XX

Land Development Characteristics in Jefferson County, Alabama

Celina Bochis, Robert Pitt, and Pauline Johnson

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 the Source Loading and Management Model (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 this paper, 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 for measurements of each source area type.

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. 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 paper to obtain the field data information have been used for many years in stormwater research projects, including several Nationwide Urban Runoff

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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, ON, Canada. These stormwater studies, amongst others, showed that land development characteristics, especially directly connected impervious areas, are generally similar amongst US and Ontario regions, but each land use categories shows variabilities in land development characteristics. One of the objectives of this paper is to show measured variabilities in these characteristics in an area in Jefferson County, Alabama.

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 paper, 125 neighborhoods located in the Little Shades Creek watershed (Jefferson County, near Birmingham, AL) and 40 neighborhoods located in five highly urbanized drainage areas situated in Jefferson County, AL (in and near city of Birmingham) were surveyed to determine the actual development characteristics and their variabilities.

xx.1 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 into major land uses categories according to their main land use (residential, institutional, industrial, commercial, open space, freeway, etc.). For local planning and modeling purposes, those major land uses can be further sub-categorized according to the population density (e.g. high /medium/low density), with the dominant activity that takes place in the land use (e.g. shopping center, offices, manufacturing, education,etc.), and with the age of the development (Pitt and Voorhees 1995).

One problem in evaluating an urban area for potential stormwater controls is the need for understanding 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 the following components: roofs, streets, sidewalks, driveways, parking lots, storage areas, playgrounds, front landscape areas, back landscape areas, undeveloped areas, and other pervious areas (Pitt and Voorhees 1995). This partitioning helps to better predict the outfall runoff characteristics and/or the effect of source area controls. Bochis (2007) showed the runoff characteristics of a commercial/mall area in Hoover, AL (Figure xx.1). This figure shows the percentage of runoff volume originating from different sources, as a function of rain depth. In this example, for precipitation depths for the smallest rainfalls that are likely to produce runoff, about 80% of the runoff originates from the parking areas. This contribution decreases to about 55% at rain depths of 0.5 inches (13 mm). This decrease in the importance of parking areas as a source of runoff is associated with an increase in runoff contributions from streets and directly connected roofs.

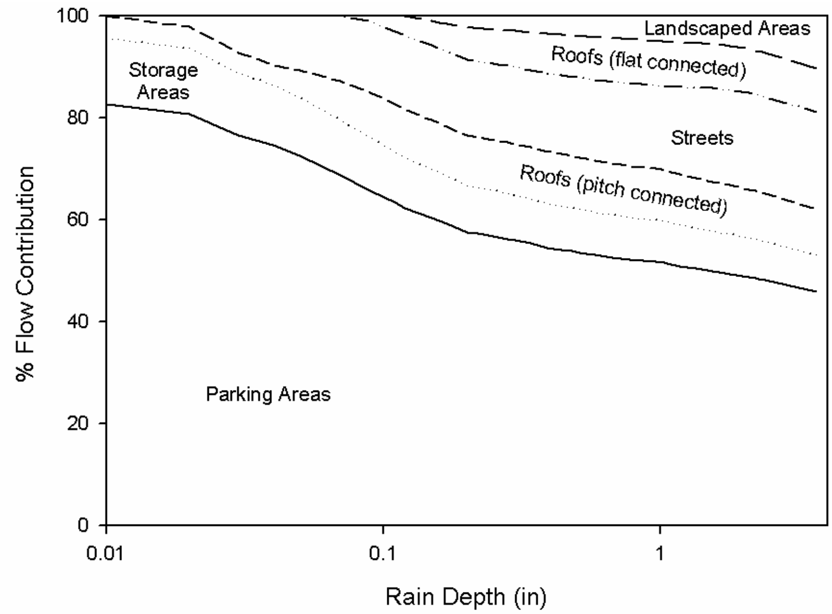

Figure xx.1. Flow Sources for Example Commercial/Mall Area (Bochis 2007).

The relative contributions of source areas for different pollutants and flows are both site specific and rain pattern dependent for different geographical regions. However, the initial runoff is always generated by the directly connected impervious areas, with pervious areas contributing runoff only during the later portions of larger rains, or during periods of large rainfall intensities.

