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Is All the Impervious Cover for Streets Necessary?

A Study to Identify Impervious Cover to Remove from Transportation Facilities for Optimal Watershed Health and Minimal Transportation Impact

Introduction

The water resources literature has established the negative impacts transportation facilities, such as roadways and parking lots, have on watersheds (e.g., Brabec, Schulte, & Richards, 2002). Many older neighborhoods and commercial centers built before ordinances limited impervious cover or required mitigation suffer from the consequences of large parking lots and wide roadways such as localized or creek flooding, poor water quality, flow extremes and erosion (Brabec, Schulte, & Richards, 2002). Cities, such as Austin, Texas, mostly manage this issue by pursuing structural stormwater engineering methods, such as construction of large detention ponds, channelization of creeks or upgrading the size of the stormwater pipe system, as retro-fits for these older areas. However, those solutions do not help to restore the waterways to more natural conditions. The impervious cover of the transportation facilities continues to disrupt the hydrological process of infiltration (for groundwater), rush water to the waterway when connected directly to stormwater pipes and to impair water quality.

An alternative approach explored in this project is to identify where roadway and parking facilities can be reduced in size that would offer the same or better improvements to the urban watershed compared with structural stormwater management approaches. The objective of this project is to use GIS to identify the roadways that are the best candidates for impervious cover reduction. The urbanized Shoal

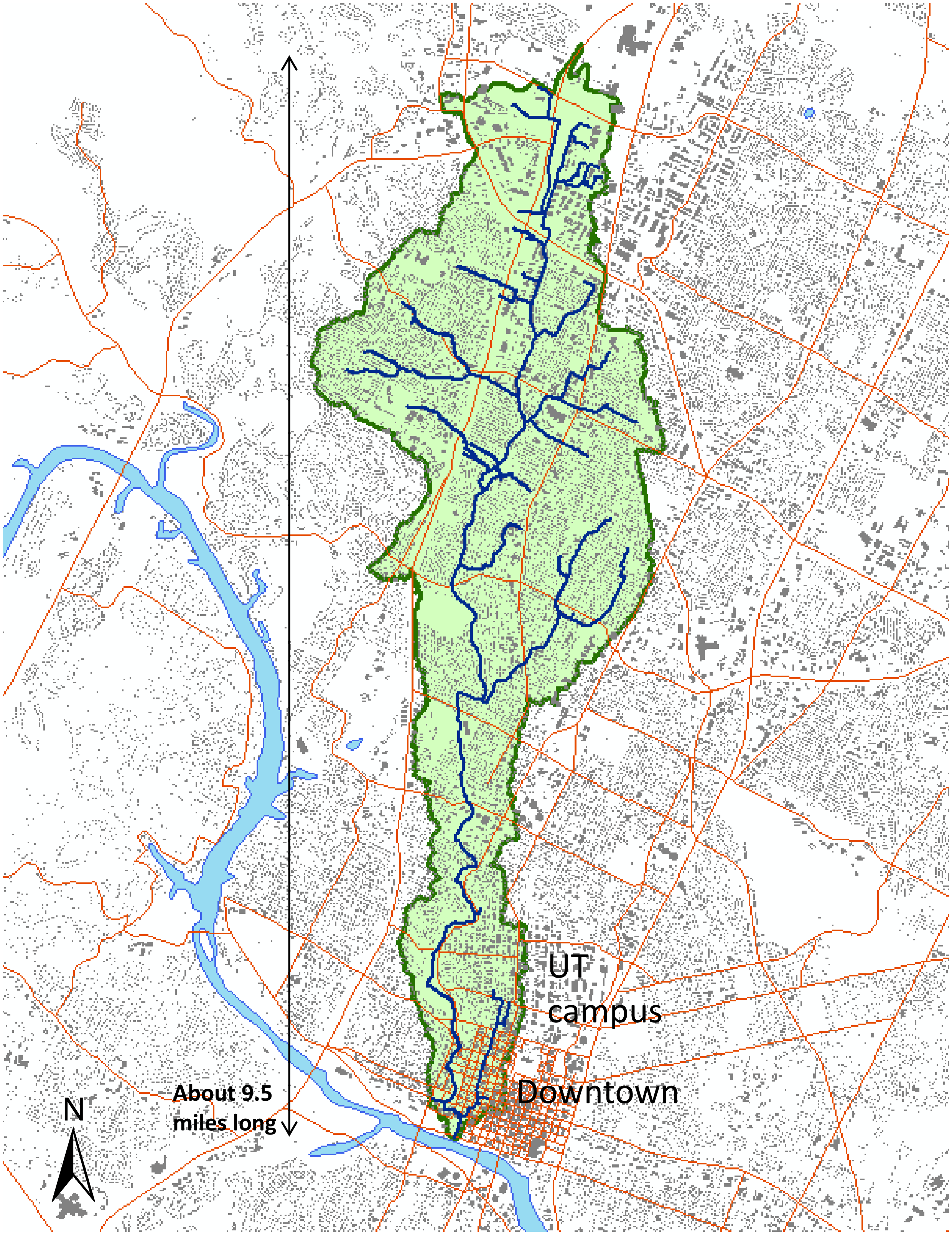
Creek watershed in Austin, Texas will be used as the case study area (Figure 3). The watershed extends from Lady Bird Lake just west of downtown to north central Austin just north of Highway 183, and consists of portions of downtown Austin, neighborhoods with houses ranging in age from the late 1800s to the late 1990s and commercial corridors. The outcome of this research is a map showing impervious cover to remove from transportation facilities in the Shoal Creek watershed.

Several communities in the U.S. have pursued impervious cover reduction of tansportation facilities, such as Seattle, WA and Portland , OR.

Figure 1. Removal of impervious cover for rain garden (Source: City of Portland, OR)

Figure 2. Reduction of street width (Source: City of Seattle, WA)

Figure 3. Shoal Creek Watershed



Literature Review

The results of the literature review suggest that the following two areas of impervious cover should be considered for removal from transportation facilities:

- effective impervious areas (EIA), which are directly connected to the stormwater pipe system and

Figure 4. Curb inlet for stormwater system directly connects street to creek

- location within a certain distance of the stream.

Figure 5. Street runoff enters creek directly

Effective Impervious Areas

The amount of impervious cover in a watershed affects the amount of stormwater runoff entering streams, however research indicates that it is not the total impervious cover (TIA) but the impervious cover hydraulically-connected to the stormwater drainage system (EIA) mostly responsible for the degradation of the waterways (Han & Burian, 2009 and Roy & Shuster, 2009).

Various methods have been used to estimate EIA within a watershed or catchment area, either alone or in combination:

- empirical equations developed from regression analysis conducted on field calculations,
- calibration of rainfall-runoff models,
- direct field assessments,
- analysis of vector-based GIS feature data, and
- analysis of raster-based GIS data.

