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Module 3: Land Development Characteristics

Introduction

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). As described in Module 1, about 6 to 12 homogeneous neighborhoods are usually needed to be surveyed for each land use category. Aerial photographs or satellite images of each site are also needed.

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. 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 module to obtain this information has been used for many years in stormwater research projects, specifically 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 development characteristics in test watersheds in Toronto, Ontario.

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.) can be directly measured. In a case study described in this module, 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 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.

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 inch 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.

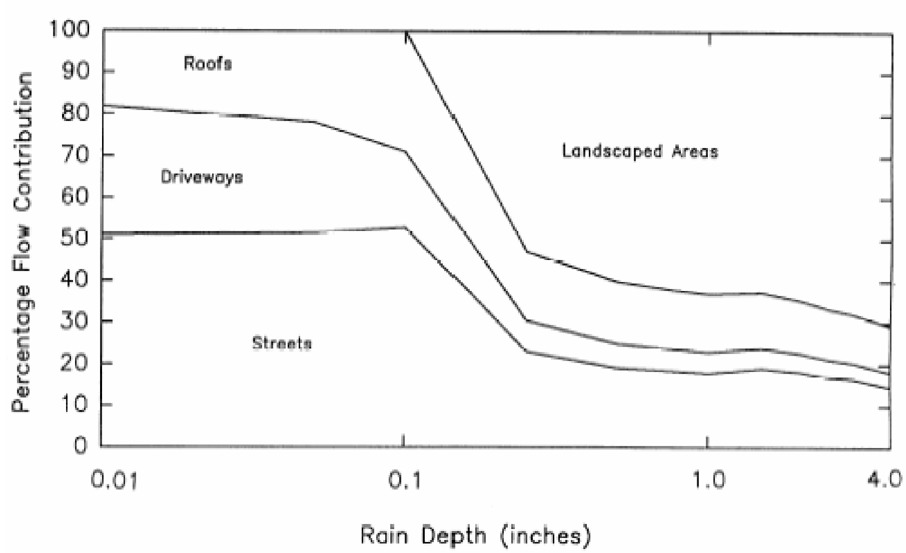

Figure 6. Flow Sources for Example Medium Density Residential Area having Clayey Soils (Pitt and Voorhees 1995)

The relative contribution of source areas for different pollutants and flows 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 1973; 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.

Field Data Collection

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. This database (Maestre and Pitt 2005) can be found at the Internet location: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

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, provided additional information for this example. 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 (SWMA) 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.

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	0.0	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. Little Shade Creek Watershed, near Birmingham, AL: Average Source Areas by Land Use – continuation

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

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:

Figure 7. Little Shades Creek Corridor Test Area Description

Figure 8. Example of Monochromatic Aerial Photograph having 1 m Resolution (USGS Photo)

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.

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

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 six 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., of Jefferson County, AL.

Figure 10. Example of Site General View

Description of Land Use
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 (rooftop), 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 (rooftop), 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 (rooftops), 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.

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

- 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.

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 development 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 the Little Shades Creek Watershed

Land use	Total area (ha)	Total area (acres)
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.

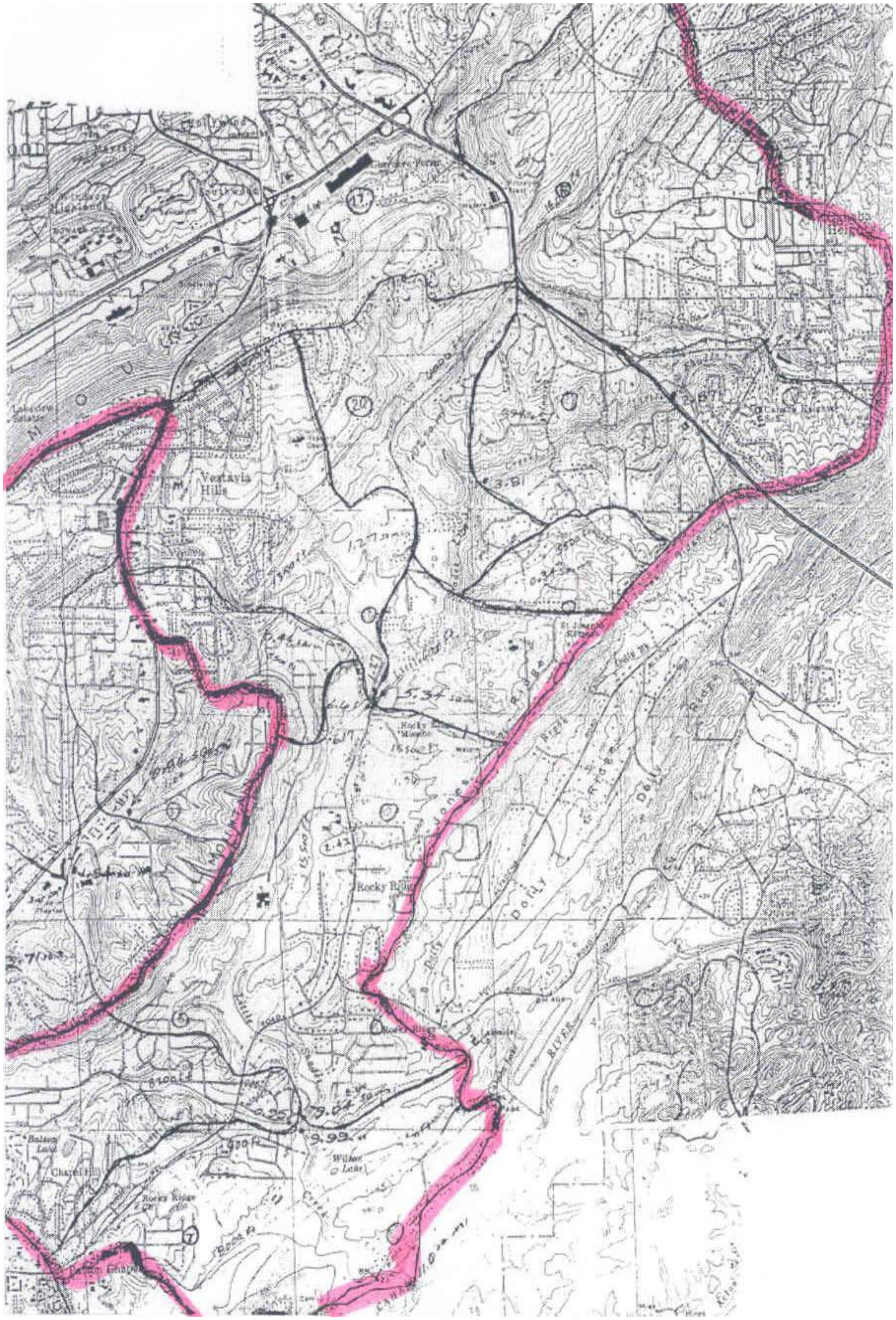

Figure 12. Map of Lower Portion of the Little Shades Creek Watershed Study Area

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.

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.

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 and 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 six 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.

Data Processing

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 m 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 m 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-m resolution panchromatic image data and 4-m 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).

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.

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-scape	Back land-scape	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 landscape	Back landscape	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 landscape	Back landscape	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. Jefferson County AL., MS4 Watersheds: Source Areas by Land Use – continuation

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-scape	Back land-scape	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 connected	Parking, unpaved	Storage, paved	Storage, unpaved	Large turf	Undeve-loped	Roof drained to impervious	Roof drained to pervious	Tracks	Pond	Other pervious	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

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 showed 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.

The second step was the electronic delineation of the six 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 six watersheds using ArcGIS 9 (ArcMap). Each watershed was saved separately as a shape file (.SHP) giving the matching name (ALJC001, ALJC002, etc).

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: 6002.8 m²

Street area density: 517.48 m²/ha

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

area: ____ m² density: X m²/ha

Sidewalk: width: ____ m length: ____ m area: ____ m² density: X m²/ha

Front landscaping: average per unit 2350 m² x 31 # units = 72838 m²

density: 6279 m²/ha

Driveways: avg. per unit 78.65 m² x 31 # units = 2438.15 m² density: 210.19 m²/ha

100 % paved; 210.19 m²/ha

0 % unpaved; 0 m²/ha

Parking areas: ____ m² density: X m²/ha 5459.8

____ % paved; X m²/ha

____ % unpaved; X m²/ha

Storage areas: ____ m² density: X m²/ha

____ % paved; X m²/ha

____ % unpaved; X m²/ha

Playgrounds: ____ m² density: X m²/ha

____ % paved; X m²/ha

____ % unpaved; X m²/ha

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

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 the 48 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, with eight frames making up one USGS quadrangle map. Each frame represents 32.3 sq.mi. at 2-FT 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-M panchromatic satellite images ("Leafoff.img" flown December 2000 and "Leaffon.img", flown summer 2001; raster format "ERDAS 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 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.

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.

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 six 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.

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

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.

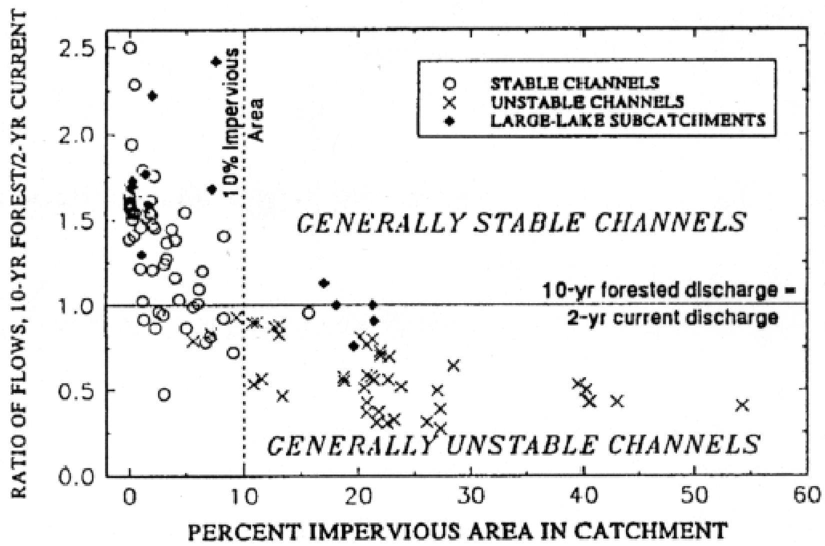

Figure 2. Channel Stability as a Function of Imperviousness (Schueler 1994 from Booth and Reinelt 1993)

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.

