Drawing voter district boundaries along watershed lines using a graph theoretic approach in Austin, Texas.

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Abstract

Watershed Protection Department is proposing a unique approach to configuring the "10-1" Austin Districting Plan. This approach makes use of watersheds as primary units in delineating district boundaries and an algorithm based on Algebraic Graph Theory to evaluate which combination of watersheds will fit the constraints of a district. This provides a non-partisan and transparent solution in fitting natural boundaries to political entities, and will produce a wide range of possible district configurations for the user to evaluate. One possible district configuration of watersheds is presented and evaluated in this report.

Introduction

Austin, Texas, is a home rule municipality with a council-manager form of government consisting of 6 at-large council members and an at-large mayor. Austin is the largest city in Texas with all council members elected at large (Blodgett, 2013). In November 2012, Austin voters approved Proposition 3, also known popularly as "10-1", a city charter amendment providing for the election of city council members from 10 geographic single-member districts with the mayor elected from the city at-large beginning with the November 2014 election. An independent 14 member city redistricting commission was created to delineate the boundaries of the 10 districts.

<u>Overview of Constraints in District Delineation</u>

The Equal Protection Clause of the XIV Amendment of the United States Constitution effectively provides that congressional voting districts must have approximately equal number of voters. Texas Government Code 26.044(e) requires that municipal districts be compact and contiguous. In reviewing proposed voting district boundaries, the courts have held that a population deviation between districts of less than ten percent is considered only a "minor deviation” and may be presumed to have resulted from a good faith effort to comply with the Equal Protection Clause (Daly v. Hunt, 93 F.3d 1212, 1220 4th Cir. 1996).

The federal Voting Rights Act of 1965 as amended (42 USC § 1973) prohibits discrimination based upon race, color, and spoken language when drawing voting districts. Specifically, Section 2 of the federal Voting Rights Act prevents actions that minimize the effectiveness of the minority community vote.

Altering proposed district for political gain is common. Gerrymandering is the practice of manipulating voting district boundaries to provide a political advantage for a particular group. The word gerrymander derives from a description of a manipulated Massachusetts state senate election district approved under Governor Elbridge Gerry in 1812 that resembled the shape of a salamander (Griffith, 1907). Many district delineation efforts have been mired in politics, resulting in highly contested processes that ultimately are resolved in judicial courts. The first American presidential veto was a rejection by Washington in 1792 of a Congressional district reapportionment plan, otherwise known as redistricting (Hayes, 1996).

Watershed Governance

John Wesley Powell, explorer of the American West, proposed the idea of “watershed governance” in the 19th Century, in which state boundaries would be drawn incompassing major watersheds (deBuys, 2001) (Figure 1). A watershed is an area of land where all the water which drains off the land travels to the same body of water such as a river. Availability of water for public supply and agricultural irrigation is a primary factor that limits the level of sustainable development in arid and semi-arid regions (CCSP, 2008). Powell recognized that apportionment of scarce water resources in the arid western United States was difficult and would only be further complicated if state government boundaries were drawn on arbitrary straight survey lines that crossed watershed lines and ignored existing landscape conditions (deBuys, 2001).