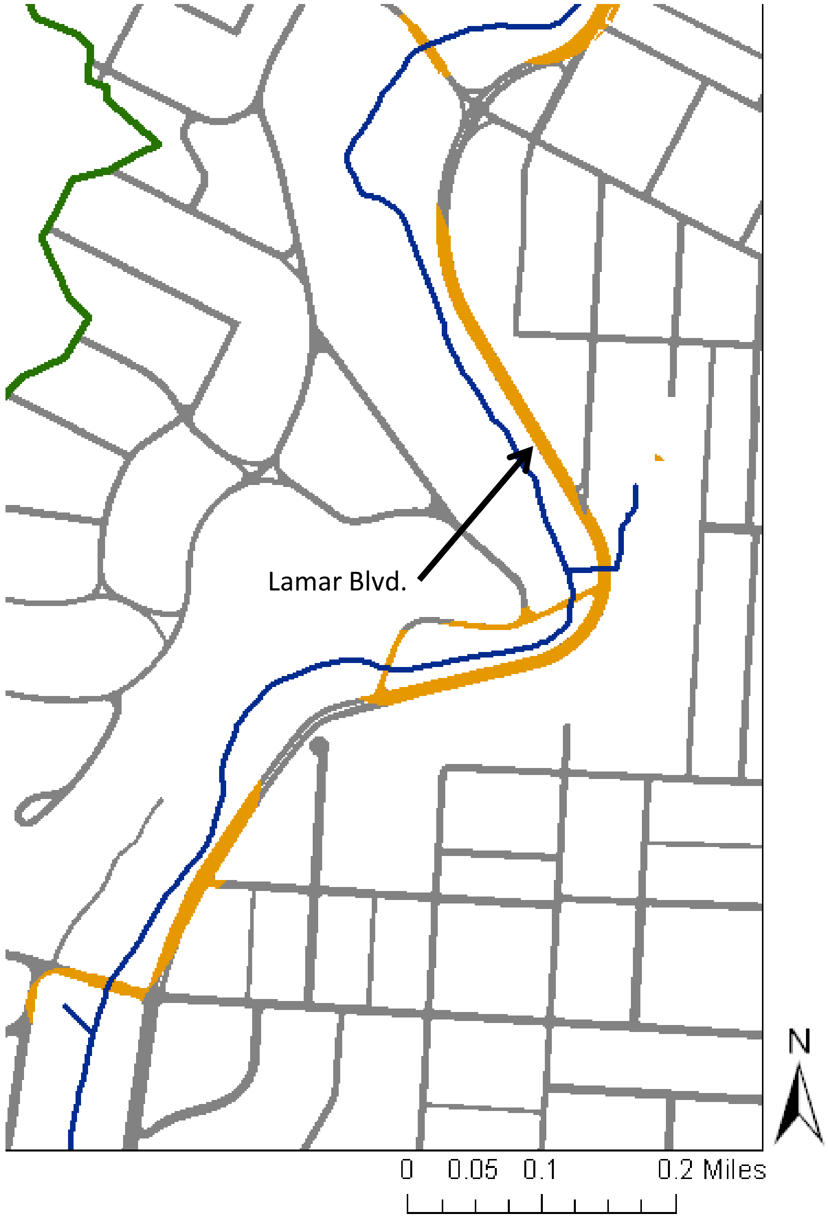
The first two methods (empirical equations and calibration of rainfall-runoff models) have the disadvantage of not indicating the spatial distribution of the EIA (Han & Burian 2009). Manual and GIS mapping methods do not have that shortcoming. Conducting field assessments are a very time-intensive process. For example, field assessments conducted for the Roy & Shuster (2009) study required two people and 54 hours of field time to closely examine the impervious cover for 441 properties.

GIS provides an automated means of finding the TIA and EIA. Roy & Shuster (2009) utilized the vector-approach in GIS to calculate areas of TIA and EIA from outlines of impervious cover areas. Han & Burian (2009) took the raster-approach, with pixels (grid cells) analyzed for type of cover (impervious or pervious), flow direction (using the steepest descent method) and flow accumulation to determine which pixels connect to the rasterized stormwater collection system. A search process was programmed into GIS to determine for each impervious cover raster cell whether it was connected or disconnected from the stormwater system (included use of the steepest gradient method to determine flow direction).

Location of Impervious Cover

Interestingly, few quantitative studies examine the importance of location of impervious cover to stream quality (Brabec, Schulte, & Richards, 2002). The literature offers limited insight into the location parameters to consider when assessing which impervious cover to remove, however Brabec, Schulte, & Richards (2002, pp. 430) stated the “distance between impervious cover and the stream channel appears to be one of the most important factors regarding placement, particularly for areas in which runoff is not piped directly to the stream,” and cited the Hammer (1972) study on stream channel enlargement due to urbanization. Impervious cover within a stream buffer of 150 feet affected nutrient concentrations, but beyond that there was not much impact (Tufford, McKellar, Jr., & Hussey, 1998). Based on the Tufford study, a buffer distance of 150 feet was used to identify the impervious cover from transportation facilities that could be potential candidates for removal.

Figure 6. Major roadway impervious cover (indicated in yellow) within 150 feet of stream



However, as described in the next few sections regarding the GIS analysis, the approach of using EIA and impervious cover within buffer areas was modified to focus more on the extra capacity of the roadways as the major criteria for impervious cover removal.

GIS Data Sources

The City of Austin (COA) ftp site provided most of the needed GIS files (ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html), but some had to be requested from the COA staff. All COA GIS datasets were already projected in the NAD 1983_ StatePlane_Texas_Central_FIPS_4203_Feet Lambert Conformal Conic. A projection in Albers Equal Area would be the ideal projection since this study focuses on the calculation of impervious areas, however since all the files used Lambert Conformal Conic and the intention is to share the results with the COA, the projection was not changed.

The following GIS and data files were retrieved from the COA ftp site:

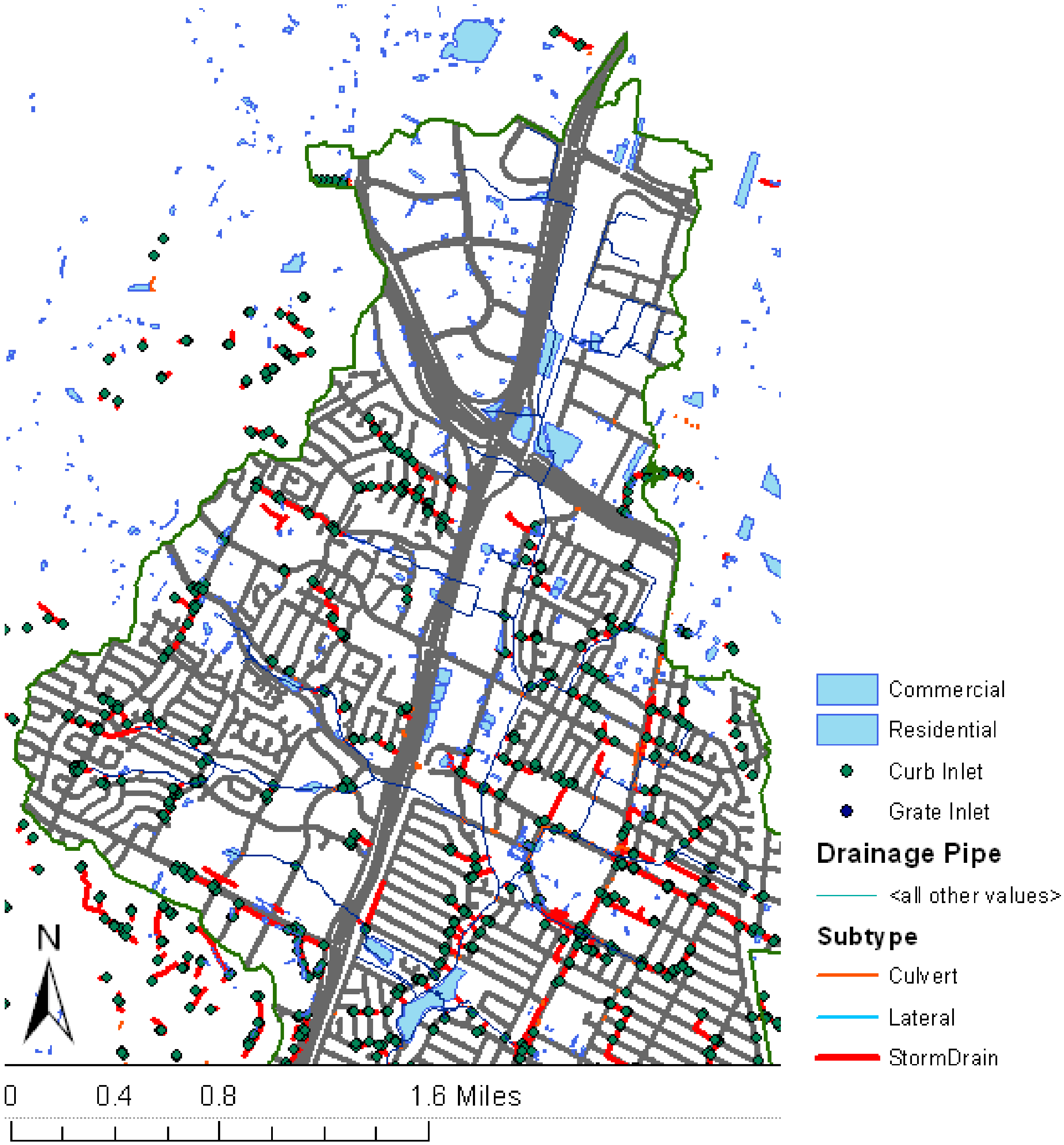
- 2003 planimetric data for transportation facilities, sidewalks and buildings
- 2003 planimetric data for building footprints
- Street “centerlines” (though not centered)
- Site plan boundaries (used for future extension of project to find parking requirements)
- Watershed boundaries and creek centerlines
- Traffic count (in spreadsheet, not GIS, form)
- Aerial images

The other GIS and data files were requested from the very helpful COA staff:

- Stormwater system (e.g., inlets, pipes, outfalls, culverts, and ponds)
    - Staff indicated this is a work-in-progress dataset; the northern part of the Shoal Creek watershed lacked most stormwater data
- Shoal Creek Digital Elevation Model (DEM)
- HEC-HMS files for Shoal Creek watershed

Missing from the above is a GIS dataset for curb & gutter and a complete stormwater system to help with the identification of EIA. Unfortunately, according to my contacts, the COA does not maintain curb & gutter data in GIS, therefore the plan to estimate EIA was changed to assuming all the roadways and parking lots are directly connected to the stormwater system. From observations of many of the roadways within the watershed and from reviewing the COA stormwater system data set, though incomplete, this is a reasonable assumption (see Figure 7 for map of some of the components of the stormwater GIS dataset).

Figure 7. Incomplete City of Austin Stormwater System



The 2003 planimetric data aligned perfectly with the aerial images, whereas the street centerline GIS dataset did not. Since street centerline data was needed to calculate street width using Euclidian distance, a new street centerline file needed to be created from the rasterized planimetric data of the transportation facilities. The next section elaborates on the GIS procedures and files used to find the impervious cover to remove from roadway facilities.

GIS Procedure

This project uses a raster-approach for GIS analysis, though polyline feature sets are used to assign values to the rasters. If determination of EIA had been feasible, raster would have been required to be able to use flow direction. Even without EIA analysis though, raster offers the ability to use the geoprocessing tools Euclidian allocation and distance, which makes the analysis of which impervious cover cells to remove from transportation facilities possible. Since several steps required visual inspection and manual adjustments of the data, a model for the GIS process used for this project was not built. The order of GIS processing to identify removable impervious cover was developed with trial-and-error since several problems were encountered throughout the project. The following GIS steps identified impervious cover to remove from public roadway facilities:

1. Select Shoal Creek watershed boundary and export as new geodatabase feature file.
2. Clip street line, planimetric and stormwater datasets to the Shoal Creek watershed boundary.
3. Convert building and transportation planimetric feature data to 1ft x 1ft raster. Use count of cells to determine the area in square feet of different types of impervious cover.
4. Modify transportation raster to create a two-color only raster for use by the ArcScan vectorization tool to create street centerlines.
5. Manually correct gaps and incorrect vectorization using Editor tools for the street centerline features created from Arcscan vectorization.
6. Convert newly created centerline features, and the COA street centerline features, to raster cells for later use in Euclidian operations.
7. Multiply road class value in COA street centerline data by 1,000 to create number to add to street width values obtained later from Euclidian distance tool.
8. Use Euclidian allocation with rasterized COA street centerline data to allocate road class to nearby raster cells.
9. Use Euclidian distance to determine distance of raster cell from rasterized street centerline dat.
10. Sum the Euclidian allocation and distance rasters using map algebra → raster calculator to create composite raster values indicating road class and street width.
11. Reclassify composite raster values to 1 for values exceeding the maximum street width for a road class, and 0 otherwise.

Identification of impervious cover to remove from parking lots in a future project will follow a different process that involves:

- Determining provided parking from a review of COA development records or estimation by aerial images,
- Determining minimum/maximum parking requirements for each site,
- Entering provided and minimum/maximum parking requirements for each site into the attribute table for the site plan,
- Using field calculator to calculate difference between provided and minimum/maximum parking and using conditional statements to assign 1 if the provided parking exceeds the minimum/maximum parking and 0 otherwise.

- Use Euclidian allocate to assign a 0 or 1 value to the rasterized planimetric data for parking lots to find areas of impervious cover to remove.

Finding the parking lot impervious cover to remove is a much more time-consuming process because research must be done to find the parking provided and the parking requirements for each site. Therefore removal of impervious cover from parking lots will not be a part of this project.

The following sections provide a more detailed explanation of the major steps above, the problems encountered, and the results that identify the impervious cover eligible for removal from public roadways.

Existing Impervious Cover

To find the area of the existing impervious cover for different land uses in the Shoal Creek watershed, the Polygon to Raster geoprocessing tool (under Conversion tools) converted the polygons of the City of Austin building and transportation planimetric data to raster cells. The Polygon to Raster tool offers more customization than Feature to Raster, and those customization tools provided a preferred raster process. For instance, per the example given in ArcGIS Help, the maximum combined area was selected as the criteria for determining how to assign a raster to a polygon because of the possibility (due to quad lines dividing the polygons) that two adjacent polygons would not separately cover the cell with enough area, but together would cover the cell with enough area to have the cell assigned to both areas.

Table 1 shows the percentage of different types of transportation and building facility impervious cover in the Shoal Creek watershed. The watershed consists of more than 50% of other uses, including parks and lawns. Combined, the area for paved streets and parking areas (24.95%) exceeds that of the area of buildings (18.0%).