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):

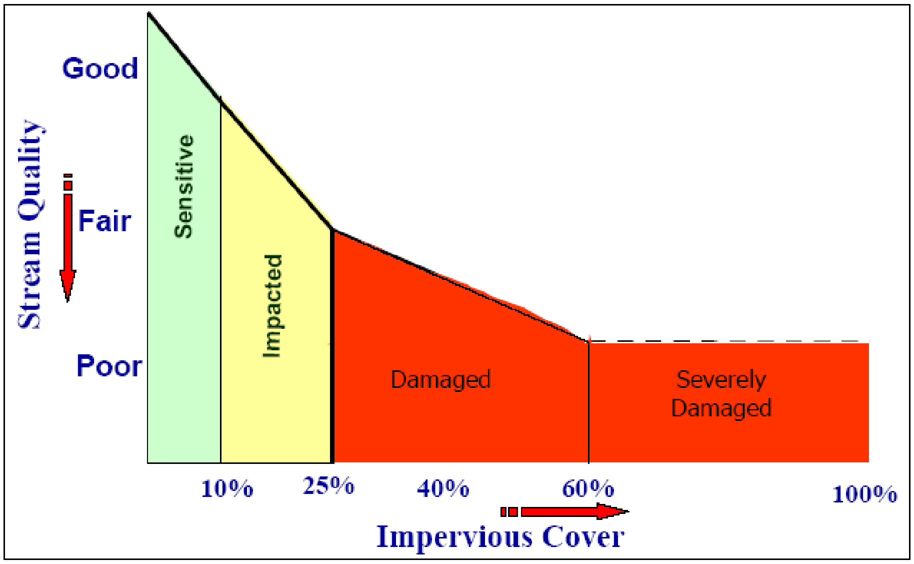

Figure 4. Relationship between Stream Quality and Watershed Imperviousness (Center of Watershed Protection 2003)

"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 (Schueler 1994)

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

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).

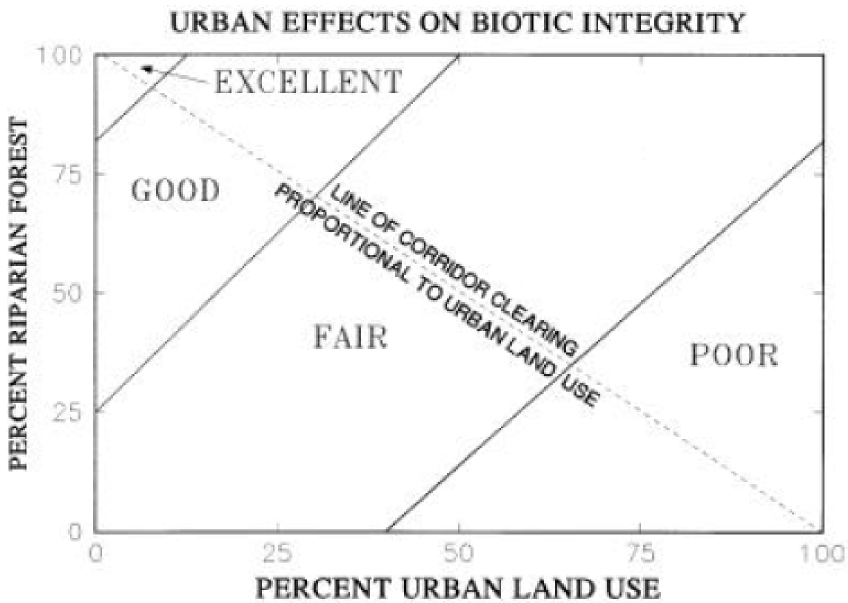

Figure5. Conceptual Relationship between Urban Land Use, Forest Cover, and Biological Conditions (Booth 2000 from Steedman 1988)

The data collected for the Little Shades Creek watershed show that this area 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 and 15).

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 16 and 17 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. The fitted exponential equations are::

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

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

Where y is the volumetric runoff coefficients (Rv) and x is the directly connected impervious areas (%) for the areas. These data and equations are plotted on Figures 16 and 17. 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 to the already high amounts of runoff the creek is receiving in all test reaches.

WinSLAMM was 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

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

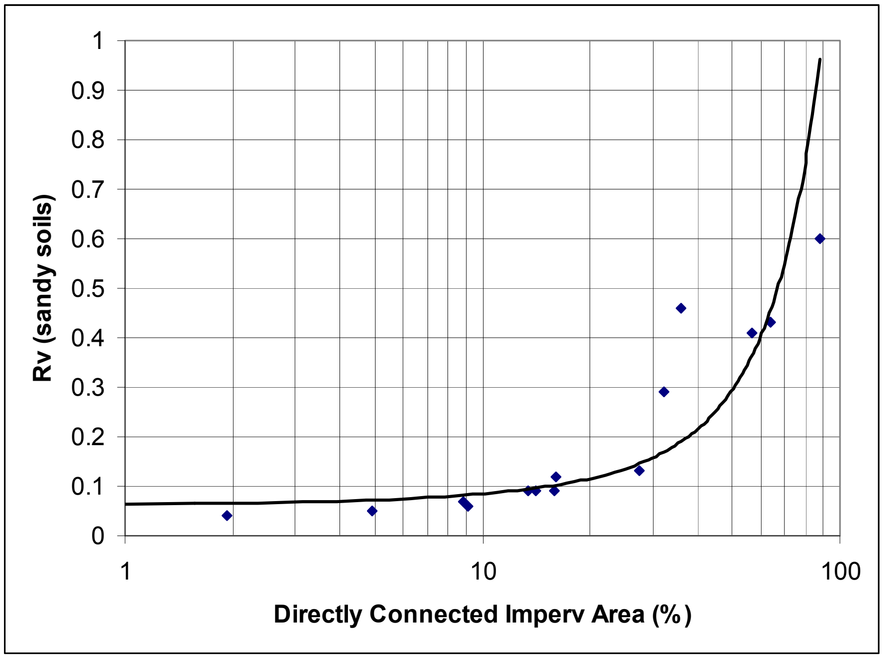

Figure 16. Relationships between the directly connected impervious area (%) and the calculated volumetric runoff coefficients (Rv) for each land use category for sandy soil

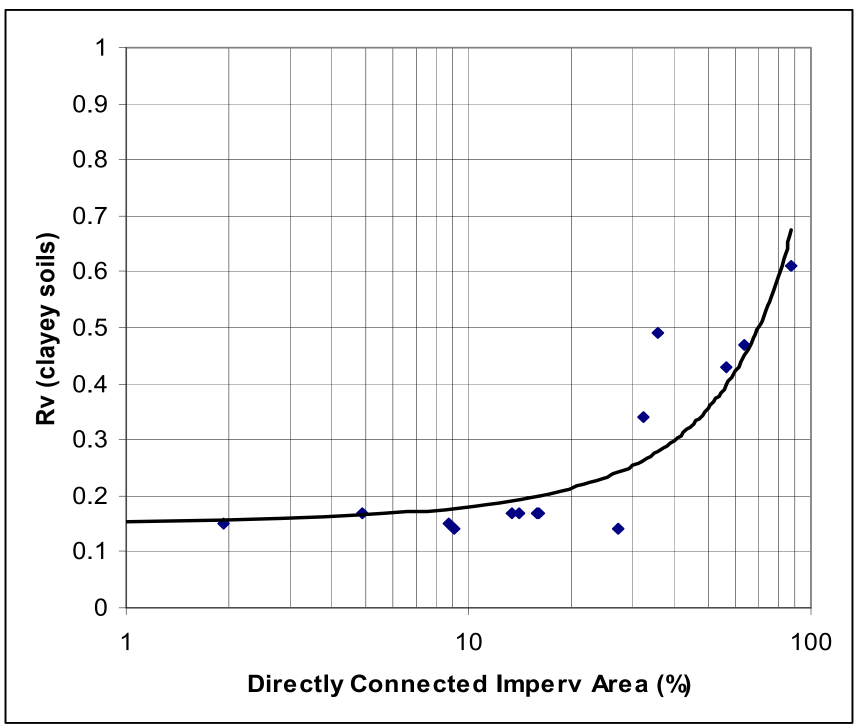

Figure 17. Relationships between the directly connected impervious area (%) and the calculated volumetric runoff coefficients (Rv) for each land use category for clayey soil

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. These data shows that all five watersheds are highly impervious, with more than 50% of the watershed area being composed of impervious covers. Also, the runoff coefficients indicate that the biological condition in these watersheds is expected to be poor, as substantiated by the biological monitoring in the area.

Table 8. Jefferson County, AL
Source Area Drainage Connections by 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*

Components of Imperviousness

In this module, impervious cover is any land surface that has been covered with material that significantly decreases or prevents the infiltration of runoff (but not considering compacted urban soils). Imperviousness refers 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 can be classified: directly connected impervious areas and non-directly connected (disconnected) impervious area (Gregory *et al.* 2005). Directly connected impervious areas 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 20ft 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).

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 mm for many land uses and soil conditions.

Module Summary

This module 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. Techniques used for estimating impervious cover in these highly urbanized watersheds included site surveys, supplemented by 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 area, a fact clearly observed for our watersheds, 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).

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 damaged for the investigated areas, a fact confirmed by in-stream investigations by the SWMA biologists.

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 summarized in the below table (Table 2).

Table 2. Impacts on Streams due to Increased Impervious Surface Areas (EPA 2004)

	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

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
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 area at 9 sites.	Luchetti & Fuersteburg	1993	Seattle

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

Watershed Indicator	Key Finding	Reference	Year	Location
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

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Appendix A: Surface Covers in the Little Shades Creek Watersheds

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).

