Stormwater Permeability in the Waller Creek Watershed of Austin, TX

University of Texas at Austin
CE 394 GIS in Water Resources
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Introduction

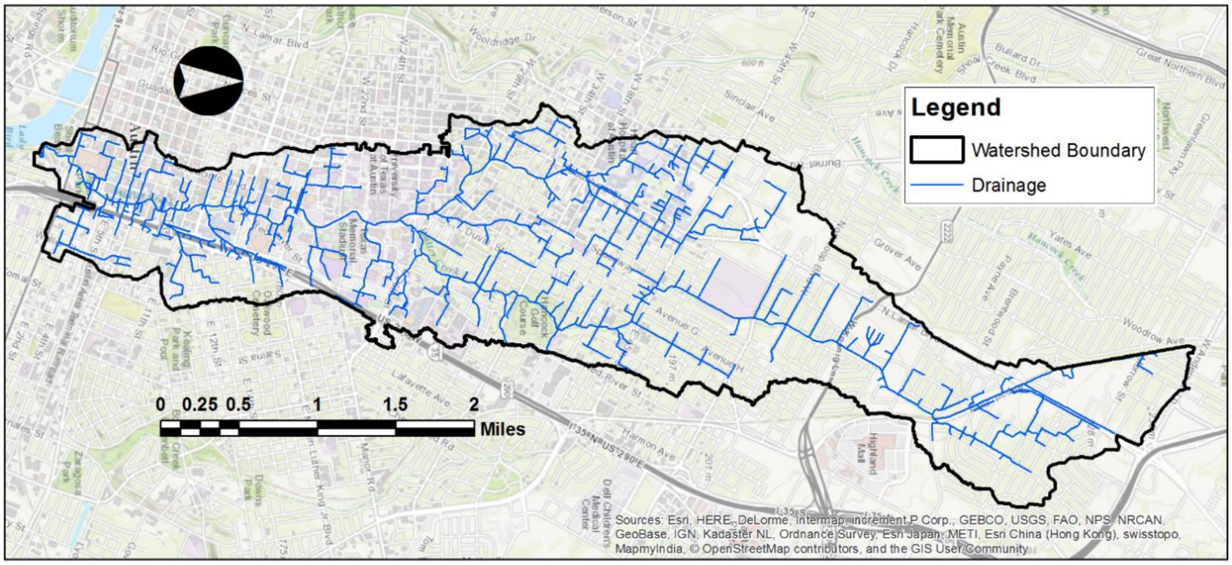
Development, through deforestation and urbanization, has decreased the land's ability to retain and absorb stormwater in affected areas. Traditional development of urban infrastructure has reduced the rate of infiltration by covering the soil with impermeable surfaces (buildings, roads, parking lots, etc.) that drain primarily through impermeable conveyance systems into natural waterways. The overflow of these basic systems causes problematic flooding of our urban infrastructure as well as the increase in polluted runoff into natural waterways.

The world urban population is expected to increase from 3.3 billion in 2007 to 6.4 billion in 2050 (United Nations, 2008). This demand for growing urban infrastructure will only make water quality issues worse with traditional development. Low Impact Development (LID) is a new method of addressing these issues. LID techniques include rain gardens, rain harvesting, bioretention swales, permeable pavers, etc. Integrating these techniques into the urban environment aim to promote the infiltration of rainfall and reduce the high level of runoff. However, the effectiveness and economic feasibility of these systems are still being debated.

The scope of this project will investigate the permeable land composition versus the urban development in the Waller Creek watershed (Figure 1) located in central Austin, TX. Waller Creek is roughly 5.64 square miles and includes a diversity of urban development types. The mile-long Waller Creek Flood Control Tunnel Project (Figure 2) is an ongoing project that is designed to remove more than 28 acres of downtown from the floodplain (City of Austin, 2015). This project reduces the impact of infrastructure flooding, but the volume of runoff into the surrounding natural water bodies has increased, bringing many unwanted pollutants with it.

This investigation will serve as an aid to future city planners that want to determine the effectiveness and economic feasibility of different LID techniques in a particular watershed. The primary objective is to show how ArcGIS can be used as a tool to provide answers to the questions below and communicate these findings in making major development decisions.

1) What is the extent of impermeable land cover with urban development?
2) Which zoning districts are having the greatest impact on stormwater runoff?
3) Where could various LID techniques be implemented to achieve the best results while maintaining economic feasibility?