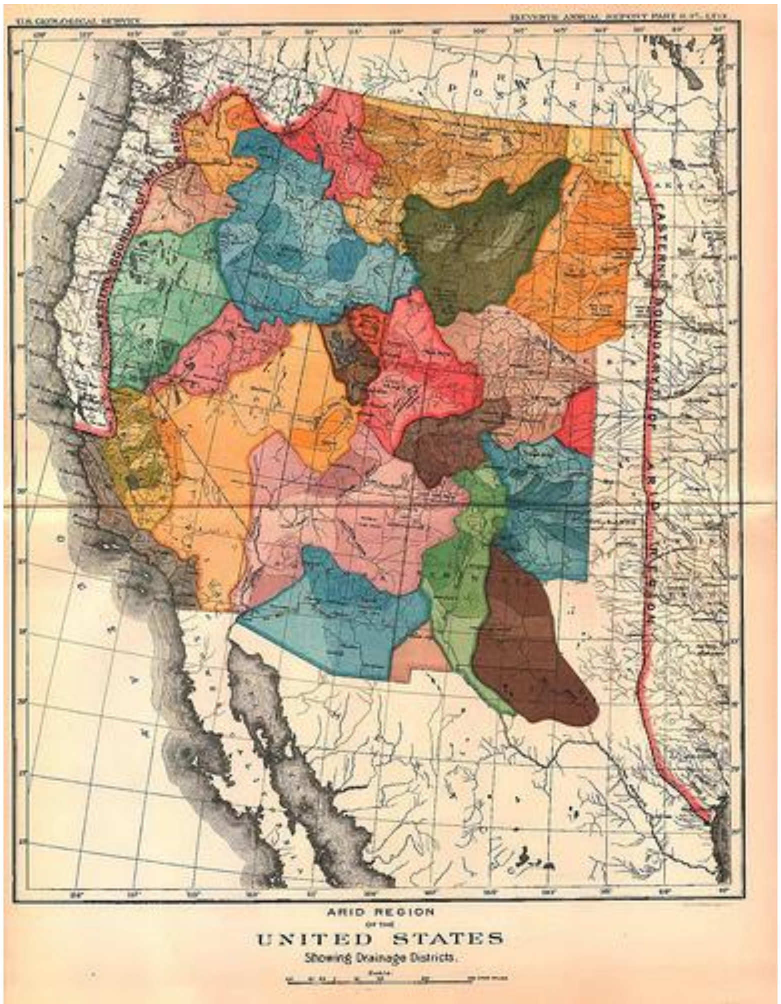

Figure 1. John Wesley Powell's proposed division of western states along watershed boundaries.

The 30-year Imagine Austin Comprehensive Plan adopted by Austin City Council in 2012, established the sustainable management of water resources and watershed health as two of the eight priority programs for the city. Austin City Code has recognized the importance and differing characteristics of watersheds in Austin for many years. In 1986, Austin adopted the Comprehensive Watershed Ordinance, superseding four previous watershed protection ordinances and establishing extended water quality protection throughout the City of Austin planning area. The Comprehensive Watershed Ordinance organized watersheds into groups based on their relationship to the City's water supply, the Barton Springs Edwards Aquifer Recharge Zone, the Northern Edwards Aquifer, and the degree of urbanization within a watershed (Figure 2).

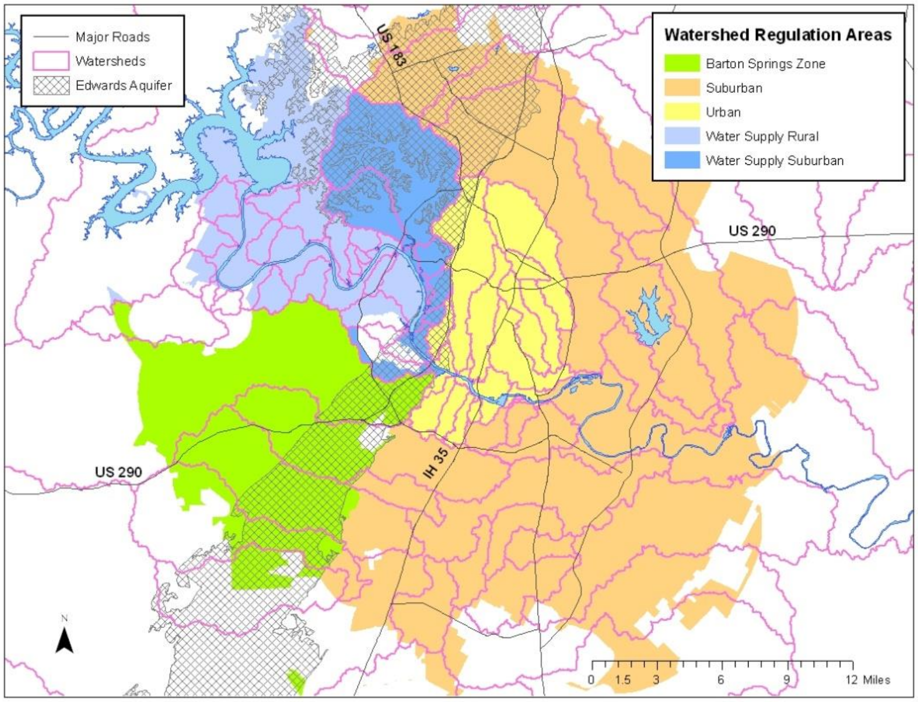

Figure 2. City of Austin watershed boundaries and watershed regulation areas established by the 1986 Comprehensive Watershed Ordinance.