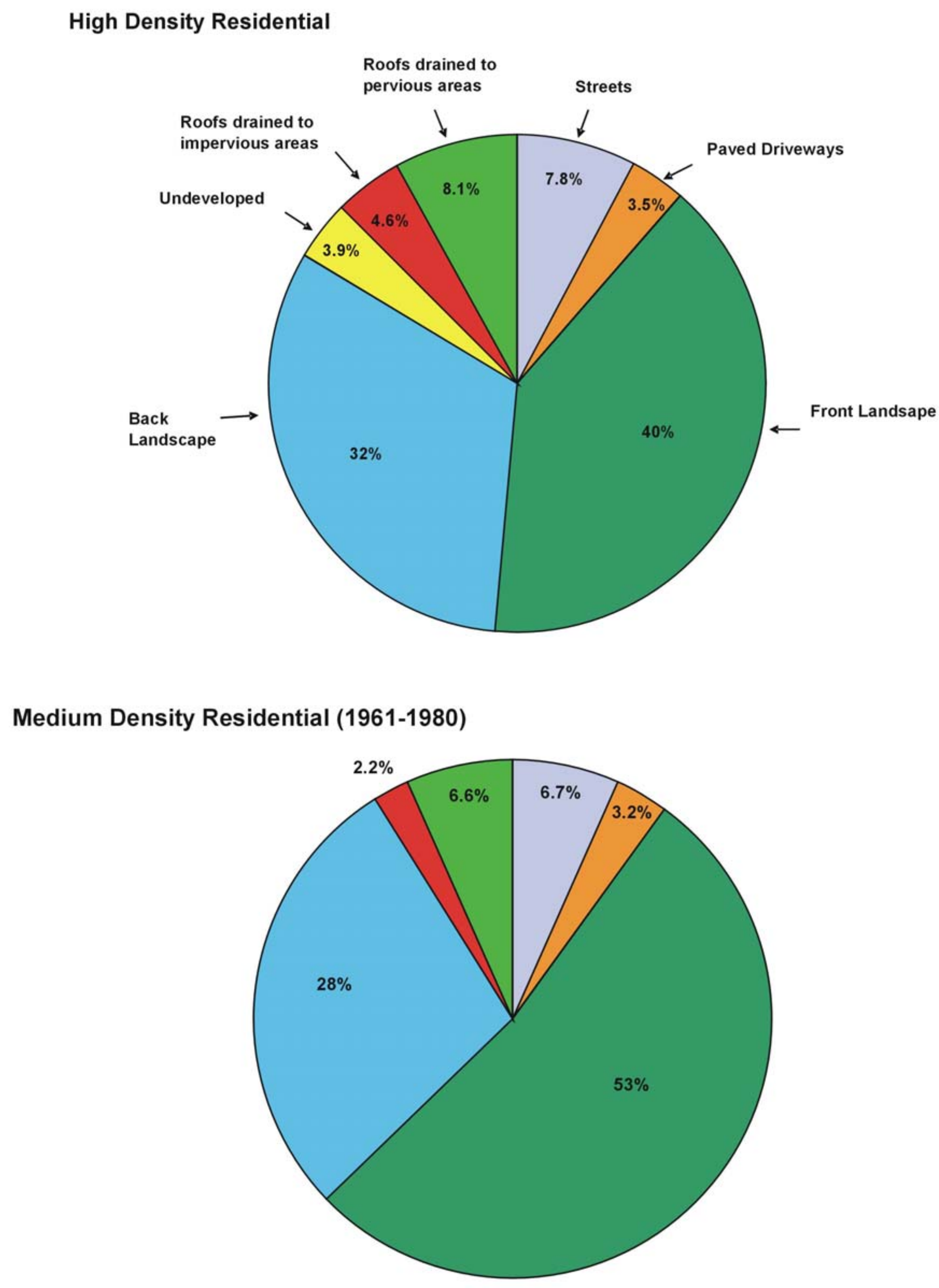
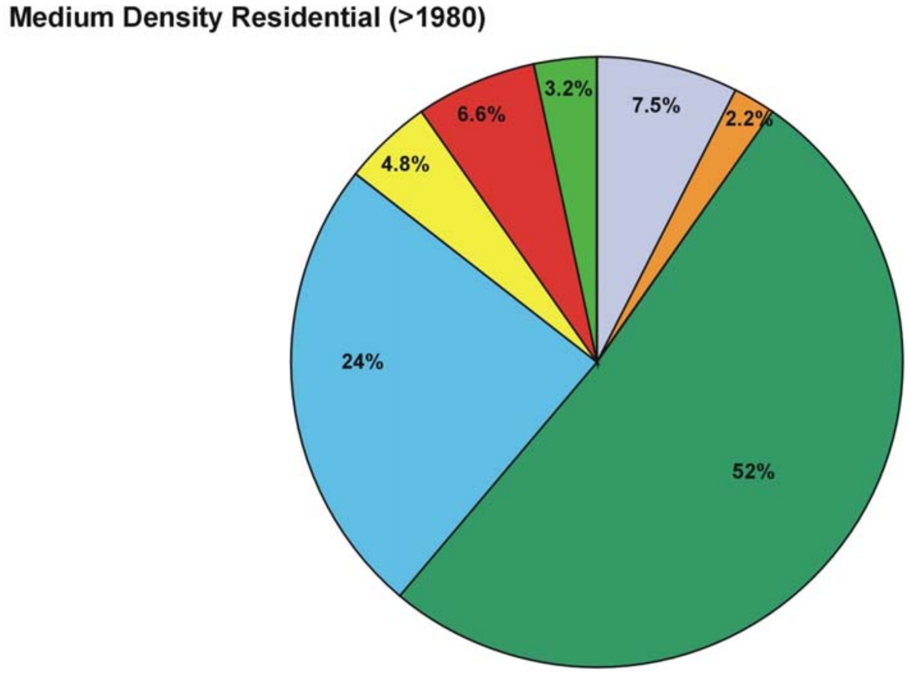


Figure 14. Little Shades Creek Watershed: Source Area Distribution using Pie Charts: Residential Land Use.



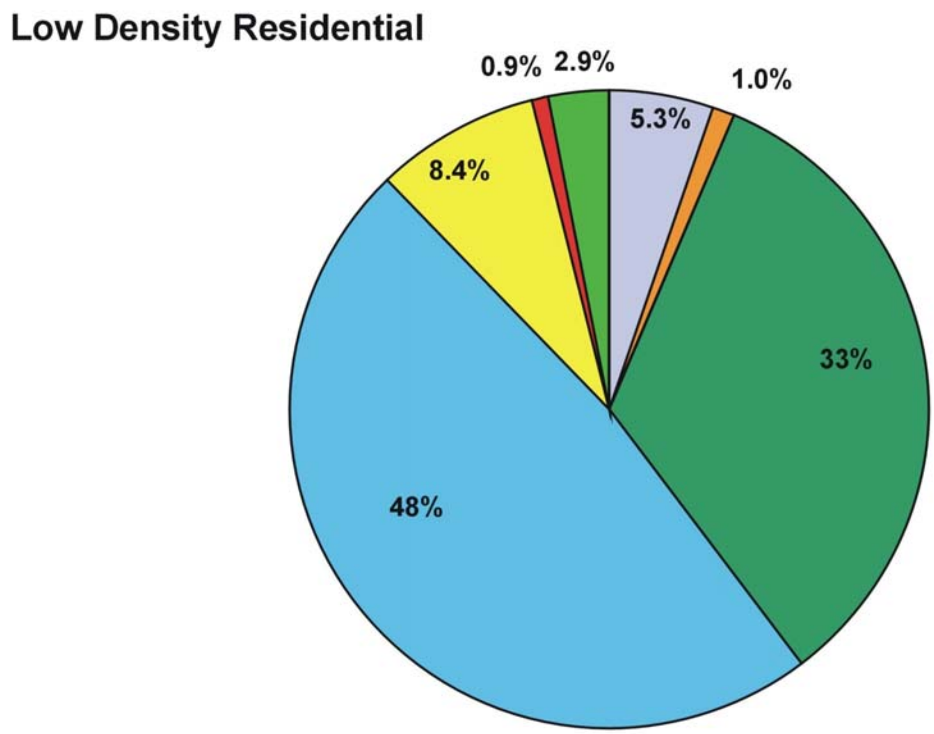
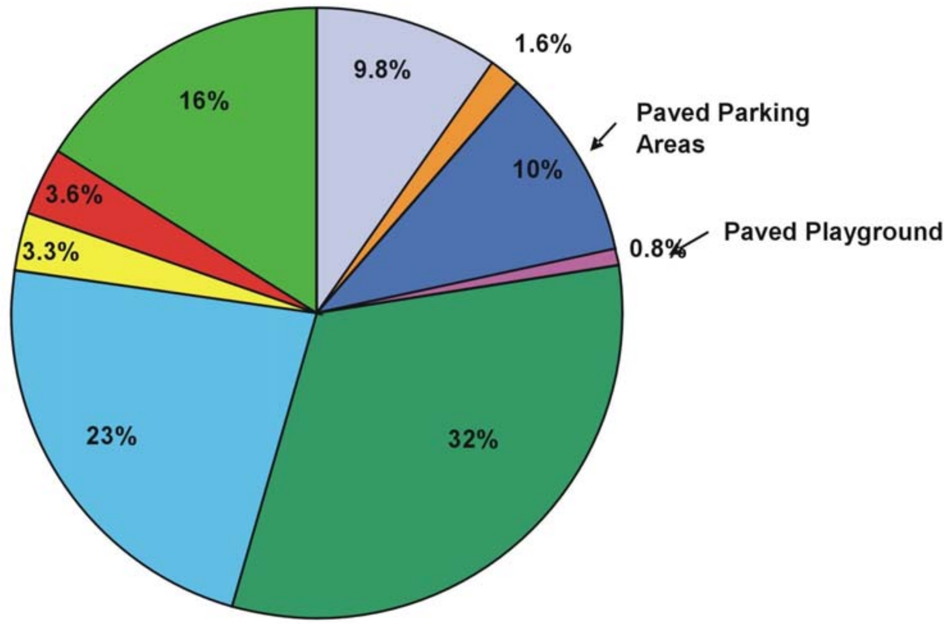
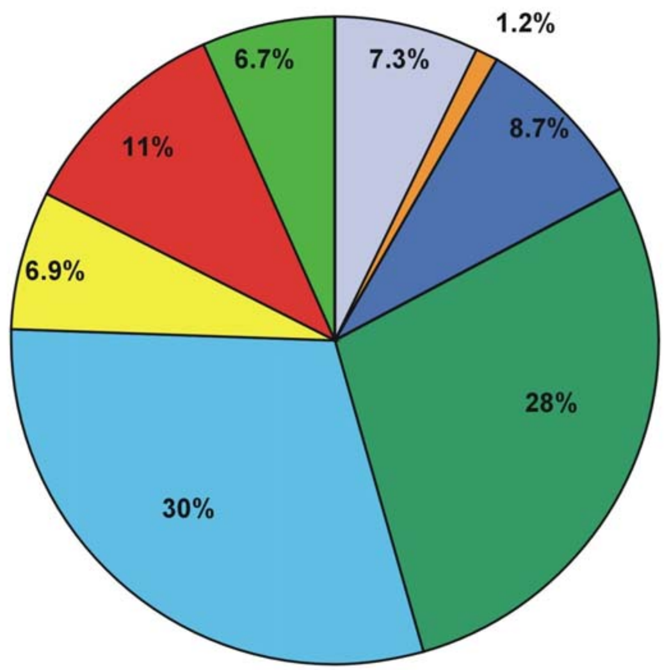


Figure 14. Little Shades Creek Watershed: Source Area Distribution using Pie Charts: Residential Land Use- *continued*