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 1: Watershed Drainage

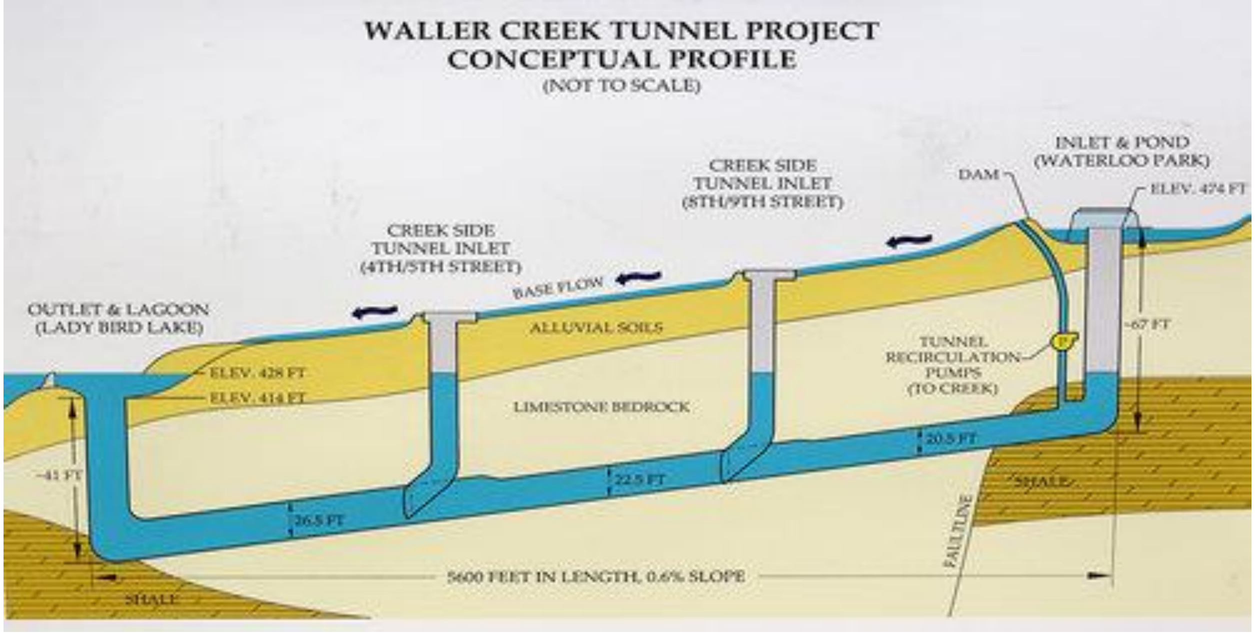


Figure 2: Waller Creek Tunnel

Methodology

This investigation utilized and evaluated the datasets shown in Table 1 below. All datasets were aqcuired directly from the City of Austin's public GIS/Map webpage. These datasets were used to determine the extent that different development areas contribute to the impermeable land area.

Table 1: Datasets used (Source: City of Austin)

DATASET:	USE:
Watersheds	To dilineate the Waller Creek Watershed and determine the total land area.
Zoning Districts	To delineate the zoning areas throughout the watershed
Building Footprints 2013	To determine the contributing area of rooftops throughout the watershed and zoning districts. To determine building size statistics.
Remaining Pervious Cover 2013	To determine the area of permeable land cover in the Waller Creek Watershed and zoning districts. By subtracting this area from the total watershed area, the impermeable land cover is determined.
Creek Lines	To determine the drainage paths for the Waller Creek Watershed
Driveways 2013	To determine the contributing area of driveways in the residential zoning district and transit corridors.
Double Line Streets 2013	To determine the contributing area of roads in the transit corridors.

The zoning districts need to be fragmented into appropriate categories. Table 2 lists the City of Austin's zoning codes that designate the various types of development classifications. Since there are over 45 different classifications, this project will simplify them into five generalized categories. Table 3 lists the five generalized zoning categories, as well as the "unzoned" public transit corridors that make up the "void" space between all zoning districts. The Public and Other categories make up a small portion of the Waller Creek Watershed and will therefore not play a major part in the analysis.

To determine the composition of the impermeable land surface, the datasets need to be extracted and superimposed on each other using the analysis tools provided by ArcGIS software. Specifically, the 'Building Footprints 2013', 'Remaining Pervious Cover 2013', 'Driveways 2013', and 'Double Line Streets 2013' datasets will be spatially analyzed based on the 'Watersheds' and 'Zoning Districts' datasets.

Table 2: City of Austin Zoning Codes

LA Lake Austin Residence	**RR** Rural Residence	**SF-1** Single Family Residence - Large Lot
SF-2 Single Family Residence - Standard Lot	**SF-3** Family Residence	**SF-4A** Single Family Residence - Small Lot
SF-4B Single Family Residence - Condominium	**SF-5** Urban Family Residence	**SF-6** Townhouse & Condominium Residence
MF-1 Multi-Family Residence - Limited Density	**MF-2** Multi-Family Residence - Low Density	**MF-3** Multi-Family Residence - Medium Density
MF-4 Multi-Family Residence - Moderate-High Density	**MF-5** Multi-Family Residence - High Density	**MF-6** Multi-Family Residence - Highest Density
MH Mobile Home Residence	**NO** Neighborhood Office	**LO** Limited Office
GO General Office	**CR** Commercial Recreation	**LR** Neighborhood Commercial
GR Community Commercial	**L** Lake Commercial	**CBD** Central Business District
DMU Downtown Mixed Use	**W/LO** Warehouse Limited Office	**CS** General Commercial Services
CS-1 Commercial-Liquor Sales	**CH** Commercial Highway	**IP** Industrial Park
MI Major Industry	**LI** Limited Industrial Services	**R&D** Research and Development
DR Development Reserve	**AV** Aviation Services	**AG** Agricultural
PUD Planned Unit Development	**P** Public	**TOD** Transit-Oriented Development
NBG North Burnet/Gateway District	**ERC** East Riverside Corridor	**TND** Traditional Neighborhood District

Table 3: Zoning Groups

General Zoning Types:	**Zoning Classification Codes**
Residential	SF-1, SF-2, SF-3, SF-4A, SF-4B, SF-5, SF-6, MF-1, MF-2, MF-3, MF-4, MF-5, MF-6, MH
Commercial	NO, LO, GO, LR, GR, CBD, DMU, CS, CS-1, CH
University	UNZ
Public	P
Other	LI, TOD
Public Transit Corridors	Remaining Area (“Unzoned”)

Results

Figure 3 illustrates the amount of remaining pervious land cover in 2013 for the Waller Creek watershed. Overall, development has covered 61.7% of the watershed, reducing the remaining permeability to 38.3%.