Recognizing the ecological and regulatory significance of watershed boundaries in Austin and inspired by John Wesley Powell's idea of "watershed governance," the object of this analysis is to determine if single-member Austin City Council districts can be programmatically and objectively drawn along watershed boundaries in compliance with the equal population requirements of federal law. The authors of this paper are licensed professional engineers and not lawyers, and nothing in this report should be construed to have been generated or reviewed by individuals competent or qualified to give legal advice.

District Delineation Process

Prior to drawing district boundaries, two decisions must be made: what units will make up the district, and what process will be used to join these units to make up the district. This report will offer a suggestion for the first decision (which units will make up the district) and provide a new method for proceeding with the second decision (the process by which the units form a district).

Determining how the units that make up the district are composed or developed is a crucial step in drawing district boundaries. If these units are large enough, then the number of units decreases, making it easier for decision makers to arrange or manipulate the units in order to favor one political constituency versus another. To combat this, one idea is to get units small enough to avoid this gerrymandering, but not too small to make the problem intractable. Typically, counties have been used as the units composing the districts in statewide redistricting schemes although this would obviously be of no use in the Austin redistricting effort. Other systems have been proposed that are not based on use of existing boundaries, such as continually dividing a state into halves while maintaining population equality until the required number of districts is satisfied (Hamilton, 1966). While nonpartisan, this arbitrary division ignores relevant geographic features contrary to Powell's primary considerations. This paper will take the novel approach of using watersheds as the basic units used in creating districts. Watersheds provide natural boundaries that cut across race, class, ethnicity, and political ideology; thus, making it conducive to governing the ecological health of watersheds.

To form district boundaries from these primary units, there are two known methods that can be used. The first method uses optimization algorithms. These algorithms produce non-political district delineations using theory from operations research and steepest-descent optimization (Hess et al., 1965; Kaiser, 1966; Garfinkel and Nemhauser, 1970). The other method utilizes an enumeration approach. For this method, all possible district delineations are enumerated based on the connectivity of the units. This allows the user the ability to evaluate a wide range of district configurations.

The advantages of optimization algorithms are its long history and depth of theory. However, the optimization algorithms will only produce a single district map. In particular, the steepest-descent path proposed by Kaiser (1966) can get stuck within local optima. Thus, it cannot be known whether other district configurations are possible. Simulated annealing (acceptance of some randomly selected incorrect path decisions) can be used to overcome this issue, although this approach could be used to subvert the unbiased computer approach to district delineation and be *de facto* gerrymandering (Hayes, 1996). To be widely accepted, an ideal algorithm for use in redistricting efforts must be simple, precise, and based on trusted data (Hayes, 1996).

Given the wide range of possible outcomes produced by the enumeration approach, enumerating all possible district configurations appears promising. Lawson (2010) lays out an argument stating that the enumeration possibilities are large but become feasible given a set of constraints. Furthermore, this approach provides a transparency in determining why certain configurations were chosen over others. This paper will utilize this approach in determining an appropriate district configuration.

Graph Theory in the Enumeration Process

Graph Theory is uniquely formulated to enumerate all possible district configurations. Graph partitioning theory has been used to demonstrate how counties may be grouped into districts of relative equal population in South Carolina (Mehrotra et al., 1998). Furthermore, Lawson (2010) recounts the mechanics of using Graph Theory to examine a search tree for possible district configurations. Graph Theory allows the user to visualize the connections between contiguous areas and see the number of connections from each area. Graph Theory also allows for this visualization to be quantified. It is this aspect of Graph Theory that has yet to be explored in redistricting. In quantifying the graph, users have found a sense of "getting something for nothing" (Godsil and Royle, 2001).