The lengths of the 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 swale 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 the National Stormwater Quality Database (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 contained in the NSQD and found significant differences in concentrations for the different land use categories for the pollutants examined. However, this method can result in large variations in predicted values. In order to reduce the variabilities, more accurate values of the actual surfaces in each land use, and how they are connected to the drainage system, can be measured and used in predictions.

xx.2 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 is 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 measurement methods used to gather land use/land cover information include: existing data conversion, detailed site surveys, aerial photograph interpretation, and satellite remote sensing (Lee and Heaney 2003; Gregory, et al. 2005).

Historically, land use/land cover information was acquired by a combination of field measurements and aerial photographic analyses, 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 remaining problems include difficulties in obtaining consistent sequential acquisition dates, intensive computer processing time requirements, and large computer storage space requirements to store massive amounts of image information. In this research, IKONOS satellite imagery (provided by the Jefferson County Storm Water Management Authority, SWMA) 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).

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

xx.3 Expected Biological Conditions as a Function of Impervious Areas in Jefferson County Watersheds

The increased presence of hard and impermeable surfaces within a watershed leads to frequent and severe floods, followed by the stream channels response. These responses are usually in the form of increasing the cross-sectional area through increases in channel width (Schueler 1994) and/or channel incision (Schumm 1999) followed by streambank erosion and sedimentation (Schumm 1999).

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. 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.

Increased imperviousness leads to poorer water quality and pollution discharges to urban receiving waters. Research from throughout the country has consistently demonstrated that a threshold in receiving water habitat quality exists at about 10-15% imperviousness, beyond which urban stream habitat quality is classified as poor (Booth and Reinelt, 1993). It has been found that there are two thresholds in the stream degradation process (Schueler 1994). The first threshold is observed to be at about 10-15% impervious cover, when stream degradation starts to occur and sensitive stream elements (macroinvertebrates, aquatic insects, fish communities) vanish from the system (Schueler 1994). 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 streams are in poor conditions and the aquatic habitat is severely damaged.

Based on the relationship between stream 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: sensitive, impacted, and damaged streams (Table xx.1).

Table xx.1 Classification of Urban Streams based on Ultimate Imperviousness (Schueler 1994)

Urban Stream 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 Pollutant Loads
Water Quality Objectives	Sediment and Temperature	Nutrient and Metal Loads	Control Bacteria

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.

xx.4 Field Data Collection

The field data used with WinSLAMM to model the runoff quantity and quality was collected during an earlier study of the Little Shades Creek watershed near Birmingham, AL (Figure xx.2), as part of a cooperative study conducted by the University of Alabama at Birmingham, the Jefferson County office of the U.S. Natural Resources Conservation Service (NRCS), the U.S. Army Corps of Engineers, and other city and county governments. The field data collection effort for the five additional Jefferson County drainage basins reported in this paper was performed during the author's master thesis research (Bochis 2007). Initially, the Little Shades Creek watershed data along with source area and outfall monitoring data were used to calibrate WinSLAMM and to examine alternative stormwater controls in this rapidly developing area. Currently, data from the five Jefferson County drainage areas (Figure xx.2) (which are included in the MS4 NSQD database for Jefferson County, AL) were used to conduct a re-validation of the model, before it was used to calculate the expected conditions for each of the land uses (Bochis 2007).