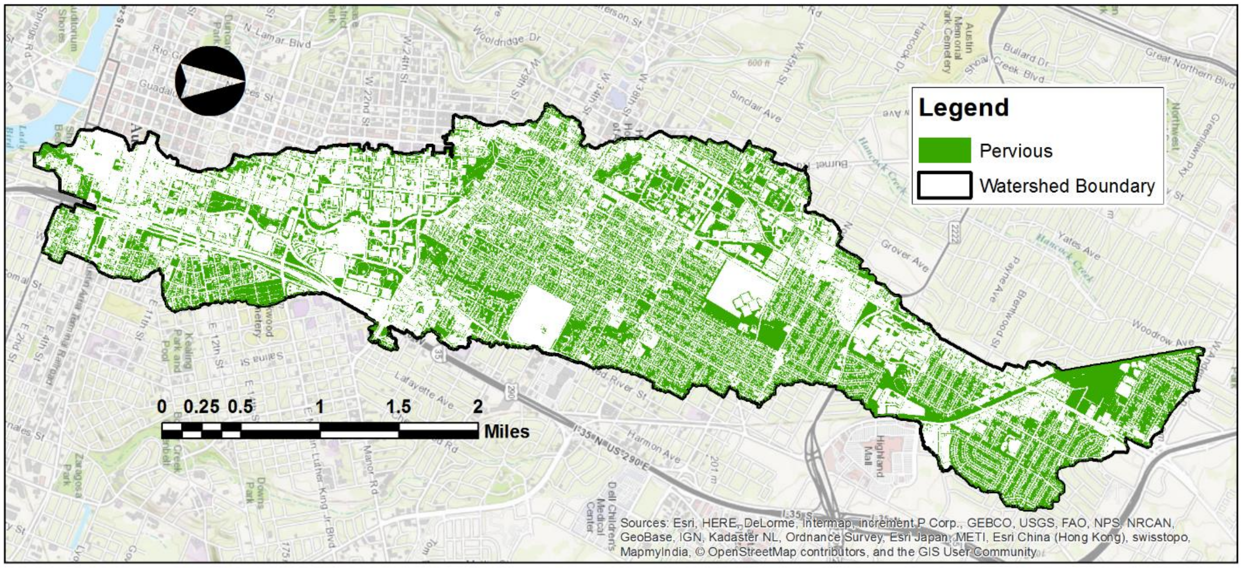


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Figure 3: Pervious Land Surface

Figure 4 illustrates the layout of building footprints throughout the Waller Creek Watershed in 2013. Overall, building footprints make up 20.6% of the total watershed area and 33.4% of the impermeable land area.

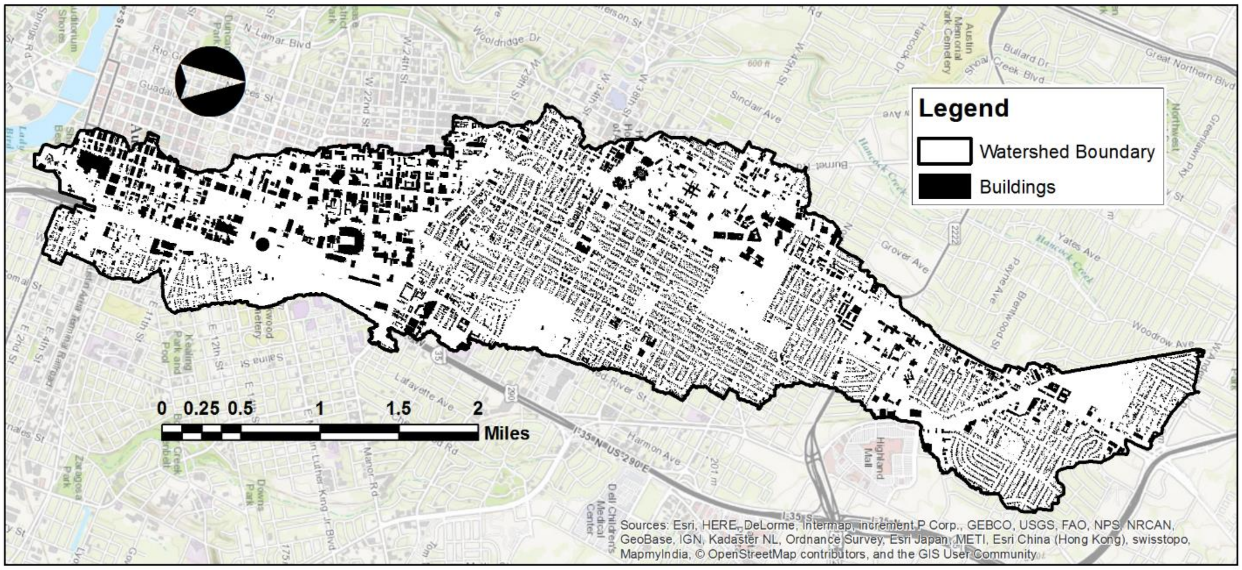

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Figure 4: Building Footprints

Figure 5 illustrates the generalized zoning groups throughout the Waller Creek Watershed. Residential, commercial and university zoning makes up 35.0%, 14.3%, and 14.8% of the total watershed area, respectively.