Furthermore, unlike many redistricting routines, Graph Theory provides a transparency in determining which areas should be joined. The Graph Theory approach is not a "black box" as a simple algorithm can be implemented to examine all possible combination of districts. This will allow for the identification of several scenarios or possible sets of district delineations. This could prove to be useful in discussing or weighing which areas get joined together to form a district.

Intent of Paper

The problem of redistricting Austin can be formulated as follows: Given n ($n > 10$) geographic units, delineate 10 non-overlapping sets of contiguous units so that each set follows the Voting Rights Act and the union of the sets covers Austin. As stated previously, the units to be used in forming the districts will be watersheds, delineated by topography and officially recognized by the City of Austin Drainage Criteria Manual. The utilization of a Graph Theory algorithm in delineating watersheds as political districts presents a novel approach to redistricting. Thus, this paper aims to accomplish the following:

1. Present an algorithm based on Graph Theory to develop 10 sets of non-overlapping and contiguous units that can be evaluated for certain constraints whose union covers Austin.
2. Apply this algorithm to watersheds as the non-overlapping units and present the results for one configuration from the possible combination of districts.

Note that the units for Goal 1 can be arbitrary and do not necessarily require watershed boundaries for delineation. This can be used in the case that watershed boundaries are not chosen as the method for district delineation. In fact, the algorithm specified here can be generalized when allocating resources (or needs) together among functionally connected entities given certain constraints.

Methods

Austin council member districts were drawn along watershed boundaries using a graph theory approach applied to 2012 U.S. Census data. The constraints on creating the 10 Austin voting districts boundaries imposed for this analysis were that the districts be spatially contiguous, generally compact, drawn along watershed boundaries as defined by the City of Austin Drainage Criteria Manual (Section 1.4.0) and of similar voting age population. No attempt was made in this analysis to draw districts in compliance with the federal Voting Rights Act minority protection requirements.

U.S. Census 2010 block geometry and associated demographic data was extracted from the U.S. Census Bureau’s Master Address File/Topically Integrated Geographic Encoding and Referencing (MAF/TIGER) Database (MTDB). The 2010 U.S. Census block layer was provided for use in the project by the City of Austin Demographer, Ryan Robinson.

The 72 Drainage Criteria Manual defined watersheds within City of Austin full purpose jurisdiction limits and limited purpose extra-territorial jurisdiction limits qualified to vote in City of Austin elections were used. Adjustments to population values for U.S. Census blocks were made proportionate to area within city jurisdiction when only partial areas of blocks fell within the voting area of the City of Austin.

Spatial contiguity was established by creating a symmetric adjacency matrix based on watershed boundaries from City of Austin Geographic Information System (GIS) layers. A 72x72 matrix was created with (*i*,*j*) cell values of 1 indicating that watershed *i* shares a boundary with watershed *j*. A separate 72x72 population identity matrix was created to provide the population within each watershed area.

Consistent with the Equal Protection Clause of the U.S. Constitution, voting age population as defined by number of persons over age 18 was used in the population analysis. No attempt was made to identify if persons of voting age were U.S. citizens, despite the use of only citizens of voting age in some Texas redistricting efforts. Similar population estimates within districts were defined as no more than 10% difference in voting age population between the largest and smallest district.

Graph Theory-Algorithm Development

Graph Theory is a mathematical discipline whose main object of study is the *graph*. A graph, X, consists of a vertex set V(X) and an edge set E(X) where each edge is an unordered pair of distinct vertices. The vertex set, V(X), is commonly thought of as a set of nodes and the edge set is a set that joins the vertices for a particular graph. Thus, every graph X will have its own unique vertex and edge set. For illustrative purposes, Figure 3 below shows the visual interpretation of graph X with a Vertex Set V(X) = {a,b,c,d,e,f,g}, and an Edge Set, E(X) = {(a,b), (a,d), (a,g), (b,g), (b,c), (c,e), (c,f), (d,e), (e,f)}.