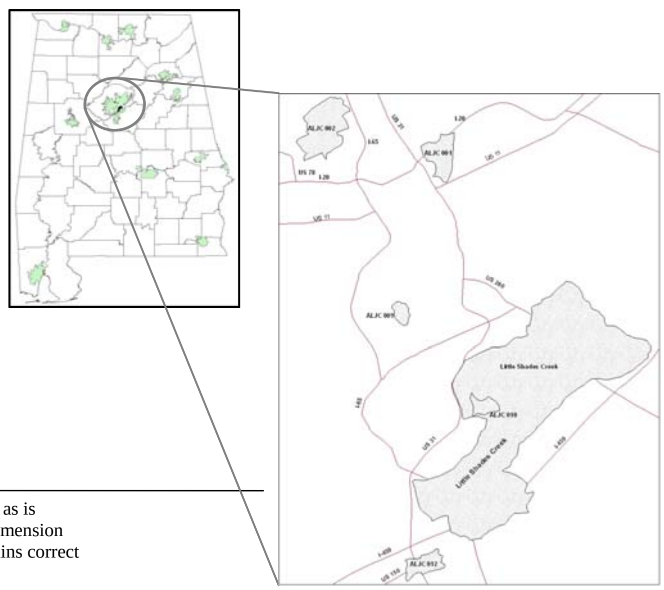

Figure xx.2. Location of Jefferson County, AL and Study Watersheds in Birmingham Area (Bochis 2007).

An "Area Description" field sheet, developed by Pitt during early stormwater projects (Pitt 1979; Pitt and Shawley 1982) was used to record the important characteristics of the approximate 150 neighborhoods in the Little Shades Creek and the five Jefferson County drainage basins during field surveys. In addition, aerial photographs from TerraServer USA (http://terraservice.net/) and satellite images provided by the Storm Water Management Authority (SWMA) in Birmingham (http://www.swma.com/) were used to assist in the measurement of the actual coverage of each type of surface in each neighborhood studied and were used to supplement the field collection information. The following briefly describes the important elements of the field sheet:

- ***Location***: The block number range and the street name are noted. Descriptions are made for homogeneous block segments (neighborhoods) in the study areas. Specific blocks to be surveyed are 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 and the other was a close-up showing about 25 by 40 cm of pavement. 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, and 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 and the approximate age of development 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.
- ***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, and the “to impervious” category is circled. 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 (the paved or unpaved driveway category is another description that may vary within a surveyed neighborhood), 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 on the survey form. Pavement condition and texture, also noted, 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 areas of individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc) were measured using a planimeter and/or GIS tools

(Bochis 2007). The data was then summarized in a spreadsheet (Table xx.2 is an example for the Little Shades Creek watershed) and was used to build the WinSLAMM files to describe each land use (Bochis 2007). Manual measurements of this information from the photographs were necessary, 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 using field surveys.

xx.5 Description of Land Use

xx.5.1 General Land Use Description for the Study Areas

A stormwater/watershed study should use the locally available land use data and planning agency 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. Table xx.3 shows the local planning agency categories that exist in the watershed. The following briefly explains the land use descriptions used in this research, according to the documentation supplied with WinSLAMM (Pitt and Voorhees 2002). 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.

Table xx.3 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**

- ***Residential Land Uses***

- High Density Residential: Urban single family housing at a density greater than 15 units/ha (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 5 to 15 units/ha (2 to 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 the previous residential areas, except the density is 2 to 5 units/ha (0.8 to 2 units/acre). Some areas may have significant amounts of very low density residential developments and may therefore require additional categories.
- Multiple Families: Buildings having 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. This category may be further divided to separate duplexes from larger buildings.
- 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: This land use contains non-retail businesses. The buildings are usually multi-story, 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: Land areas that 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. This land use includes the buildings, grounds, parking and storage lots, roads, and drives.

• ***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, roads, 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, interior and adjacent 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.

xx.5.2 Little Shades Creek Watershed Land Use Description

The Little Shades Creek watershed has an area of about 2,100 ha (8 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.

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 exception being multi-family areas where most of the roofs were directly connected to the impervious 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. Much landscaping was present in the area and was mostly lawns and evergreen shrubs, with some large trees in the older residential areas. 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 in the watershed. The school roofs were flat and drained slightly more unto impervious surfaces than toward pervious areas. However, school playgrounds were mostly unpaved. Churches had pitched roofs that drained to impervious areas. Landscaped 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 processing 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 building stormwater drains 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.

xx.5.3 Jefferson County Drainage Basins Land Use Description

The five basins used to re-validate the older regional calibrations of the WinSLAMM model are located in Jefferson County, AL, and are being monitored for the county MS4 stormwater permit program. This data is incorporated in the NSQD database (Pitt, et al. 2004 and Maestre and Pitt 2005). About 10 events have been sampled at each of these areas by SWMA since 2001. Manual sampling was used, with composite samples collected during the first three hours of rainfall events. Each of the five sampling sites is described in the following paragraphs and summarized in Table xx.4.