Apartments



Multiple Families



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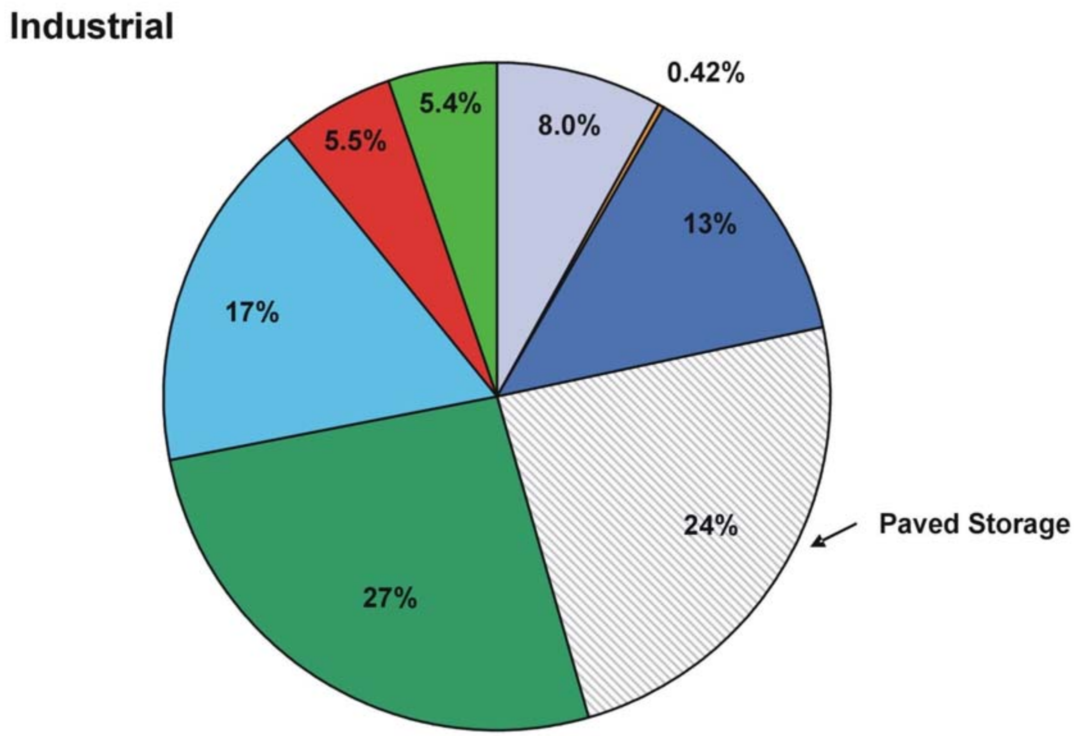

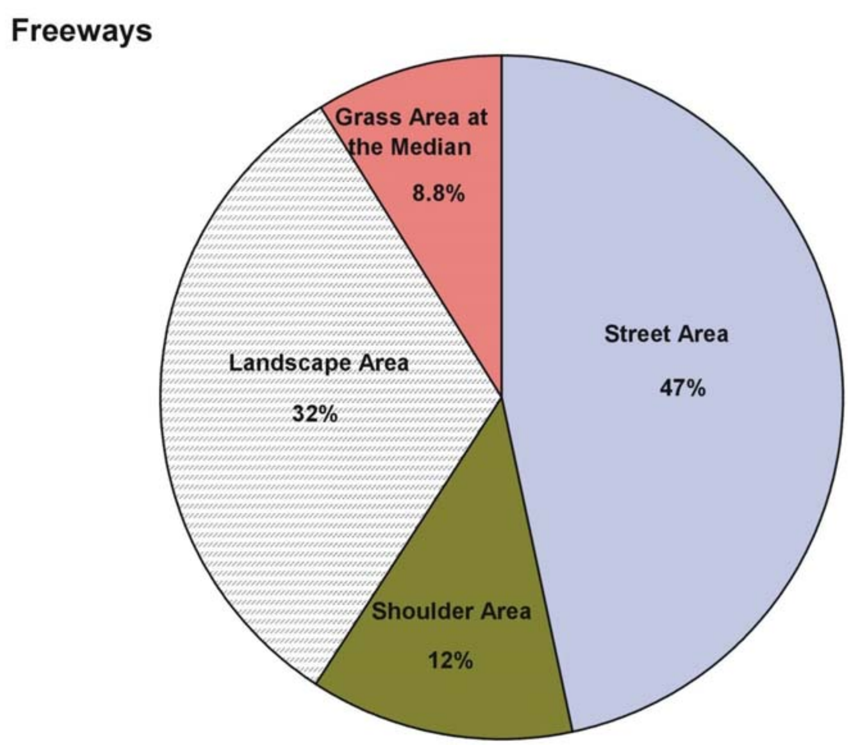

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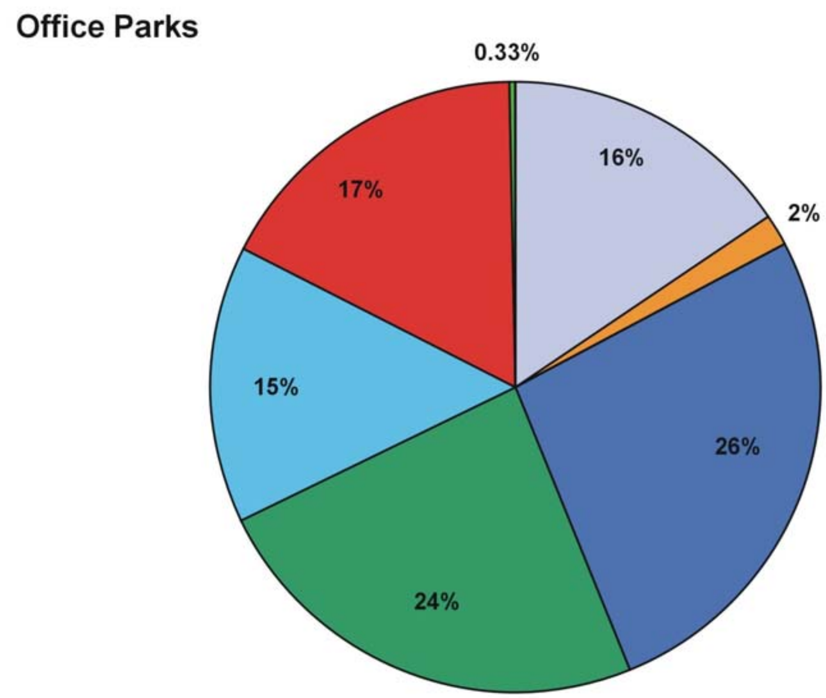

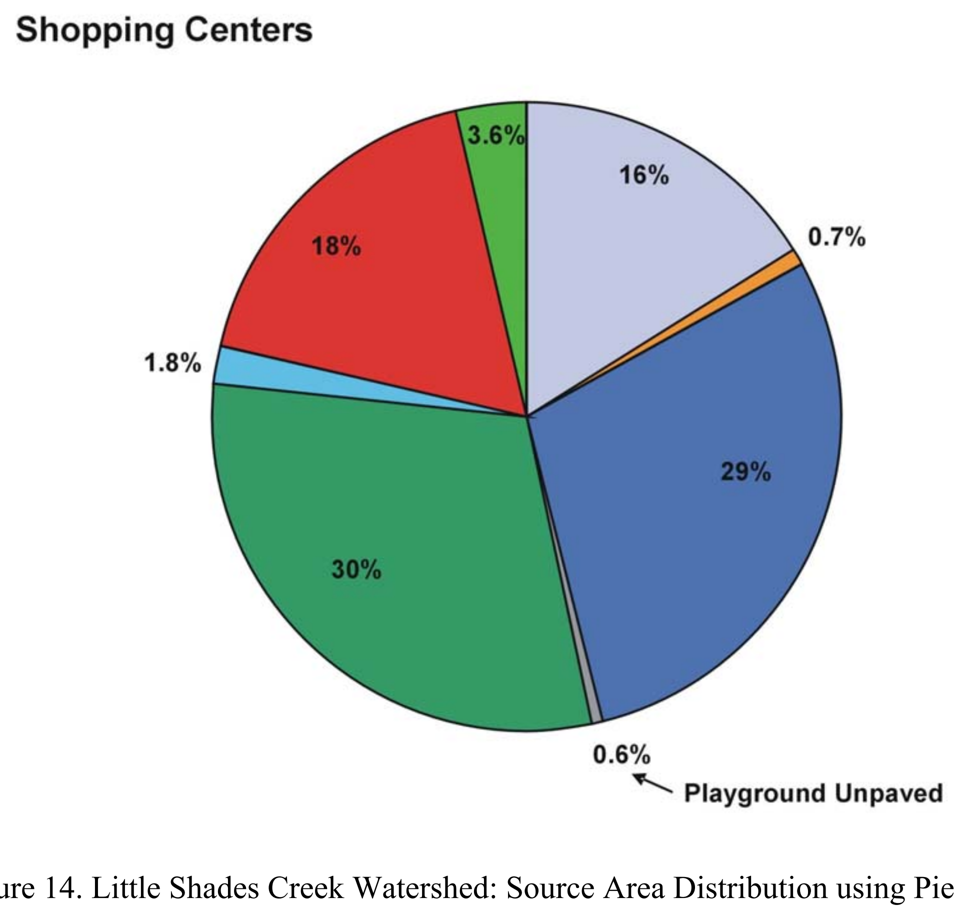

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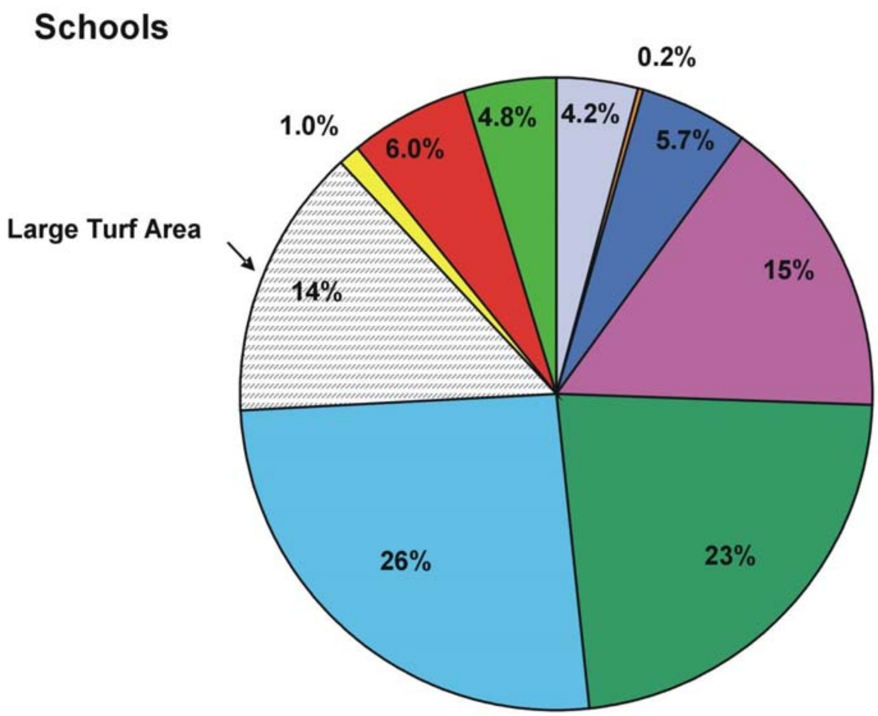