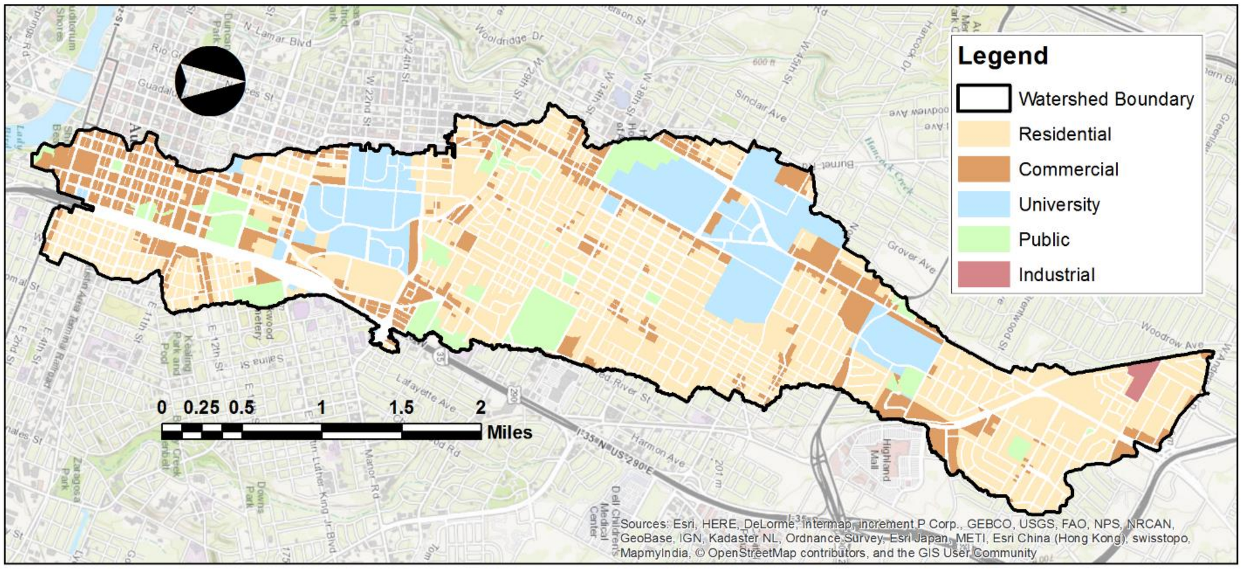

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Figure 5: Zoning Groups

Figure 6 illustrates the public transit corridors throughout the Waller Creek Watershed. This map was generated from the void space between the generalized zoning groups. The public transit corridors make up 24.5% of the total watershed area.

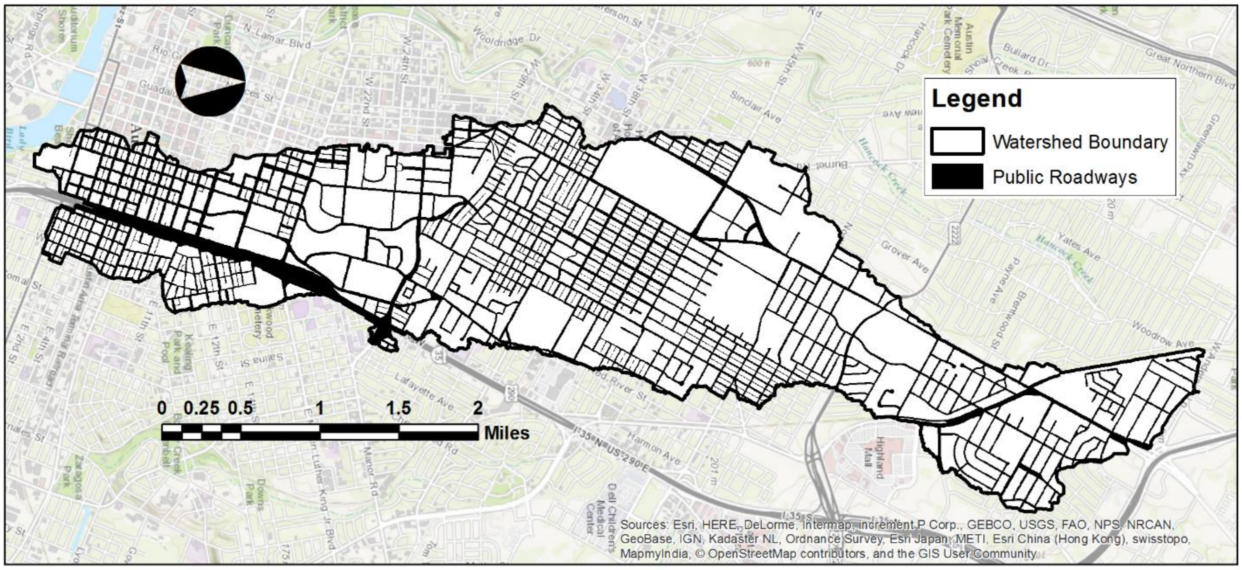

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Figure 6: Public Roadways

Based on Figure 5, Figure 7 shows the contribution of each zoning group to the overall watershed area (a) and to the impervious area (b).