- ***Light Industrial (ALJC001)***. Drainage area is 138 ha (341 ac). This area drains approximately 62% industrial property (manufacturing, junk yards, garages), 12% commercial land use (shopping centers), a small percentage of high-density residential (8.5%) and open space (6.4%) areas (cemeteries, undeveloped land). About 11% of this watershed is represented by freeways without grass medians.

- ***Heavy Industrial (ALJC002).*** Drainage area is 292 ha (721 ac). Approximately 75% of the drainage area is industrial land use (iron cast industry, junk yards, railroad yards, truck garages), while 14.5% is high-density residential and a small percentage (2.5%) is represented by commercial land use (small shopping areas) and forest as open space (6.7%)
- ***High-Density Residential (ALJC009).*** Drainage area is 42 ha (102 ac). Most of the drainage area is comprised of residential lots 0.1 ha (0.25 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, several small churches, 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 drainage area is almost entirely residential lots greater than 0.1 ha (82.5%), except for a small portion of undeveloped land (17.5%) on a steep slope that is wooded with heavy cover.
- ***Commercial Mall (ALJC012).*** Drainage area is 92 ha (228 ac). Most of the drainage basin is composed of strip shopping centers and a fragment of the large Riverchase Galleria shopping mall, except for some residential apartments that make up 25% of the drainage area along with some undeveloped woodland, which is 5% of the drainage area.

A great deal of imperviousness was found in those five Jefferson County drainage basins. The stormwater drainage system was predominantly formed of curbs and gutters in good or fair condition with very little use of grass swales. Therefore most of the roofs (pitched in residential and institutional areas and flat in rest) were directly connected to the drainage system. The streets and most of the commercial parking lots had asphalt pavement (smooth or medium texture), but industrial parking lots and residential sidewalks/driveways had smooth concrete as their predominate surface cover.

xx.6 Data Processing

XX.6.1 Aerial Photograph Measurements

The second step in this study was the processing of the aerial photographic data, using GIS tools and statistical tools. After the field data description sheets were completed for each neighborhood survey, the corresponding aerial photographs from TerraServer USA and satellite images provided by SWMA were examined, and the individual elements (roofs, parking areas, street areas, sidewalks, landscaping, etc) were measured using GIS tools. The aerial photograph area measurements were tabulated, summarized and used to build the WinSLAMM files to describe each land use area (Bochis 2007).

The aerial photograph measurements for the 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, using one sheet for each site surveyed.

The first step in the study of the five Jefferson County drainage basins was to procure the IKONOS satellite imagery taken during 2001 and 2003, plus the watersheds paper maps from SWMA. The second step was the delineation of the five watersheds using map digitizing and GIS tools. The multi-spectral image for Jefferson County (1999) and the paper maps of the watersheds were used to manually digitize and then cut each one of the five watersheds using GIS, having as an output a shape file of the watershed. After that, two 1-m panchromatic satellite images (“Leafoff.img” flown December 2000 and “Leaffon.img”, flown summer 2001) of Jefferson County were used to overlap the shape files and cut the corresponding satellite image for each watershed. The overlapping/cutting process made use of GIS tools and each image was saved separately 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 GIS and stored in the shape file attribute table.

xx.6.2 Data Measurements, Storage, and Processing

The older Little Shades Creek area measurements were manually obtained from aerial photographs and manually transferred into electronic format, while the individual elements of the five Jefferson County watersheds were measured in square feet units and recorded directly in an electronic format. Normalization of the actual area measurements so they summed 100% was performed to account for minor rounding errors. The normalized data (percentages) were then used to build the WinSLAMM files, with each land use file totaling 100 acres (Table xx.2 and Table xx.4).

xx.7 Discussion and Conclusions

The data collected for the Little Shades Creek watershed show that this area in Birmingham, AL, 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 xx.5). 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. Figure xx.3 shows the average land cover distribution for a high density residential land use. For a typical high density residential land use in this region (having 15 or more units/ha), the major land cover was found to be landscaped areas, subdivided into front and back yard categories, and about 25% of this land use area is covered by impervious surfaces broken down into three major subcategories: roofs, streets, and driveways. Also, for a typical high density residential land use located in the Birmingham area, the total amount of impervious area does not vary much. There is an apparent variability in front landscaped vs. back landscaped areas, the reason being the position of the house on the lot, but in fact, the total amount of landscaped areas has a low variability for residential land use areas.