Table 1. Impervious Areas Calculated from Rasterized Planimetric Polygons (1ft x 1ft cell size)

Description	FEA Code	Area (ft^2)	% of total
Paved streets	210	45,716,262	12.66%
Unpaved streets	211	18,137	0.01%
Parking areas	213	44,405,877	12.29%
Paved driveways longer than 150 feet	214	199,859	0.06%
Bridge	215	1,158,797	0.32%
Median wider than 10 feet	218	2,220,517	0.61%
Edge of paved alleys	219	704,926	0.20%
Edge of unpaved alleys	220	17,869	0.00%
Unpaved driveway	221	33,839	0.01%
Open storage	222	1,377,884	0.38%
Buildings	30,31,32	64,824,355	18.0%
Remainder of Watershed	999	200,508,413	55.46%
	SUM	**361,186,735**	

Priority Impervious Cover to Remove

As discussed previously, the review of the literature revealed two types of impervious cover to prioritize removal of effective impervious areas and impervious areas within a certain distance of the stream channel.

However, data for EIA analysis is not available, therefore the EIA analysis is not performed. The results of the GIS analysis show major roadways, such as Lamar Blvd, within a 150 foot stream buffer. Doubting removal of sections of Lamar Blvd. would be acceptable, the GIS analysis for this project focused instead on identifying transportation facilities eligible for impervious cover removal based on the existing street width for different road classes.

Eligible Transportation Facilities

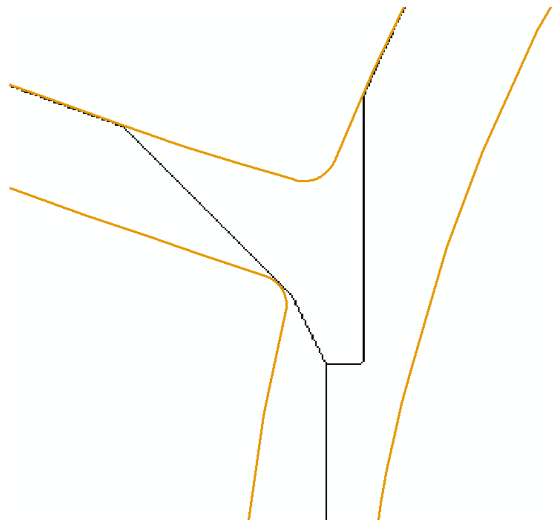
The intention of removing impervious cover, at least for this study, is not to unnecessarily decrease the capacity or performance of the transportation facilities. Therefore, the criteria for determining eligible transportation facilities focuses on removing the "extra" capacity. Ideally the assessment of capacity would include a comparison of actual traffic counts to capacity of the roadway, however most streets did not have traffic counts. Instead, extra impervious cover is determined by comparing actual street width with a preferred street width based on traffic lane widths of 12 feet and a maximum street width for each road class (see Table 2).

Street Centerlines

The existing COA GIS datasets did not include information about pavement width, therefore critical to this project was the estimation of street width. To find street width, Euclidian distance of raster cells was found from street centerlines. The street centerline file from the City of Austin however did not align with the centerlines of the planimetric streets (see Figure 9). Since the planimetric polygons aligned well with the aerial images, the City of Austin street centerlines were not used, and instead, a way of creating street centerlines from the rasterized roadways was pursued.

The first attempt used the Thin geoprocessing tool to create a centerline from the raster street data, however that did not provide acceptable results (see Figure 8).

Figure 8. Thin Tool Results

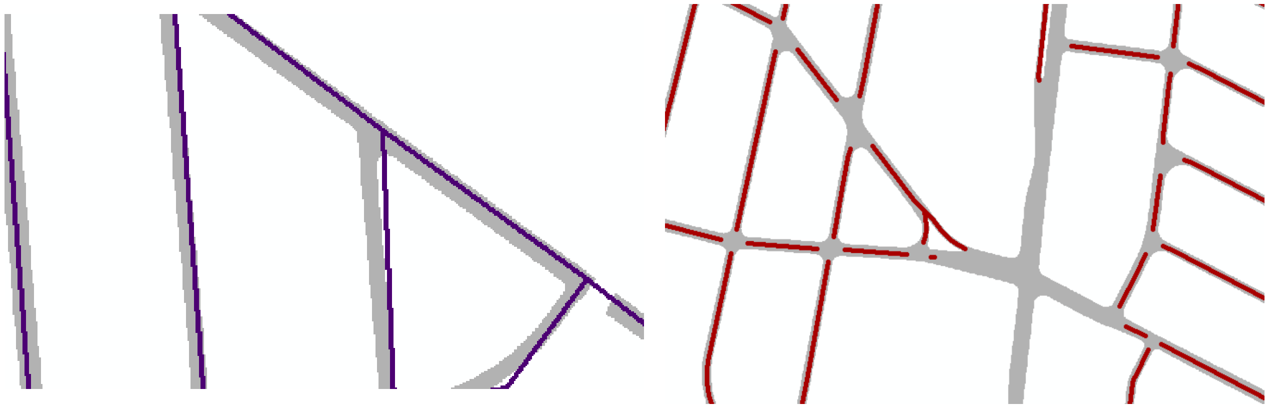


To vectorize the raster of the paved streets (FEA code 210) only, the paved street raster had to be in two colors only so that the ArcScan tool could be programmed to create a centerline based on the selected color (file name str_reclass). Before going into edit session, I first had to add a new feature dataset to the Transport Facilities feature dataset within the project geodatabase. The new feature line file was called str_vectorization. After creating that feature class, I started the edit session (under Editor), selected str_reclass as the raster and began the vectorization process.

The vectorization toolbar did not recognize that I had just created a new feature class, so I had to go into the "Create Features" window, click on organize templates, and select the new feature class. The street vectorization worked to produce a centerline, however there are gaps in the vectors, or missing vectors (see Figure 9). Several remedies were tried, including the Repair Geometry tool and Extend Line tool. The Repair Geometry tool appeared to make no changes, and the Extend Line tool after several days of GIS processing resulted in many errors in line extensions to fix.

Following the failure of those tools to correct the centerline vectors, the decision was made to manually connect the lines using Editor. The distance measurement tool and editing tools such as snap and copy parallel were used extensively to create seamless street centerline features.

Figure 9. City of Austin Street Centerlines (L) vs. Street Centerlines Created From ArcScan Vectorization (R)



Composite Raster Value

Each raster cell needed to contain two pieces of information (road class and street width) needed for determining removal eligibility of the impervious cover raster cell. The maximum street width for a roadway depended on the class of roadway. Raster cells can only contain one value, therefore a composite raster value was created that gives in one raster value:

- road class
- street width between centerline and street edge

The idea for creating the composite raster value came from reading the approach taken by Thomas & Endreny (2008) to record the roadway width and National Land Cover Database (NLCD) land class in one raster value by multiplying roadway width by 1,000 and adding the two-digit NLCD land class value to the 4-digit roadway width value using raster addition.

The Euclidian Allocation geoprocessing tool under Spatial Analysis → Distance allocated to the raster cells the road class indicated in the street centerline file from the City of Austin. Since the centerlines are not centered, there is some error in allocation, however inspection revealed acceptable results. The Euclidian Distance geoprocessing tool was used to assign the distance from the centerline feature created from the ArcScan vectorization to the raster cells. Summation of the two rasters resulted in a composite raster value to compare with maximum street widths for each road class to determine eligible impervious cover cells within the rasterized transportation planimetric data.