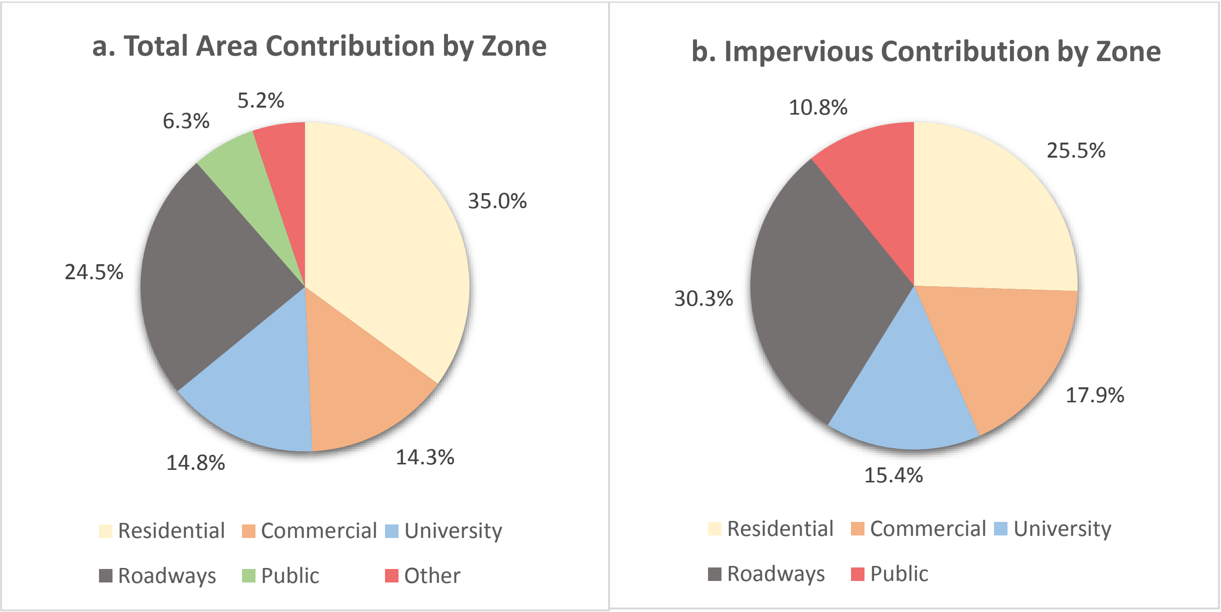


Figure 7: Total and Impervious Area Contributions

Superimposing Figures 3 and 4 onto Figure 5 allowed the impermeable composition of different zoning classifications to be determined. Furthermore, superimposing Figure 3 onto Figure 6 allowed the impermeable composition of the public roadway corridors to be determined as well. Figure 4 was not superimposed for this dataset because building footprints are not present in public roadway corridors.

Figure 8 provides an overview of the impermeable land composition for each spatial category analyzed. Tables 4 – 7 further details the total areas of varying impervious surfaces that make up the total impervious areas in a particular zoning group. The area for the sidewalks in the public transit corridors was obtained by subtracting the ‘Double Line Streets 2013’ and ‘Driveways 2013’ datasets from the total impervious area.