WinSLAMM was used to investigate the relationships between watershed and runoff characteristics for each of the individual 125 neighborhoods investigated. An example evaluation is shown on Figures xx.4 and xx.5 which shows the obvious relationships between the directly connected impervious area values and the calculated volumetric runoff coefficients (Rv) for each land use category (using the average land use characteristics for these plots), 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 (Bochis and Pitt 2005):

Sandy soils: $y = 0.062e^{0.031x}$ ($R^2 = 0.83$) (xx.1)

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

where:

y = the volumetric runoff coefficients (Rv)
x = the directly connected impervious areas (%) for the areas

It is interesting to note that the Rv values are 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.

As part of this research, SWMA biologists 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, as expected from the calculated runoff values and the measured large amounts of impervious areas.

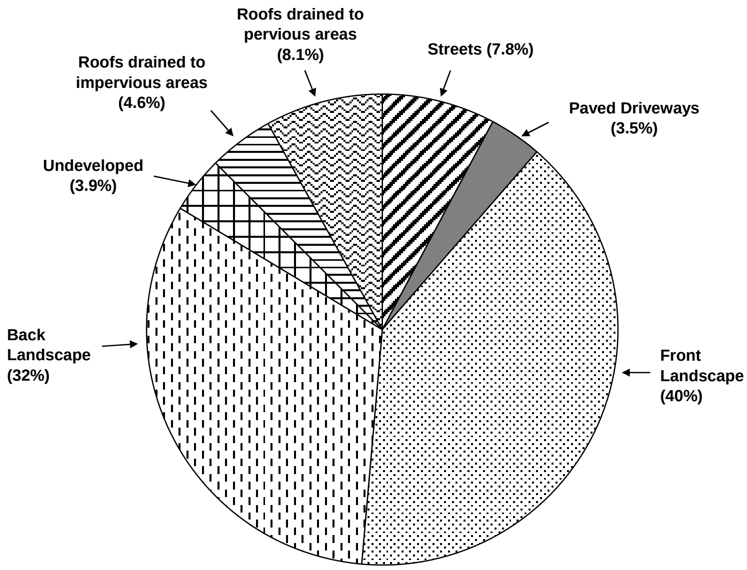

Figure xx.3 Little Shades Creek Watershed: High Density Residential Source Area Distribution using Pie Charts (Bochis 2007)

WinSLAMM was modified to track the amounts of directly connected and partially connected impervious areas in modeled areas, and predict 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 xx.6 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 show that all five watersheds are highly impervious, with more than 50% of the watershed areas 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 conducted by the SWMA biologists.

Table xx.5 Little Shade Creek Watershed, Birmingham, AL Source Area Drainage Connections by Land Use (Bochis 2007)

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

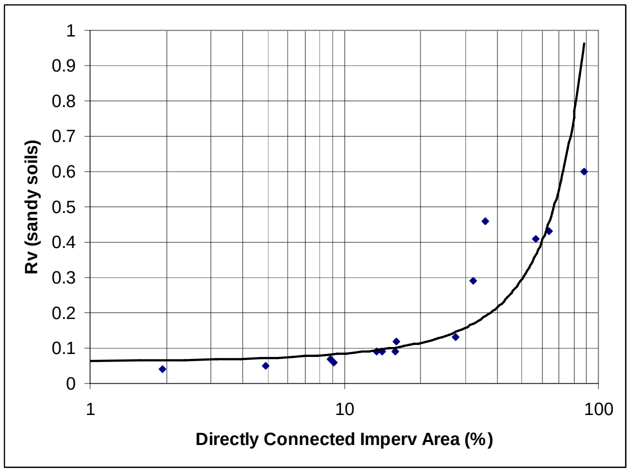

Figure xx.4 Relationships between the directly connected impervious area (%) and the calculated volumetric runoff coefficients (Rv) for each land use category for sandy soil (Bochis and Pitt 2005)