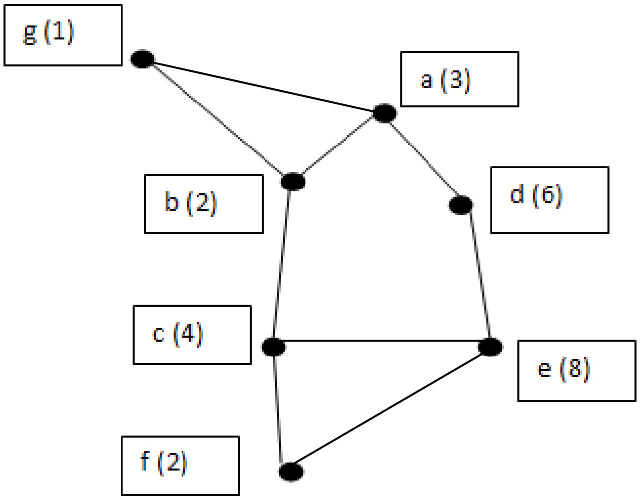

Figure 3: A graph of X with a Vertex Set, an Edge Set, and the Population at each vertex is given in parentheses.

This graph can be quantified using an adjacency matrix, as discussed in the preceding section. This matrix consists of 1's and 0's, where row *i* and column *j* are 1 if the edge *ij* is present in the graph. The adjacency matrix for graph X is shown (Figure 4). The connection between vertices *a* and *b* is represented with a 1 at the entry in the a-row and b-column. Because the edges have no direction, the matrix is symmetric. Thus, there is also a 1 at the a-column and the b-row.

A	a	b	c	d	e	f	g
a	0	1	0	1	0	0	1
b	1	0	1	0	0	0	1
c	0	1	0	0	1	1	0
d	1	0	0	0	1	0	0
e	0	0	1	1	0	1	0
f	0	0	1	0	1	0	0
g	1	1	0	0	0	0	0

Figure 4. Example adjacency matrix for graph X presented in Figure 3.

Additionally, a diagonal matrix can be constructed of the population at each vertex so that row *i* and column *i* consist of the population at vertex *i*. The population at vertex *a* is represented with a 3 at the entry in the a-row and a-column (Figure 5).

P	a	b	c	d	e	f	G
a	3	0	0	0	0	0	0
b	0	2	0	0	0	0	0
c	0	0	4	0	0	0	0
d	0	0	0	6	0	0	0
e	0	0	0	0	8	0	0
f	0	0	0	0	0	2	0
g	0	0	0	0	0	0	1

Figure 5. Example population matrix.

The key to the development of the algorithm is the multiplication of the adjacency matrix and the population matrix. This yields a matrix whose *ij* entry is the population of vertex *i* at vertex *j* if there is an edge (or connection) between vertices *i* and *j*. The *ji* entry is the population of vertex *j* at vertex *i* if there is an edge (or connection) between vertices *j* and *i*. Adding *ij* and *ji* together joins the population of vertices *i* and *j*, if there is a connection between the two (Figure 6). This can be seen in the PA matrix below. Please note that while the adjacency matrix is symmetrical, the population-adjacency matrix is not. The population at vertex *a* can be joined with the b-vertex, the d-vertex, and the g-vertex, which can be seen with the 3's in the a-row and the b-column, d-column, and g-column, respectively.

PA	a	b	c	d	e	f	g
a	0	3	0	3	0	0	3
b	2	0	2	0	0	0	2
c	0	4	0	0	4	4	0
d	6	0	0	0	6	0	0
e	0	0	8	8	0	8	0
f	0	0	2	0	2	0	0
g	1	1	0	0	0	0	0

Figure 6. Example PA matrix combining the adjacency matrix of Figure 4 with the population matrix of Figure 5.

In order to make the joining of the populations work, a symmetrical matrix must be constructed by adding PA to the transpose[1] of its matrix, AP. The result is below and shows a symmetrical matrix where the ij^{th} (and ji^{th}) entry is the combined population of vertices *i* and *j* if there is an edge between vertices *i* and *j*. Thus, PA + AP gives all possible combinations of pairs of areas that are connected to each other (Figure 7). The combined population of vertices *a* (population 3) and *b* (population 2) is shown with a 5 in the a-row and b-column. Similarly, the symmetry of the matrix shows that the b-row and a-column gives the same population of 5.