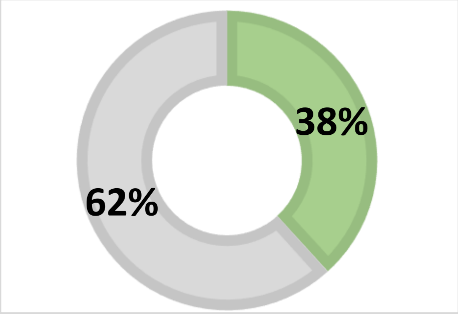
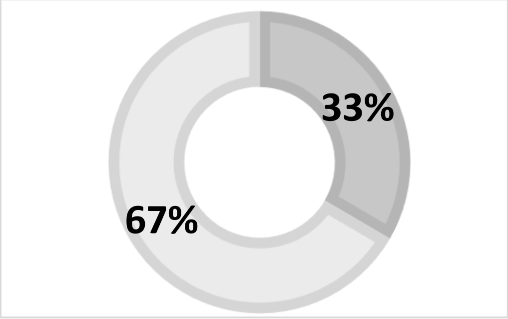
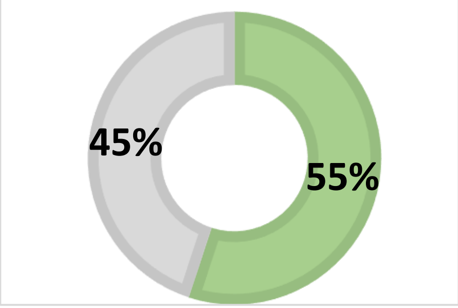
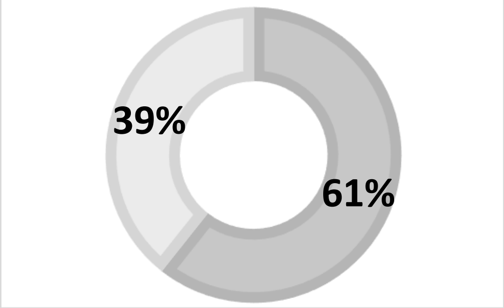
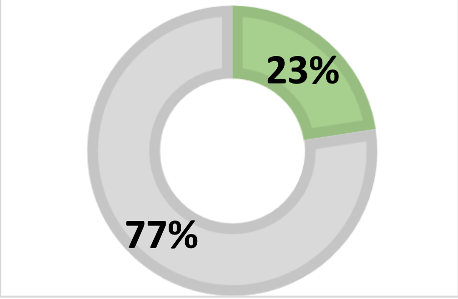
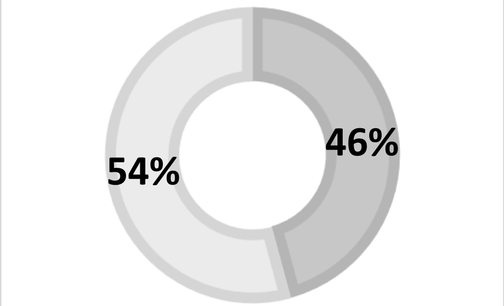
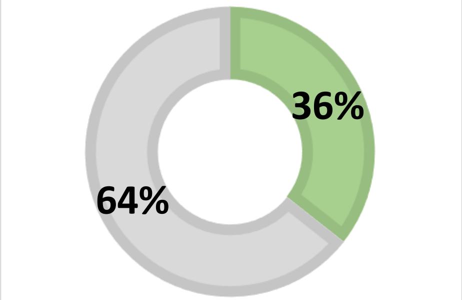
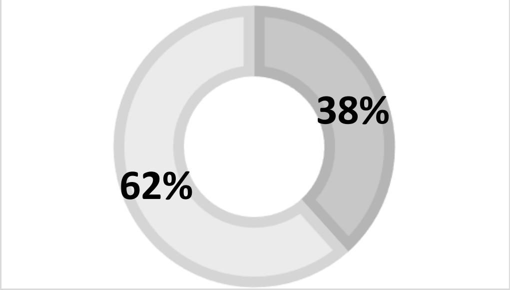
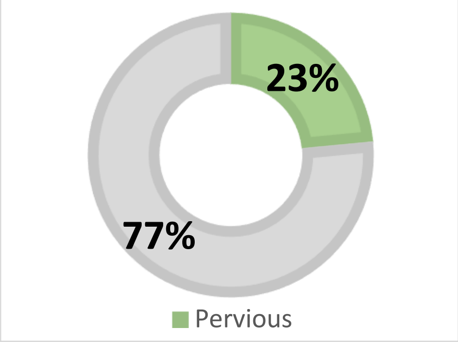
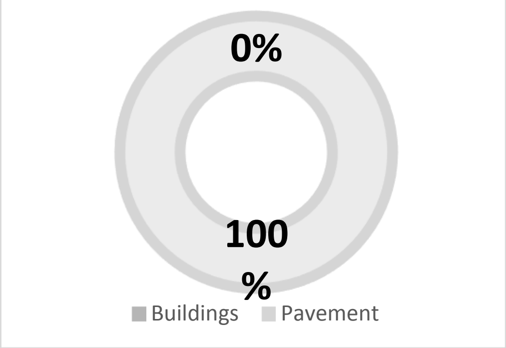
Area	Impermeability	Impermeable Composition
Watershed		
Residential		
Commercial		
University		
Roadways		

Figure 8: Summary of Impermeable Composition

Table 4: Impervious Composition for Residential Zoning

Impervious Surface:	**Area:** (Squared Feet x 10^6)	**Percent of Impervious Area:** (%)
Buildings:	15.0	60.7
Driveways:	3.1	12.4
Paved Surfaces / Parking Lots:	6.7	27.0

Table 5: Impervious Composition for Commercial Zoning

Impervious Surface:	**Area:** (Squared Feet x 10^6)	**Percent of Impervious Area:** (%)
Buildings:	8.0	45.8
Paved Surfaces / Parking Lots:	9.4	54.2

Table 6: Impervious Composition for University Zoning

Impervious Surface:	**Area:** (Squared Feet x 10^6)	**Percent of Impervious Area:** (%)
Buildings:	5.7	38.4
Paved Surfaces / Sports Fields:	9.2	61.6

Table 7: Impervious Composition for Public Transit Corridors

Impervious Surface:	**Area:** (Squared Feet x 10^6)	**Percent of Impervious Area:** (%)
Roads:	22.4	76.2
Driveways:	0.9	3.0
Sidewalks:	6.1	20.8

Table 8 lists the building size statistics for each of the three main zoning groups and the overall watershed. Figure 9 is a cumulative building size distribution that determines the percent of impervious area for all buildings footprints larger than a particular building size criteria. Figure 10 shows all the buildings within Waller Creek that have a building size criteria of greater than 50,000 square feet.