Table 2 presents the maximum street width used to create street width cut-offs for determining which impervious cover should be removed from a roadway. Table 3 presents an example of the calculation of the composite raster value.

Table 2. Road Classes and Street Widths for Composite Raster Value

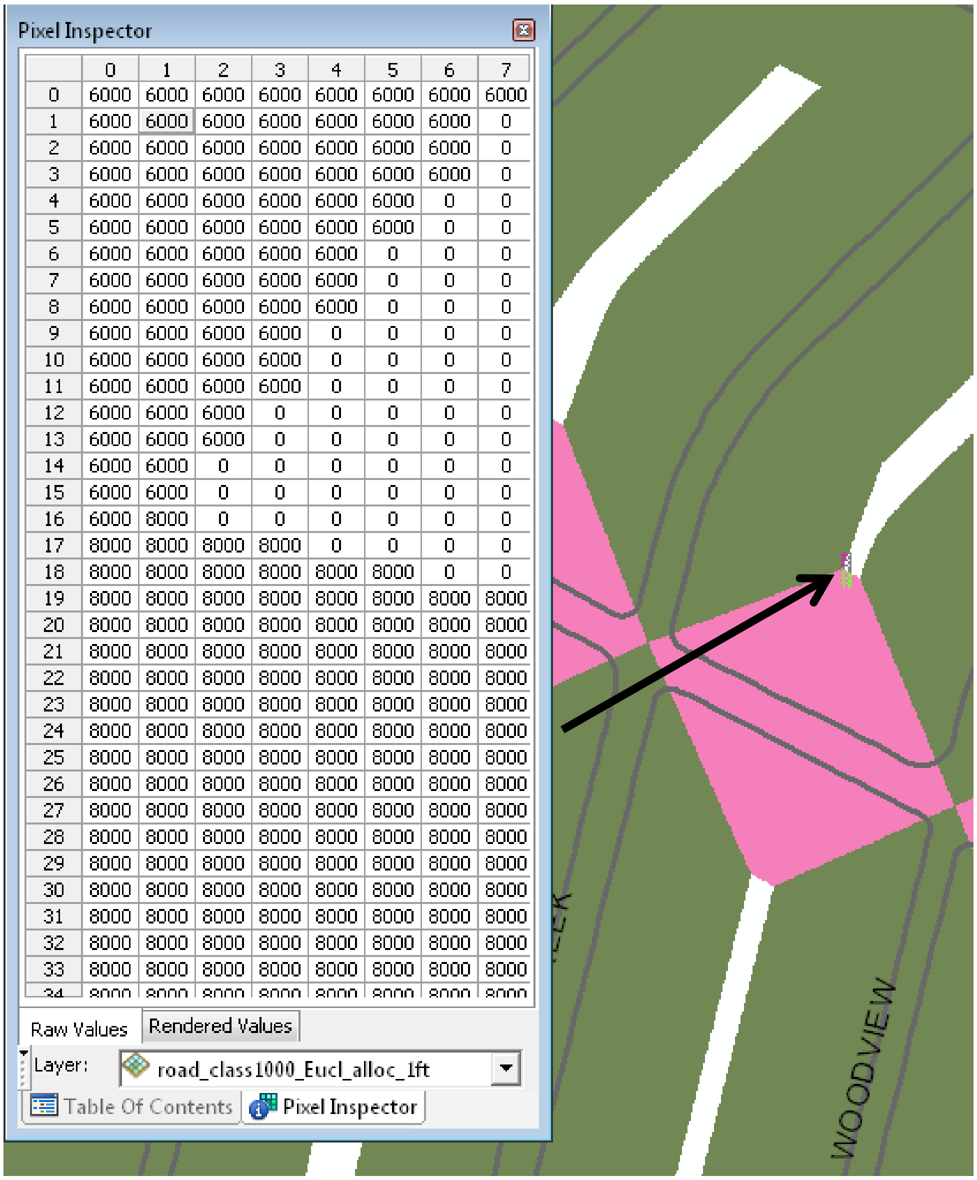
Road Class	Type of Road	Description	Max Half Street Width (feet)	Full Street Width (feet)	Raster Value	Composite Values for Cells that Qualify for Removal
4000	Major arterial	5 lanes	30	60	4030	4030<value<5000
5000	Minor arterial	3 lanes	18	36	5018	5018<value<6000
6000	Local street	2 lanes	12	24	6012	6012<value<7000
8000	Collector	2 lanes	12	24	8012	8012<value<9000

Table 3. Composite Value Raster Calculations

	Road class|Euclidian distance	Raster Value
Street feature	New field of road class values (e.g., 6 * 1000 = 6000)	
Raster 1	Euclidian allocate road class value	6000
Raster 2	Raster Euclidian distance (feet) from centerline	22
	Map algebra raster 1 + raster 2	+
New raster	Composite raster value	6022
	Conditional raster analysis Since 6022 > 6012 (maximum half-street width for class 6), 1 0 Otherwise	1 (eligible)

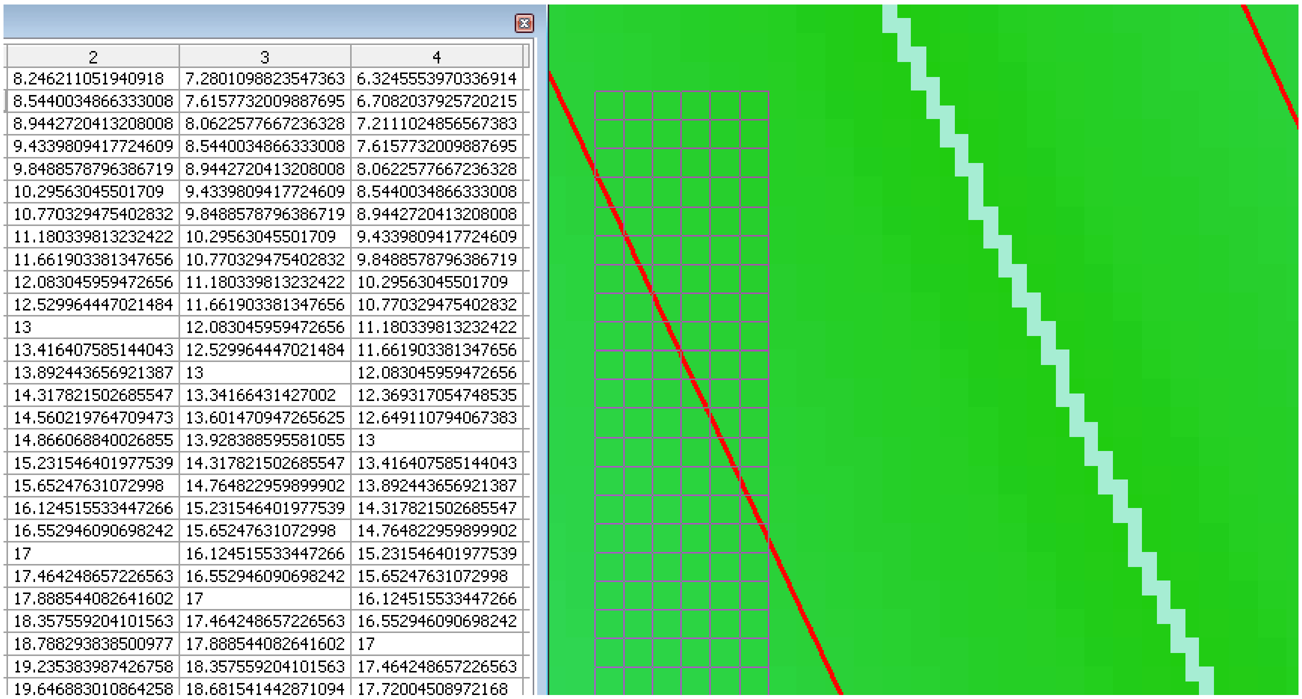
Figure 10 (road class allocation), Figure 11 (street width distance), and Figure 13 (composite raster value) shows screenshots of the raster cell values visible in the Pixel Inspector window. Figure 12 shows the screenshot of the map algebra window.