AP+PA	a	b	c	d	e	f	g
a	0	5	0	9	0	0	4
b	5	0	6	0	0	0	3
c	0	6	0	0	12	6	0
d	9	0	0	0	14	0	0
e	0	0	12	14	0	10	0
f	0	0	6	0	10	0	0
g	4	3	0	0	0	0	0

Figure 7. Example symmetrical matrix constructed by adding PA to the transpose of its matrix, AP, giving all possible combinations of pairs of areas that are connected to each other.

From this matrix, an evaluation can be made to determine which pairings meet (or have yet to meet) the constraints. Those groups which exceed the constraints can be eliminated from consideration. In this way, the number of possible combinations is continuously being reduced and the remaining entries meet (or are within) the constraints provided. Those that meet the constraints can be considered to be a district and remain in the matrix to see if other possible combinations exist.

This process can continue for grouping more than two areas. To group three contiguous areas, the same principle is applied. The population matrix would be the only change in that the combined population for vertices *i* and *j* can be input into either the ii^{th} or jj^{th} entries in the population matrices. The revised population matrix can again be multiplied by the adjacency matrix to arrive at the combined population of vertices *i* and *j* with the third vertex, *k*, if there is a

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[1] The transpose of PA can be proved to be formulated as $(PA)^T = AP$.

connection between vertices *j* and *k* or *i* and *k*. Figure 8 shows the revised population matrix with the population at vertices *a* and *d* combined into the *dd*th diagonal, which was determined from the AP+PA matrix above. The combined population of vertices *a* (population 3) and *d* (population 6) is shown with a 9 in the d-row and d-column. The population of the *a* vertex is set to 0 to conserve the population throughout the matrix.

P'	a	b	c	d	e	f	g
a	0	0	0	0	0	0	0
b	0	2	0	0	0	0	0
c	0	0	4	0	0	0	0
d	0	0	0	9	0	0	0
e	0	0	0	0	8	0	0
f	0	0	0	0	0	2	0
g	0	0	0	0	0	0	1

Figure 8. Revised population matrix for grouping 3 contiguous areas.

Figure 9 shows the result of the multiplication of the revised population matrix and the adjacency matrix. The combined population of vertices *a* (population 3) and *d* (population 6) with vertex *e* (population 8) is shown with a 17 in the e-row and d-column. All possible combination triplets starting with *a* and going through *d* are shown in the d-column. There is only 1 such possible combination, *ade*, which has a value of 17. The remaining columns play no role in the grouping of vertices *a* and *d* with other vertices.

AP'+P'A	a	b	c	d	e	f	g
a	0	2	0	9	0	0	1
b	2	0	6	0	0	0	3
c	0	6	0	0	12	6	0
d	9	0	0	0	17	0	0
e	0	0	12	17	0	10	0
f	0	0	6	0	10	0	0
g	1	3	0	0	0	0	0

Figure 9. Result of the multiplication of a revised population matrix and the adjacency matrix to group three contiguous areas.

Again, after this iteration, each entry can be evaluated for the constraints and any entries exceeding the constraints are removed. This algorithm of matrix multiplication and constraint evaluation can continue for more than three groupings until the areas have all been utilized or the number of districts has been reached. To the authors' knowledge, this aspect of graph theory has yet to be utilized in practical problems.

Algorithm Refinement

The algorithm can be refined for a large number of vertices by starting with the vertices with either the least number of connections[2] or the greatest population, or both. This presents the

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[2] The number of connections at each vertex can be determined by looking at the diagonals of the A^2 matrix.

limiting case, as only a small number of outcomes would be possible. Then each of these outcomes can be presented as a plausible scenario. Conversely, those vertices with the largest number of connections and the smallest population can be removed from the analysis and then added to the end. If the population of these vertices is truly insignificant, it would not affect the outcome. This process will be made clear in the results section below.

Results

Based on the 2012 U.S. Census block records of persons over 18 years of age clipped and proportionately adjusted to Austin voting areas, the estimated voting age population in Austin is 620,743 persons. The constraints given by the Voting Rights Acts and used in the algorithm were that the units in the 10 districts had to be contiguous and the districts must contain a voting age population in the range of 58,971 and 65,179 persons to be within 10% variation in size from the smallest to the largest district.