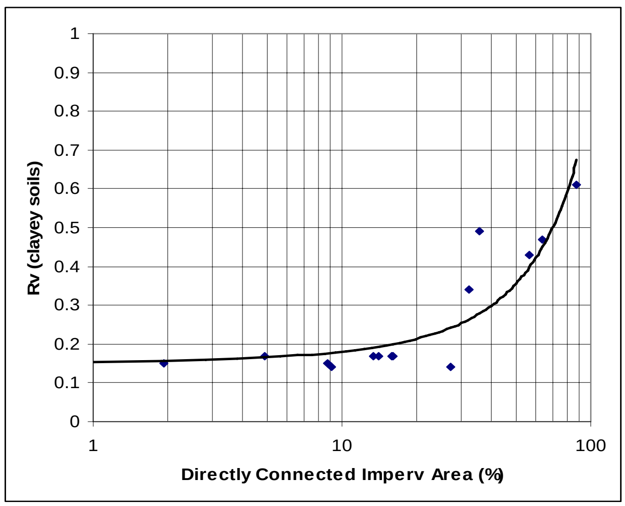

Figure xx.5 Relationships between the directly connected impervious area (%) and the calculated volumetric runoff coefficients (Rv) for each land use category for clayey soil (Bochis and Pitt 2005)

Table xx.6 Jefferson County, AL
Source Area Drainage Connections by Land Use (Bochis 2007)

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	
Watershed Weighted Average		*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	
Watershed Weighted Average		*40*	*53*	*7.3*	*0.51*
ALJC009	High Dens. Residential	59	28	13	
	Commercial	0.0	100	0.0	
	Institutional	19	74	7.1	
Watershed Weighted Average		*54*	*34*	*12*	*0.37*
ALJC010	Med. Dens. Residential	57	34	9.5	
	Undeveloped	100	0.0	0.0	
Watershed Weighted Average		64	28	7.9	*0.30*
ALJC012	Apartments	60	27	14	
	Commercial	28	72	0.0	
Watershed Weighted Average		*36*	*61*	*3.4*	*0.61*

This paper 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 covers 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 were used to process and present the data.

Schueler (1994) found that the transportation component (streets) often exceeds the rooftop component in terms of total impervious area, a fact clearly observed for our watersheds. 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). Also, Schueler (1994) and Center of Watershed Protection (2003) found that there is a direct relationship between stream quality and watershed imperviousness. Data from Tables xx.2, xx.5 and xx.6 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.

Urbanization radically transforms natural watershed conditions and introduces impervious surfaces into the previously natural landscape. Total impervious areas are mostly composed of rooftop and transportation related 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 stormwater pollutant mass discharges under most conditions. Data from Tables xx.5 and xx.6 also show that impervious areas in Little Shades Creek and Jefferson County watersheds are almost entirely directly connected, and that there is a large variability between the land use categories.

For small rain depths, almost all the runoff and pollutants originate from directly connected impervious areas, 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 drainage system. In many cases, pervious areas are not hydrological 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. However compacted soils can greatly increase the flow contributions from pervious areas during smaller rains.

The hydrologic and geomorphic impacts associated with increases in impervious surfaces are often accumulative 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 (wider streets, more parking lots, and garages). Also, the tendency towards 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. Knowledge about the impervious surfaces, and how they can be managed, is an effective stormwater management tool and can be used to help reduce the impacts of developments within watersheds.

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Appendix X: Land Development Characteristics in the Southern United States.

Celina Bochis, Robert Pitt, and Pauline Johnson

Oversized tables from Chapter xx.

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Table xx.2. Little Shade Creek Watershed, near Birmingham, AL: Average Source Areas by Land Use (Percent Unless Otherwise Noted) (Bochis 2007)

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

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
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

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

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
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

Table xx.4. Jefferson County AL., MS4 Watersheds: Source Areas by Land Use (Percentages, Unless Otherwise Noted)* (Bochis 2007)

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 impervious	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

Apartments (Residential) Land Use

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

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

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