Figure 10. Pixel Inspector Check of Euclidian Allocation of Road Class City of Austin Street Centerline to Raster Cells



	0	1	2	3	4	5	6	7
0	6000	6000	6000	6000	6000	6000	6000	6000
1	6000	6000	6000	6000	6000	6000	6000	0
2	6000	6000	6000	6000	6000	6000	6000	0
3	6000	6000	6000	6000	6000	6000	6000	0
4	6000	6000	6000	6000	6000	6000	0	0
5	6000	6000	6000	6000	6000	6000	0	0
6	6000	6000	6000	6000	6000	0	0	0
7	6000	6000	6000	6000	6000	0	0	0
8	6000	6000	6000	6000	6000	0	0	0
9	6000	6000	6000	6000	0	0	0	0
10	6000	6000	6000	6000	0	0	0	0
11	6000	6000	6000	6000	0	0	0	0
12	6000	6000	6000	0	0	0	0	0
13	6000	6000	6000	0	0	0	0	0
14	6000	6000	0	0	0	0	0	0
15	6000	6000	0	0	0	0	0	0
16	6000	8000	0	0	0	0	0	0
17	8000	8000	8000	8000	0	0	0	0
18	8000	8000	8000	8000	8000	8000	0	0
19	8000	8000	8000	8000	8000	8000	8000	8000
20	8000	8000	8000	8000	8000	8000	8000	8000
21	8000	8000	8000	8000	8000	8000	8000	8000
22	8000	8000	8000	8000	8000	8000	8000	8000
23	8000	8000	8000	8000	8000	8000	8000	8000
24	8000	8000	8000	8000	8000	8000	8000	8000
25	8000	8000	8000	8000	8000	8000	8000	8000
26	8000	8000	8000	8000	8000	8000	8000	8000
27	8000	8000	8000	8000	8000	8000	8000	8000
28	8000	8000	8000	8000	8000	8000	8000	8000
29	8000	8000	8000	8000	8000	8000	8000	8000
30	8000	8000	8000	8000	8000	8000	8000	8000
31	8000	8000	8000	8000	8000	8000	8000	8000
32	8000	8000	8000	8000	8000	8000	8000	8000
33	8000	8000	8000	8000	8000	8000	8000	8000

Figure 11. Pixel Inspector Check of Euclidian Distance of Raster Cells to Rasterized Street Centerline Created from ArcScan Vectorization



2	3	4
8.246211051940918	7.2801098823547363	6.3245553970336914
8.5440034866333008	7.6157732009887695	6.7082037925720215
8.9442720413208008	8.0622577667236328	7.2111024856567383
9.4339809417724609	8.5440034866333008	7.6157732009887695
9.8488578796386719	8.9442720413208008	8.0622577667236328
10.29563045501709	9.4339809417724609	8.5440034866333008
10.770329475402832	9.8488578796386719	8.9442720413208008
11.180339813232422	10.29563045501709	9.4339809417724609
11.661903381347656	10.770329475402832	9.8488578796386719
12.083045959472656	11.180339813232422	10.29563045501709
12.529964447021484	11.661903381347656	10.770329475402832
13	12.083045959472656	11.180339813232422
13.416407585144043	12.529964447021484	11.661903381347656
13.892443656921387	13	12.083045959472656
14.317821502685547	13.34166431427002	12.369317054748535
14.560219764709473	13.601470947265625	12.649110794067383
14.866068840026855	13.928388595581055	13
15.231546401977539	14.317821502685547	13.416407585144043
15.65247631072998	14.764822959899902	13.892443656921387
16.124515533447266	15.231546401977539	14.317821502685547
16.552946090698242	15.65247631072998	14.764822959899902
17	16.124515533447266	15.231546401977539
17.464248657226563	16.552946090698242	15.65247631072998
17.888544082641602	17	16.124515533447266
18.357559204101563	17.464248657226563	16.552946090698242
18.788293838500977	17.888544082641602	17
19.235383987426758	18.357559204101563	17.464248657226563
19.646883010864258	18.681541442871094	17.72004508972168