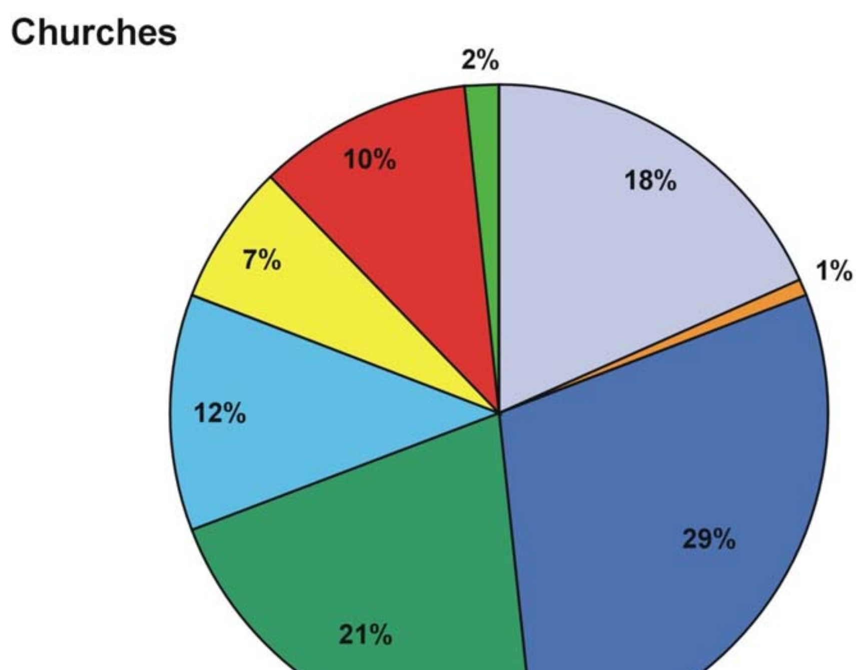

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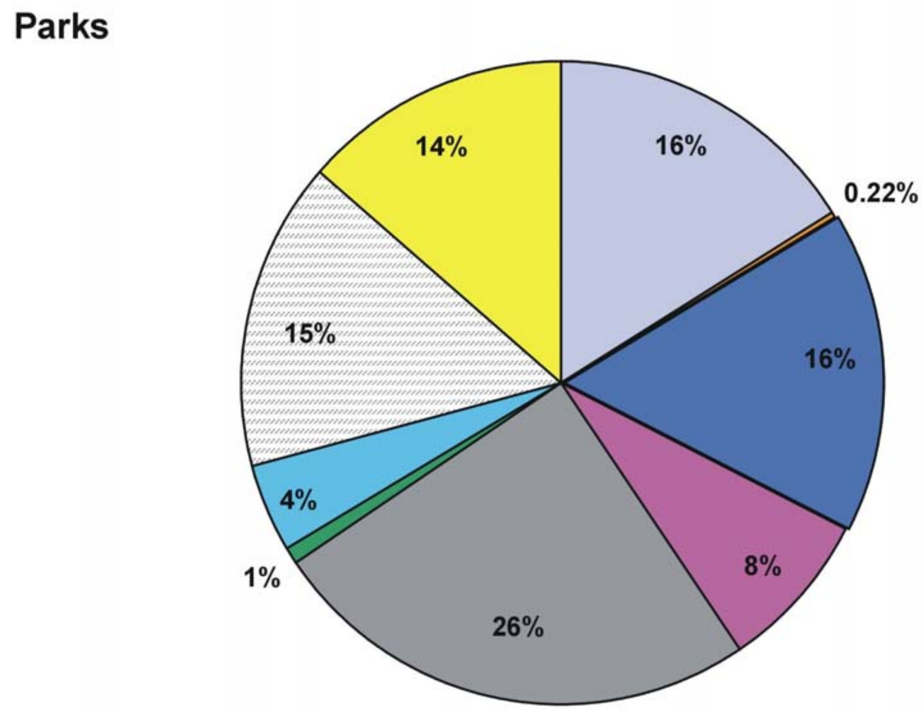

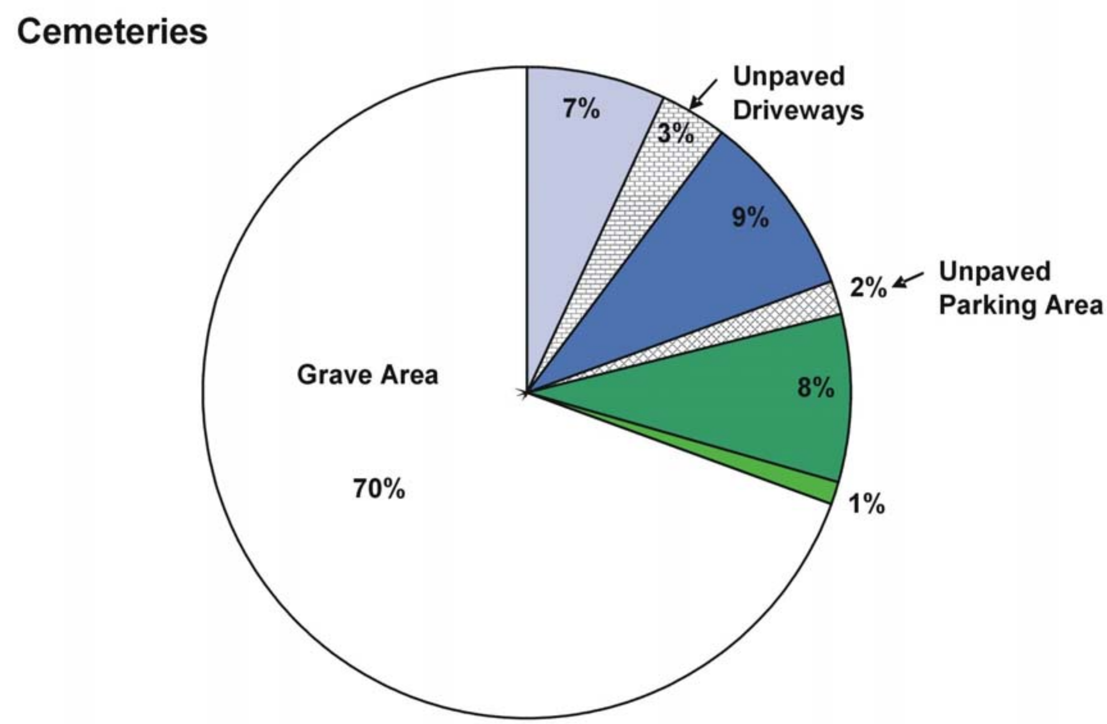

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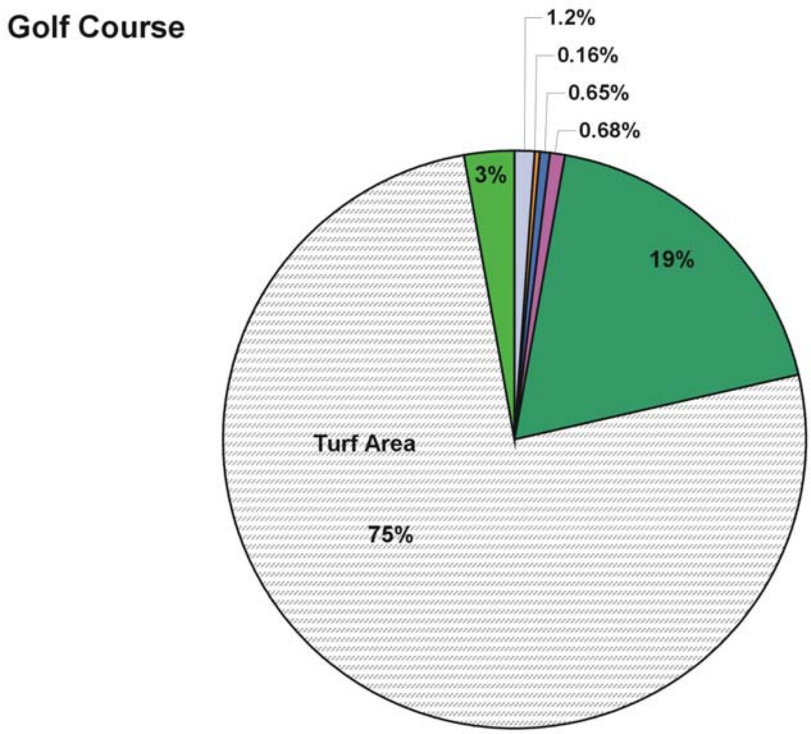