Table 8: Building Size Statistics

	Residential	**Commercial**	**University**	**Watershed**
Total Area: (Squared Feet x 10^6)	15.0	8.0	5.7	32.4
Mean: (Squared Feet)	1,500	5,500	16,000	2,800
Standard Deviation: (Squared Feet)	3,300	12,000	34,500	10,900
Number of Buildings:	9,795	1,445	358	11,507

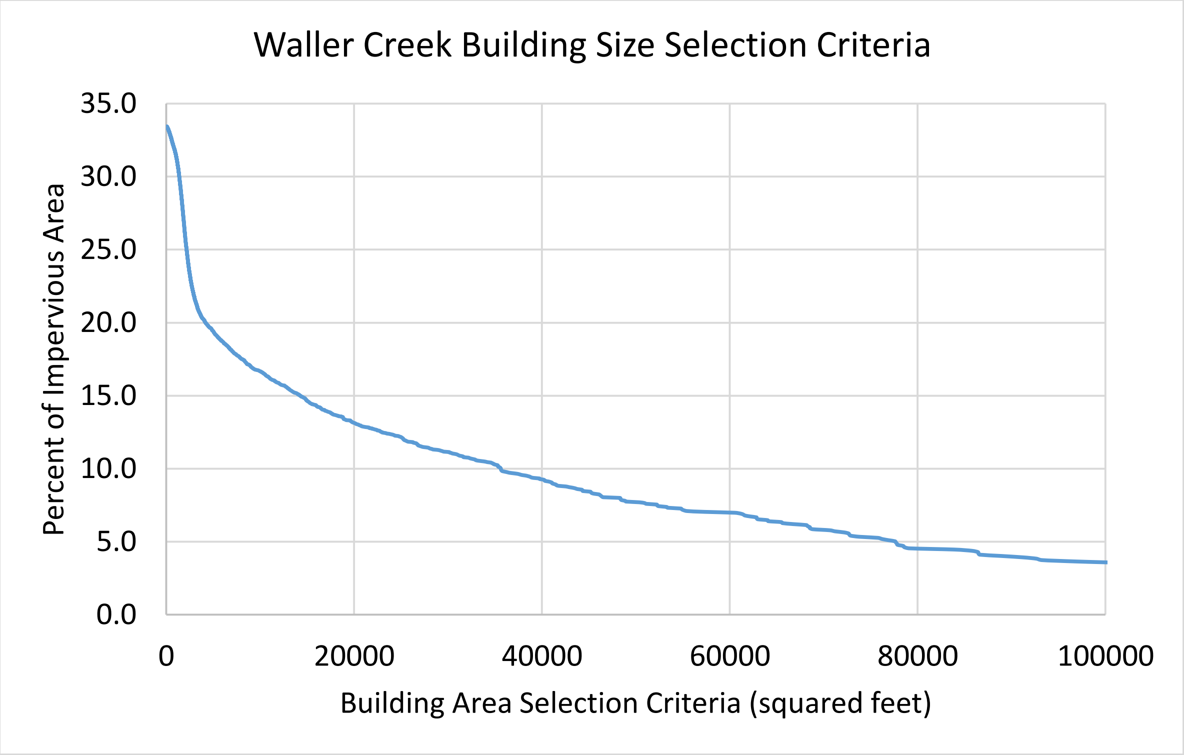


Figure 9: Waller Creek Building Size Selection Criteria

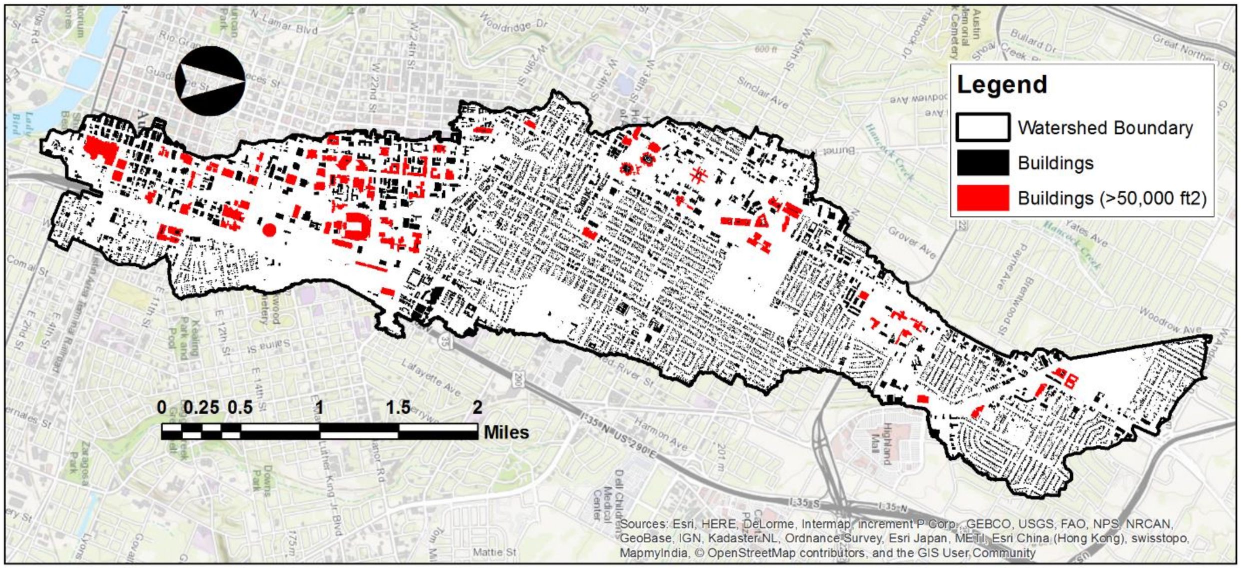


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Figure 10: Building Footprints (w/ areas greater than 50,000 square feet)