Figure 12. Map Algebra Raster Calculator Expression for Creating Composite Value

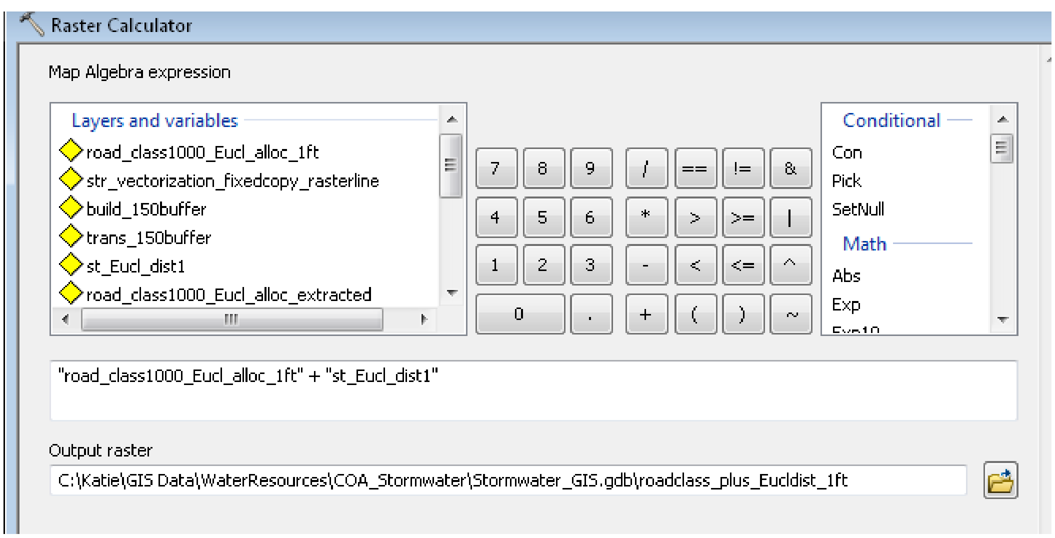
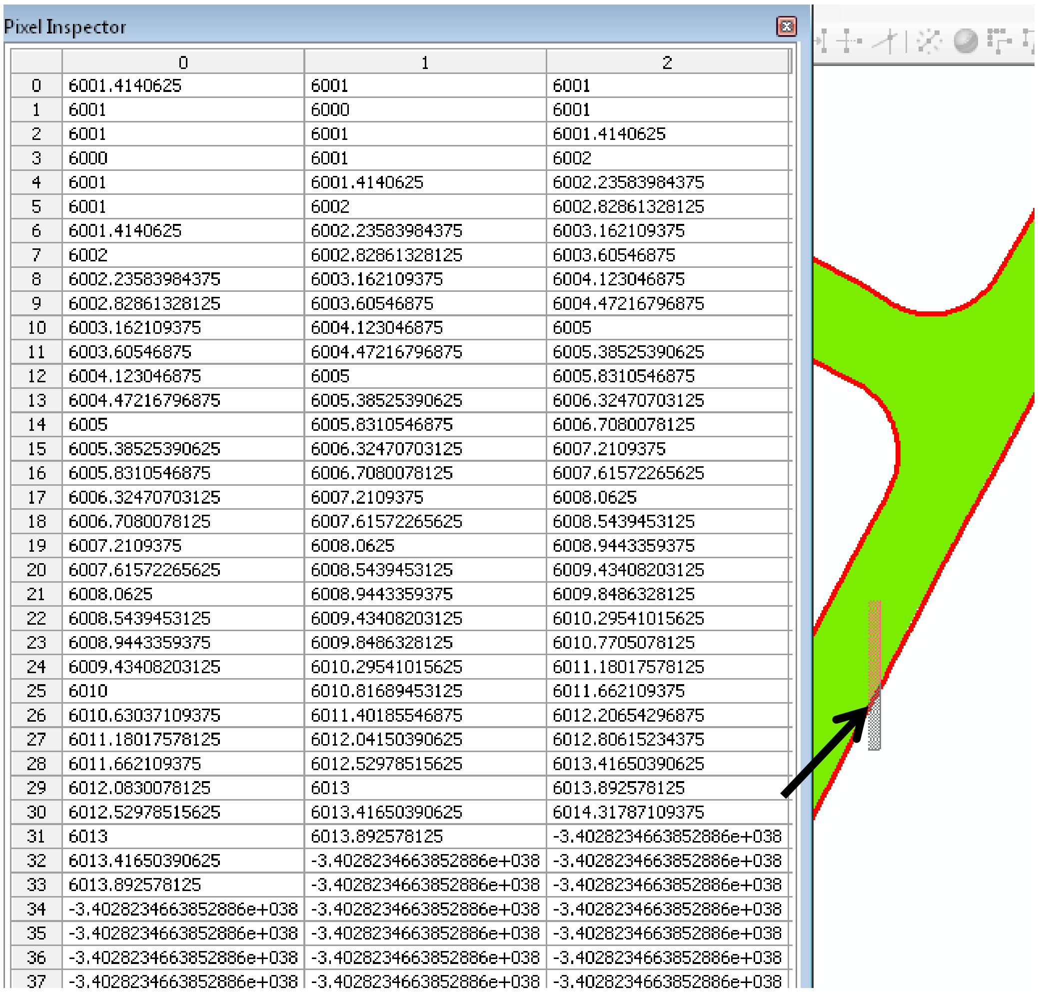


Figure 13. Pixel Inspector Check of Addition of Euclidian Allocation of Roadway Class with Euclidian Distance

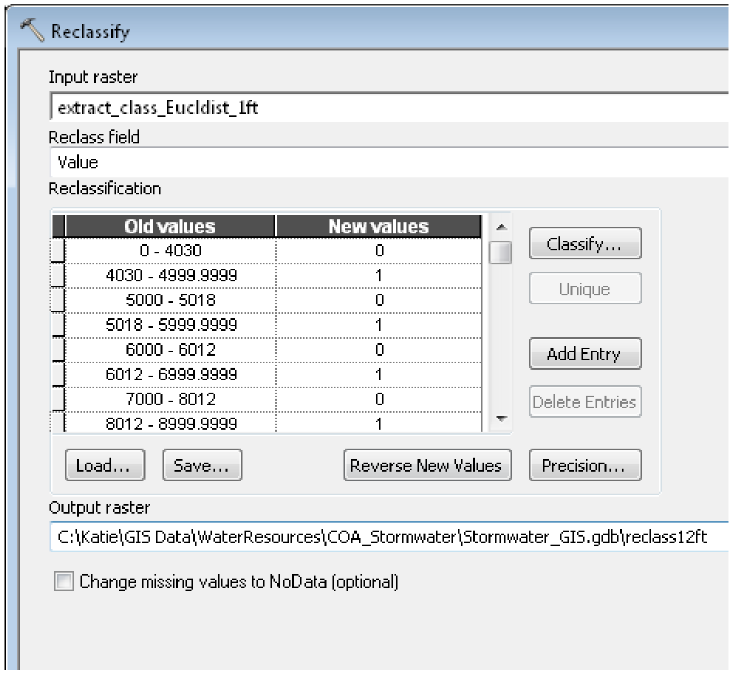


	0	1	2
0	6001.4140625	6001	6001
1	6001	6000	6001
2	6001	6001	6001.4140625
3	6000	6001	6002
4	6001	6001.4140625	6002.23583984375
5	6001	6002	6002.82861328125
6	6001.4140625	6002.23583984375	6003.162109375
7	6002	6002.82861328125	6003.60546875
8	6002.23583984375	6003.162109375	6004.123046875
9	6002.82861328125	6003.60546875	6004.47216796875
10	6003.162109375	6004.123046875	6005
11	6003.60546875	6004.47216796875	6005.38525390625
12	6004.123046875	6005	6005.8310546875
13	6004.47216796875	6005.38525390625	6006.32470703125
14	6005	6005.8310546875	6006.7080078125
15	6005.38525390625	6006.32470703125	6007.2109375
16	6005.8310546875	6006.7080078125	6007.61572265625
17	6006.32470703125	6007.2109375	6008.0625
18	6006.7080078125	6007.61572265625	6008.5439453125
19	6007.2109375	6008.0625	6008.9443359375
20	6007.61572265625	6008.5439453125	6009.43408203125
21	6008.0625	6008.9443359375	6009.8486328125
22	6008.5439453125	6009.43408203125	6010.29541015625
23	6008.9443359375	6009.8486328125	6010.7705078125
24	6009.43408203125	6010.29541015625	6011.18017578125
25	6010	6010.81689453125	6011.662109375
26	6010.63037109375	6011.40185546875	6012.20654296875
27	6011.18017578125	6012.04150390625	6012.80615234375
28	6011.662109375	6012.52978515625	6013.41650390625
29	6012.0830078125	6013	6013.892578125
30	6012.52978515625	6013.41650390625	6014.31787109375
31	6013	6013.892578125	-3.4028234663852886e+038
32	6013.41650390625	-3.4028234663852886e+038	-3.4028234663852886e+038
33	6013.892578125	-3.4028234663852886e+038	-3.4028234663852886e+038
34	-3.4028234663852886e+038	-3.4028234663852886e+038	-3.4028234663852886e+038
35	-3.4028234663852886e+038	-3.4028234663852886e+038	-3.4028234663852886e+038
36	-3.4028234663852886e+038	-3.4028234663852886e+038	-3.4028234663852886e+038
37	-3.4028234663852886e+038	-3.4028234663852886e+038	-3.4028234663852886e+038

To find the impervious cover to remove, an attempt was made to use map algebra with the "Con" tool to assign 1's to raster cell values exceeding the street width, 0's if not. After several trials, it came to my attention that the "&" sign used for "and" operation only works to compare a cell in one raster to a cell in the same location in another raster file; but, not to compare a raster cell to a specified value given in map algebra.