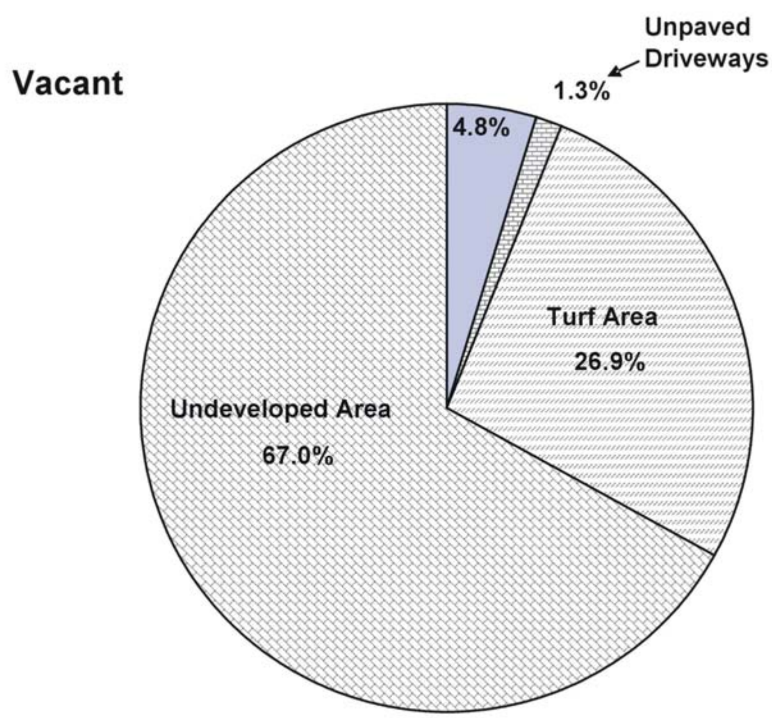

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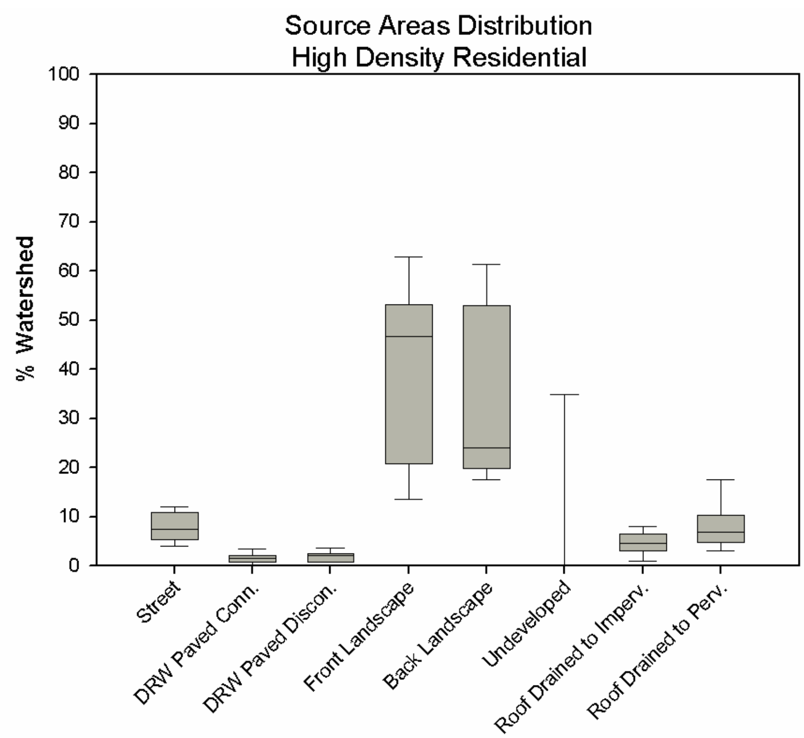
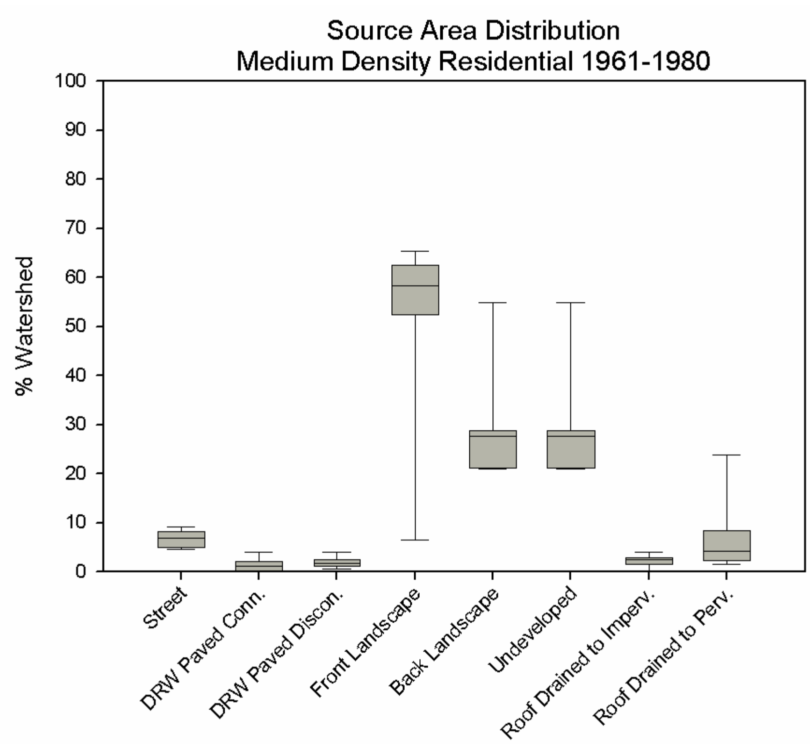
Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots





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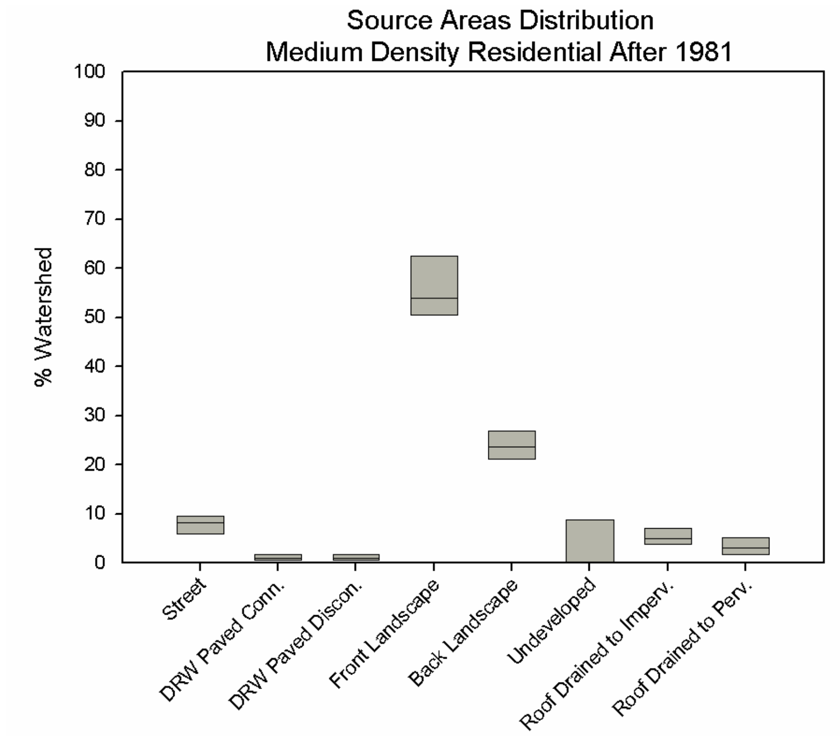


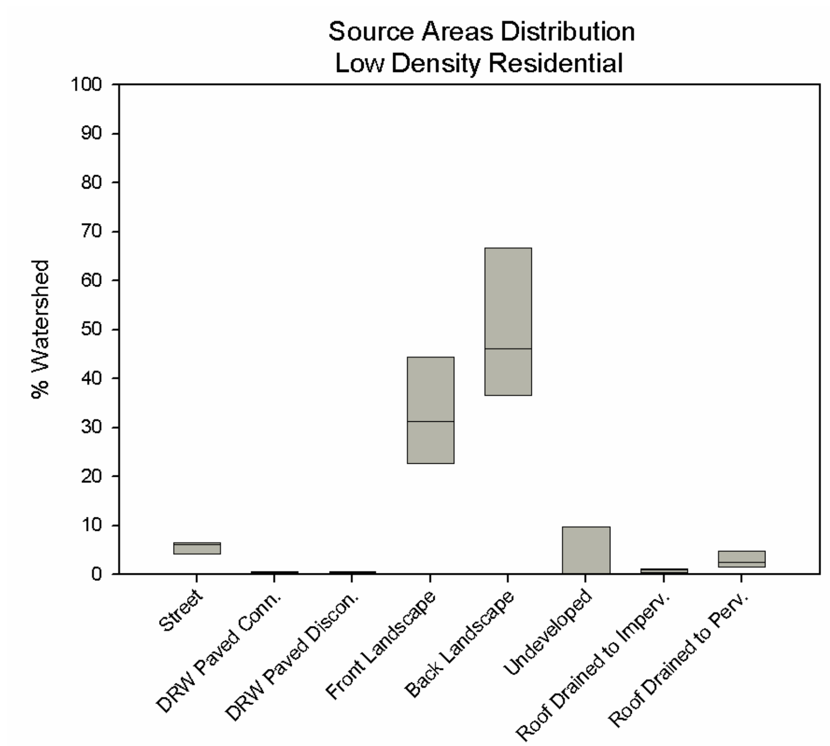
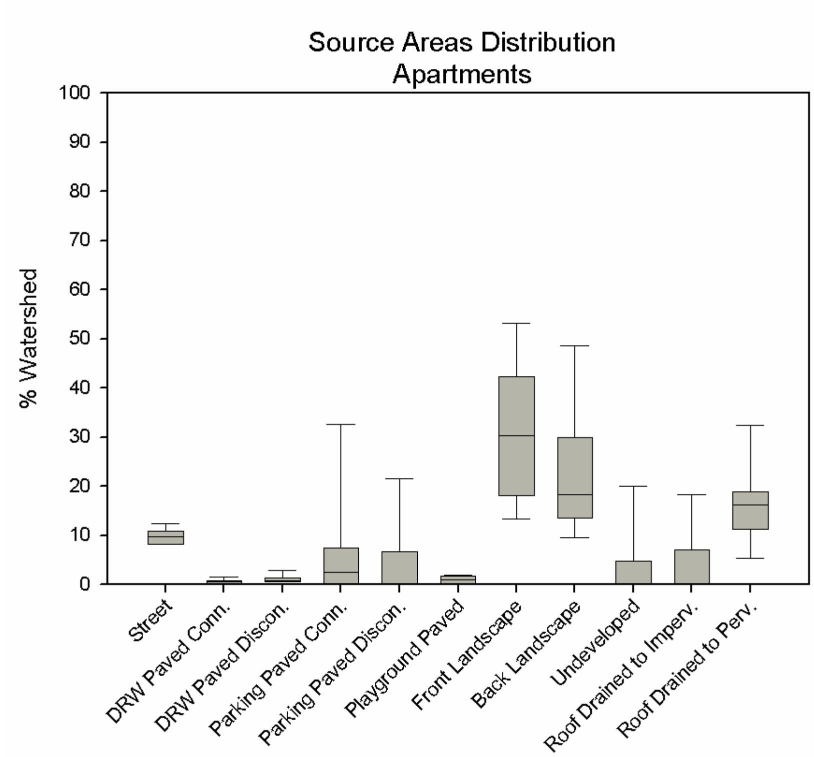


Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots - *continued*



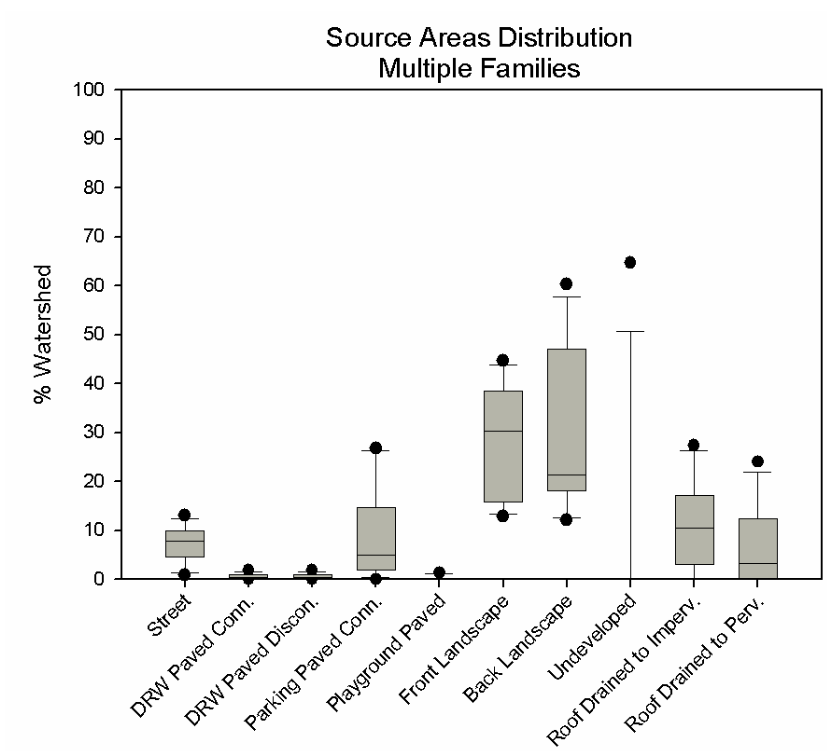
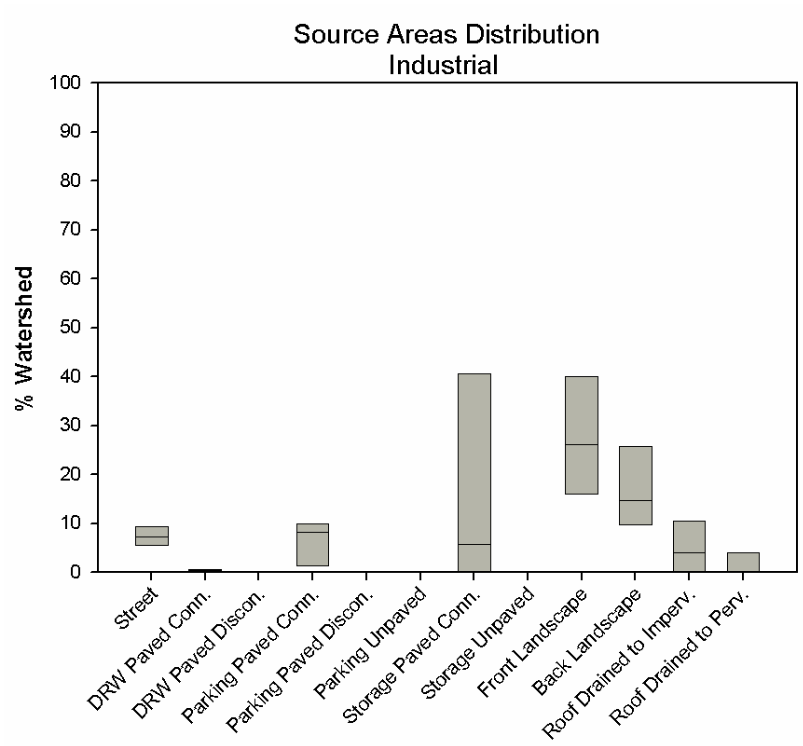


Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots – *continued*



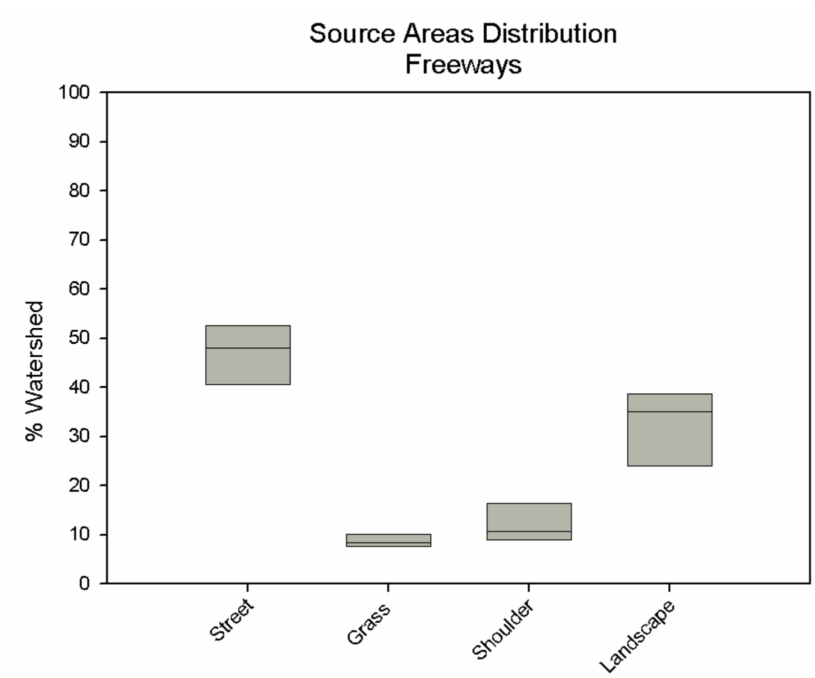
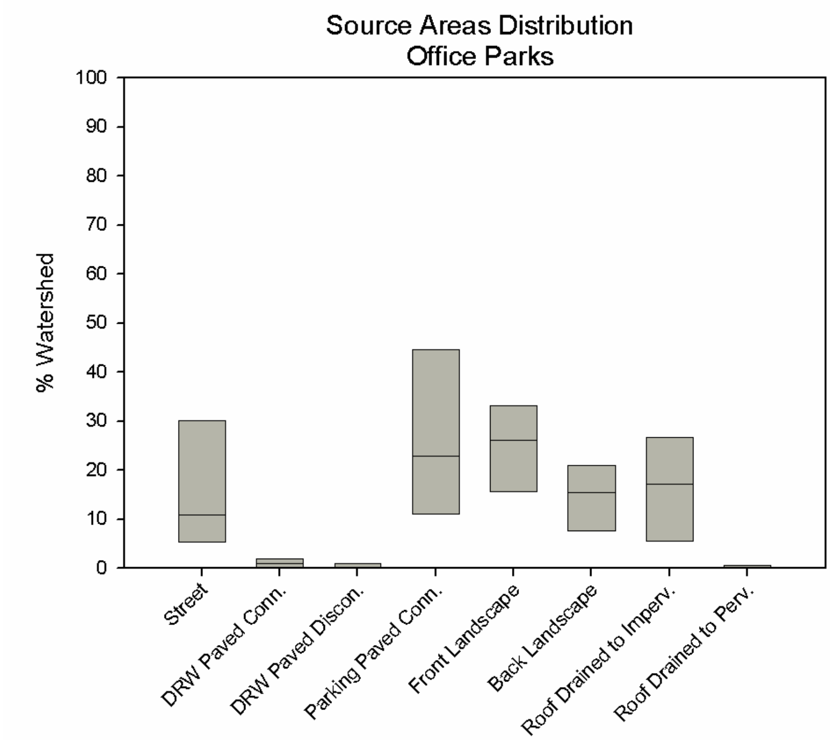


Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots – *continued*



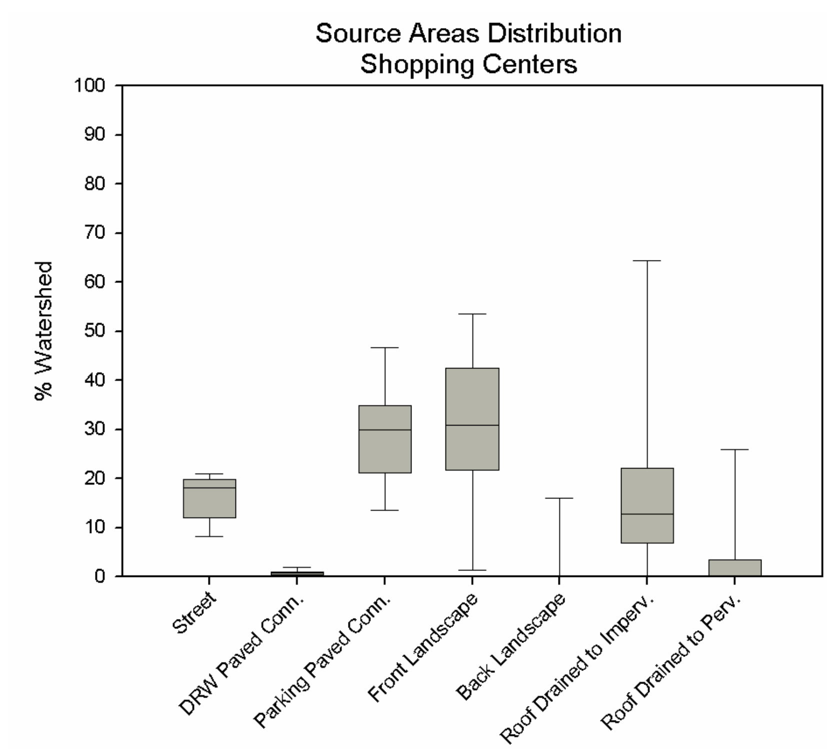
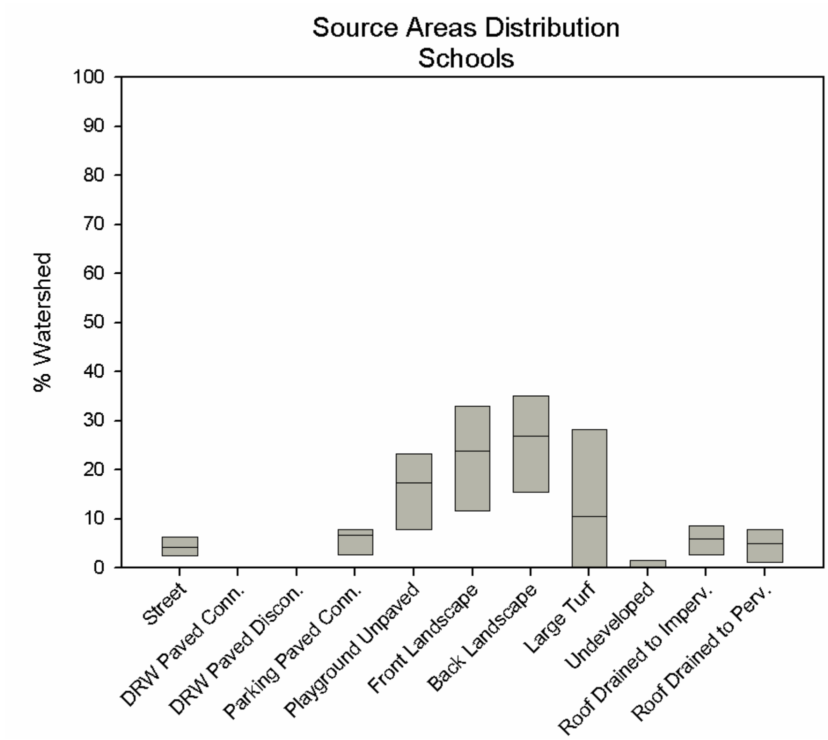


Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots – *continued*



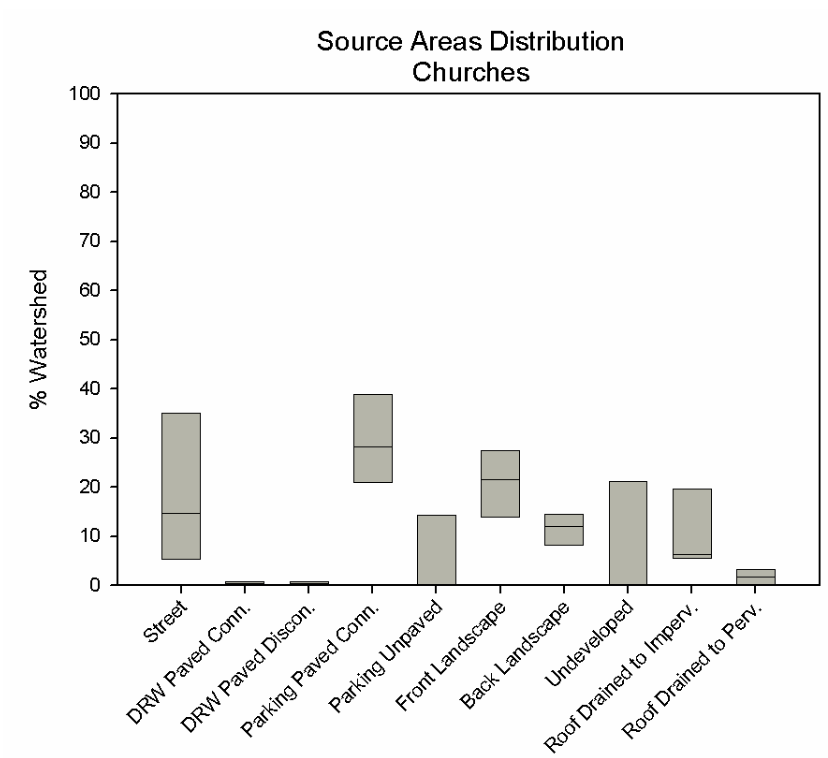
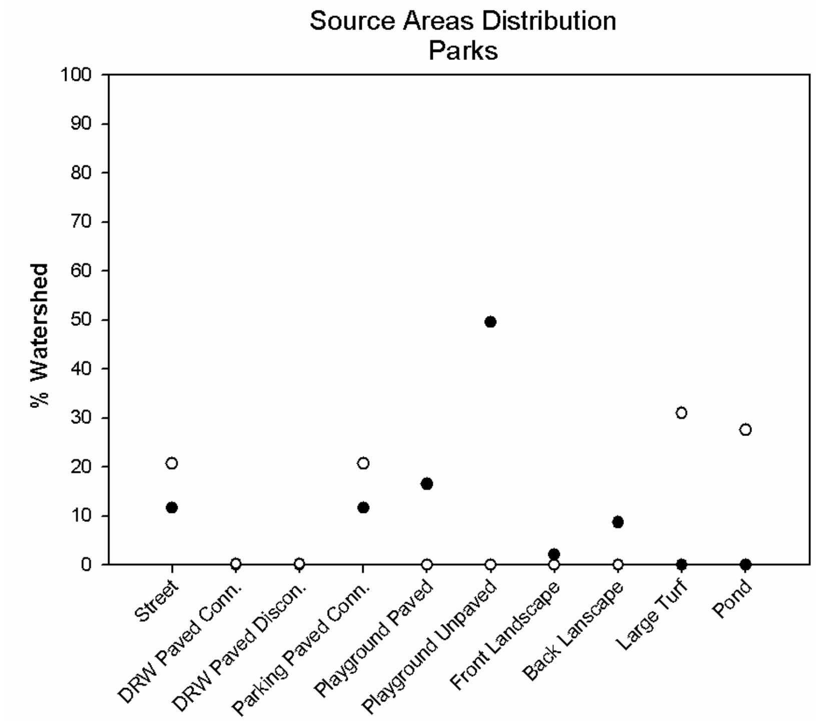


Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots – *continued*



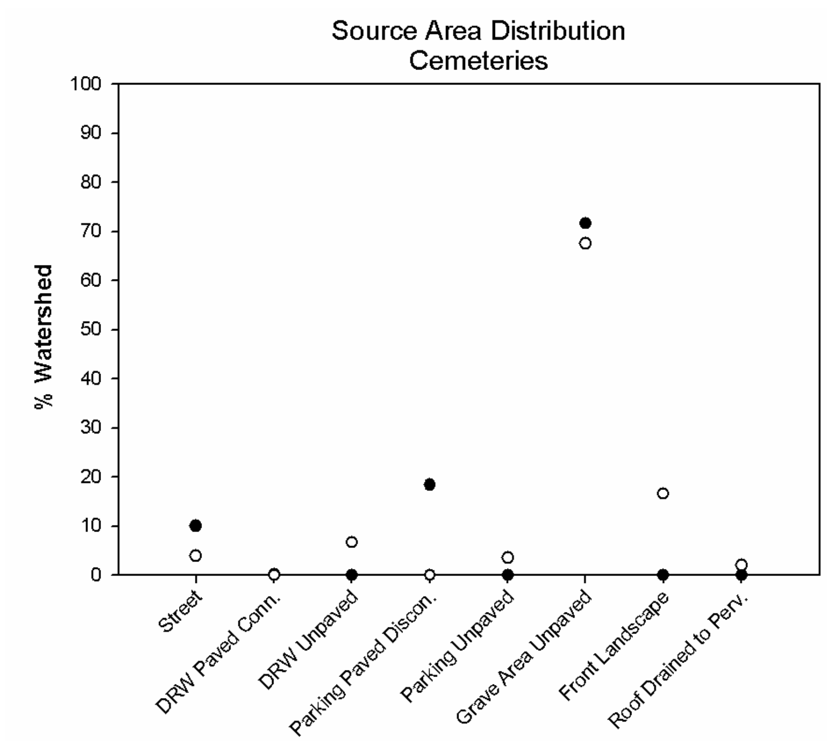
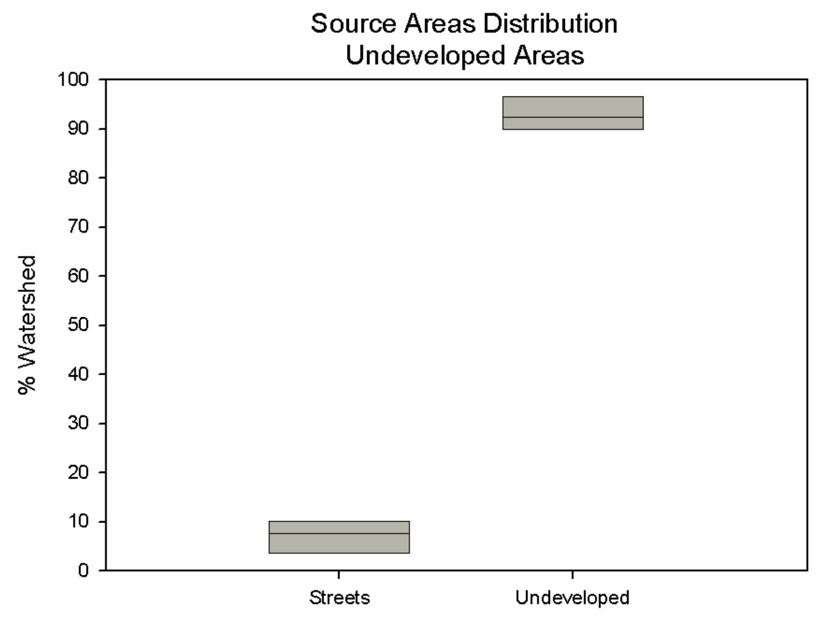
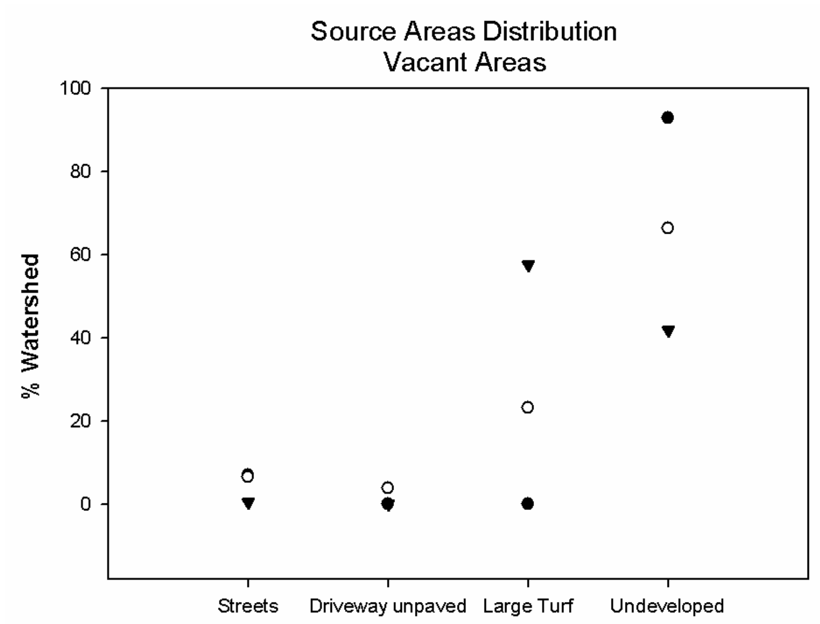


Figure 15. Little Shades Creek Watershed: Source Area Distribution using Box Plots – *continued*


Source Areas Distribution
Undeveloped Areas
% Watershed
100
90
80
70
60
50
40
30
20
10
0
Streets
Undeveloped


Source Areas Distribution
Vacant Areas
% Watershed
100
80
60
40
20
0
Streets
Driveway unpaved
Large Turf
Undeveloped