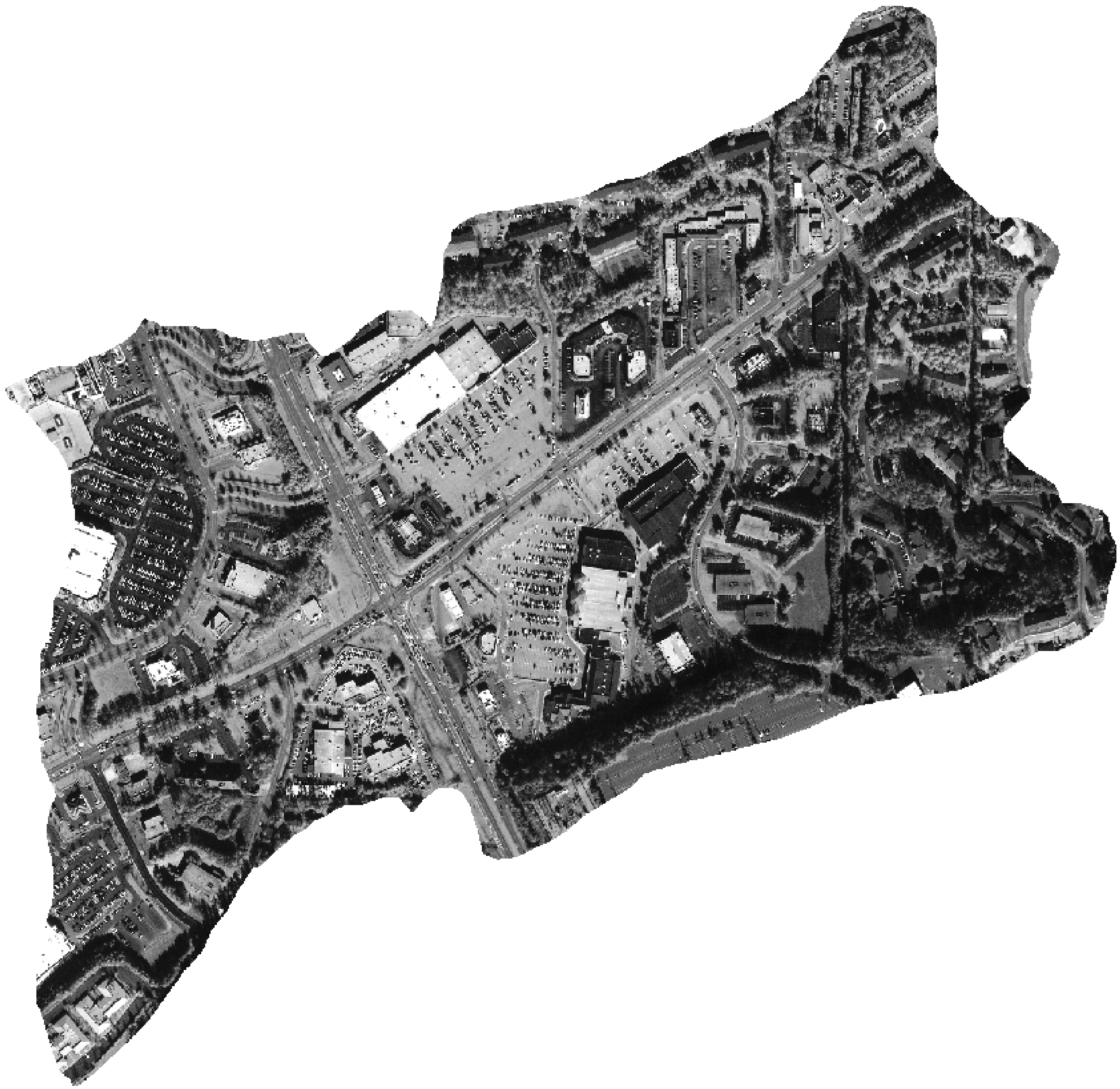


Fig. B22. ALJC012 Mixed Commercial Area - Site Satellite Image