Therefore, instead of using map algebra, the reclassify tool was successfully used to reclassify the range of composite raster values for distances for each road class exceeding the maximum street width as removable impervious cover. Figure 14 shows a screenshot of the reclassify tool window.

Figure 14. Screenshot of Reclassify Window Used to Identify Impervious Cover to Remove



Results

After weeks of evaluating the data, geoprocessing, trying to automate correction of the street centerline data, overcoming the failures of automation with hours of manual correction, and surmounting other difficulties, the GIS analysis concluded with the results of a raster reclassification providing the total area of impervious cover eligible for removal from transportation facilities. The example in Figure 15 depicts in red the impervious cover identified as eligible for removal. The actual removal of impervious cover would not necessarily need to be symmetrical as shown in the GIS map. For instance, if the eligible impervious cover is shown as a 3-foot wide strip along each side of the roadway, instead of removing the cover from both sides, a 6-foot strip of cover could be removed on one side and replaced with a rain garden, pervious pavement for pedestrians and cyclists, or some other "green" feature.

Figure 15. Impervious Cover to Remove from Paved Streets (White Rock Drive Pictured as Example)

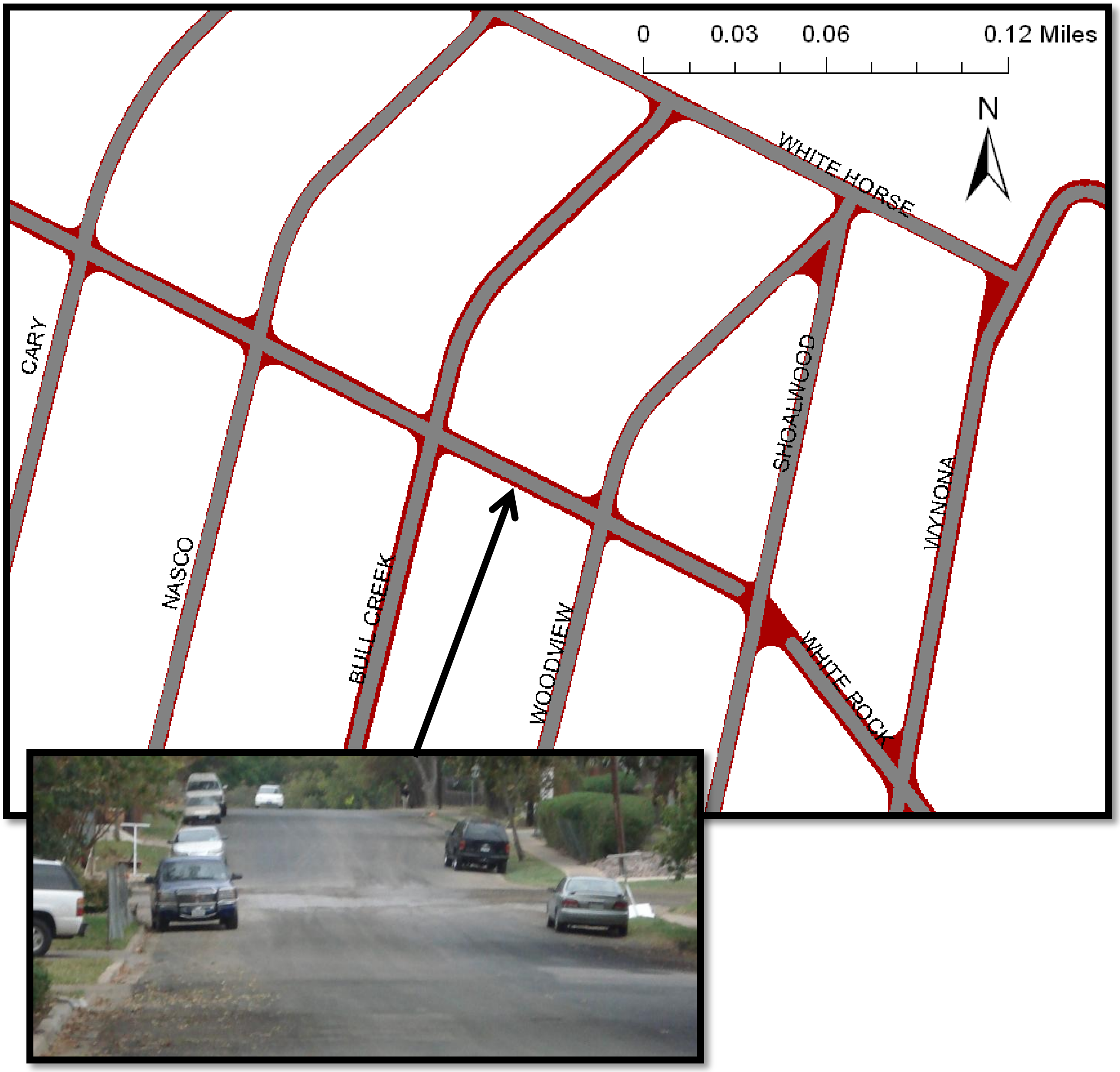


Table 4 presents the results from the raster reclassification. The removal of impervious cover from paved streets would result in a 21.22% decrease in the amount of impervious cover from paved streets. However, the reduction appears very small compared to the overall watershed area; removal of the impervious cover would only decrease the total impervious cover in the watershed by 2.65%.

Table 4. Impervious Cover to Remove According to Raster Reclassification

Raster Value		Area (ft^2)	% of total paved streets
0	Impervious cover from paved streets to remain in place	35,525,746	
1	Impervious cover to remove from paved streets (FEA Code 210, road class 4, 5, 6, 8)	9,566,591	21.22%
	Total impervious cover from paved streets[1]	45,092,337	

Summary and Extensions

Though the removal results in a relatively small percentage decline in impervious cover, research will continue to determine the additional amount of impervious cover that can be removed from 1) parking areas and 2) paved streets with different street widths (i.e., reducing the street width from 12 foot a lane to 11 or 10 foot a lane, or to even reduce residential streets to one lane only). This project took an extremely large amount of my time, and spending additional days to manually collect site plan and parking data from the COA website and entering it in to GIS will require more time than available for the latter part of the semester. However the research will be pursued because of the potential of removal of impervious cover from transportation facilities to avoid additional investment in new or enlarged stormwater pipes that rush water to the streams and contribute to the decline in stream quality. To minimize cost and disruption from the removal of impervious cover removal, the removal could be accomplished during the scheduled street resurfacings and reconstructions scheduled for pavement maintenance every few years.

The project provides the data needed to later test the hypothesis that by removing from transportation facilities a certain amount of impervious cover connected to the stormwater system (EIA) and in close proximity to the stream, there can be a significant reduction in cfs flow to the receiving waters, for less cost compared to managing stormwater using structural approaches (i.e., pipes and large detention facilities).

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[1] A comparison of Table 4 with

Table **1** shows a total impervious area for paved streets of 45,716,262 square feet according to the transportation facilities planimetric data, and slightly less than the total impervious cover from paved streets.

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