Discussion

The ‘Remaining Pervious Cover 2013’ dataset that was used for this investigation provides a binary classification for areas that are either pervious or not. Unfortunately, the data does not account for the percent of impermeability and there are some grey areas as a result. For example, the sports playing fields and golf course in the watershed were considered impermeable by the dataset, which is not necessarily true. The likely reason for this is probably due to the impacts of drainage maintainence. To provide ideal playing conditions, networks of perforated piping are installed to drain excess water quickly, resulting in an increased runoff coefficient. Therefore, the dataset considers the land area as effectively “impermeable.”

Figure 7 shows the contribution of each zoning group to the overall watershed area (a) and to the impervious area (b). The comparison of these two graphs shows which zoning groups contribute an impermeable surface area that is higher than average. For instance, the roadway corridors take up 24.5% of total watershed area, but contribute to 30.3% of the impermeable land surface. The data for impermeability in Figure 8 also illustrates this relationship. The average impermeability for the watershed is 62% while the roadway corridors are 77% impermeable. The residential zoning group is the only area that has an impermeability that is lower than the average. This data suggests that the residential zoning group has the least impact on impermeability for this watershed.

Rainwater harvesting techniques could have the potential to reduce runoff impacts by storing and utilizing rooftop runoff for building facilities or irrigation. Overall, building footprints make up 33.4% of the impermeable area. However, it would not be economically feasible to collect rainwater for every structure. Texas Water Development Board passed a mandate requiring all new government buildings with roof areas greater than 50,000 square feet to utilize rainwater-harvesting technology (NCSL 2013). The purpose of this mandate is to reduce water demand and increase water savings. If we applied this same criteria for all buildings, the area from these building footprints would contribute to roughly 7.1% of the impermeable area, based on Figure 9. Figure 10 provides a map of where these buildings are located throughout the watershed.

Table 8 lists the building size statistics for each of the three main zoning groups and the overall watershed. These results show that the mean building size for the University zoning group is around 16,000 square feet, which is significantly greater than the mean building size of 2,800 square feet for the entire watershed. Based on these statistics, it could be concluded that the building footprints should make up a much greater portion of the impermeable surface. However, the results shown in Figure 8 suggest otherwise, as the building footprints only make up 38% of the impermeable surface. This discrepancy is likely a result of the issues discussed above with using a binary pervious cover dataset. The University zoning group consists of many sports playing fields, which the dataset considers impervious and therefore gets classified in the results as “pavement.” Therefore, this is a zoning group that would greatly benefit from using a dataset that provides percent of effective permeability rather than a binary classification.

Bioretention swales can be installed along parking lots, sidewalks, and roadways to slow runoff down and promote infiltration through the land surface. The roadway corridors group would be the best area to install bioretention swales because it is comprised of all the roadways and sidewalks, contributing 30.3% of the watershed’s impermeability. The bioswales can be installed in the 23% of unused pervious land cover by creating depressions that trap roadway runoff. The second option would be to implement in the high presence of parking lots in the commercial area, which contribute 17.9% of the watershed’s impermeability. Parking lots are represented by the Pavement type in Figure 8. These areas are also composed of 23% unused pervious land cover that can be optimized to slow down the lot runoff and allow sufficient time for infiltration.

Permeable pavers can be installed as an alternative to traditional sidewalk paving. Many pavers are designed to allow rainfall to percolate between them and be temporarily stored in hollow channels underneath, allowing time for the water to infiltrate into the ground. Sidewalks are accounted for in the roadway corridors group and were approximated to be 20.8 % of the impermeable surface. A GIS dataset that maps out only the sidewalks in the city would have provided higher accuracy for this analysis.

Conclusions and Future Work

To obtain higher accuracy in this investigation, a dataset that provides the percent of impermeability could be used. The ESRI Living Atlas servers provide NLCD Percent Impervious Data. However, this data is limited by its resolution of 30m x 30m, which is generally too low for the small development scales that we are working with. Additionally, this dataset doesn’t seem to take into account the application of field drainage systems, which significantly increase the runoff coefficient. Therefore, until more detailed impermeability datasets are developed, results will be primarly limited by the quality of this data used.

When developing a complete analysis of LID techniques for a watershed, the particular point or non-point sources of contamination must be considered. Some developments may have low runoff coefficients but higher sources of contamination. For instance, residential zoning groups will, in most cases, have the least impact on permeability. However, if a main source of pollution is coming from chemicals leaching from residential roofing materials, then the implications change for that particular development. This could be achieved by collecting water quality samples throughout the watershed at varying development drainages.

Overall, this project serves as a demonstration in determining the composition of the impermeable land surface in varying development classifications. Utilizing ArcGIS for this purpose may serve as an aid to future city planners that want to determine the effectiveness and economic feasibility of different LID techniques. This project was only applied on the Waller Creek Watershed, but scaling this analysis for an entire city would provide a comprehensive understanding of that city’s unique land composition overall.

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