Three-letter watershed codes from the City of Austin Drainage Criteria Manual are used to represent watershed names. The population of the Walnut Creek (WLN) and Williamson Creek (WMS) watersheds exceeded the upper population similarity limit. WMS was split into two watershed units on a north-south line approximately following the eastern (downstream) Edwards Aquifer Recharge Zone boundary, and the subdivided units were named WMS1 and WMS2. WLN was split into two watershed units on an east-west line approximately at Sprinkle Road north of US 290 corresponding to the 2-mile extra-territorial jurisdiction boundary and the subdivided units were renamed WLN1 and WLN2. The Lady Bird Lake adjacent direct contributing areas cover irregular areas adjacent to the lake on both north and south shores. Including this as a singular watershed unit could prevent joining of watersheds north and south of Lady Bird Lake into combined districts. This area was split into 3 separate watershed units approximately at the MoPac/Loop 1 bridge and the Lamar Blvd bridge. The subdivided units were renamed LBL1, LBL2 and LBL3.

The process used by the algorithm in determining one plausible district configuration with watersheds as the primary unit began with examining the 72 x 72 population matrix of the 72 watersheds. The 27 watersheds with population less than 1,000 people were removed from the analysis. The result was a 45 x 45 population and adjacency matrix. Next the watershed with the highest population, WLN2 (Pop. = 62,790), was identified. Since this watershed was already near the maximum limit of the constraint range, WLN2 was determined to be its own district. This removed another watershed from the analysis.

The next two highest population watersheds were SHL (Pop. = 54,581) and WMS1 (Pop. = 48, 798). Because WMS1 had the lesser number of adjoining watershed connections, WMS1 was chosen as the limiting case from which all possible configurations would follow (Figure 10).

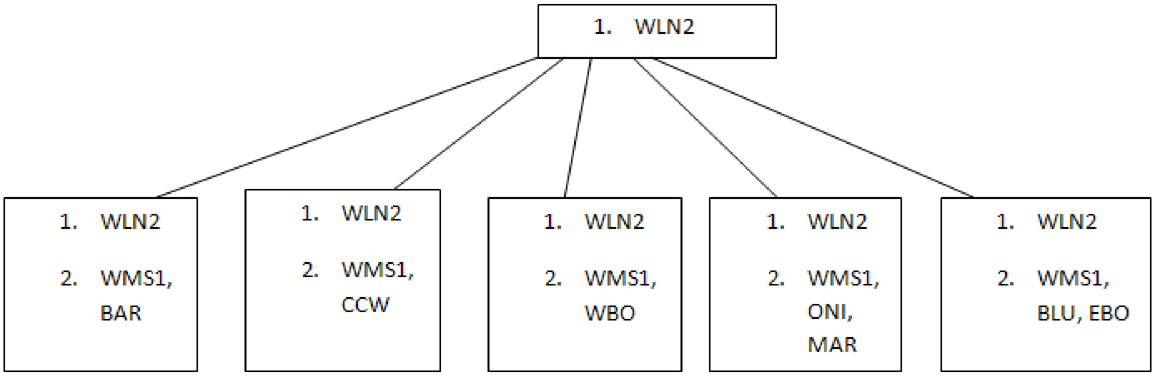

Figure 10: Beginning of the Decision Tree

Figure 10 shows the start of the decision tree to be used in determining the 10 districts. Since there were no other options for WLN2, there were no other possible configurations for WLN2. However, WMS1 had five options to meet the population constraints. These five options were obtained by first looking for all the pairs that met the constraints (using matrix multiplication) and then looking for all triplets that met the constraints (using matrix multiplication of the revised population matrix). From this, WMS1 could be joined with either:

- BAR;
- CCW;
- WBO;
- ONI and MAR; or
- BLU and EBO.

These five options are depicted as the five branches in Figure 10. The process will now continue along the WMS1, BAR branch. Ideally, the process would continue along each branch until there was a configuration that wouldn't work due to either connectivity or the constraints. While this process may seem formidable, the number of possible permutations decreases as units continue getting eliminated by going further down the branch.

Next, with WLN2, WMS1, and BAR eliminated from the analysis, SHL was chosen as the next limiting case due to its population size. From the matrix multiplication, there were four possibilities, which included two possible pairings a possible triplet, and a possible quadruplet (Figure 11).

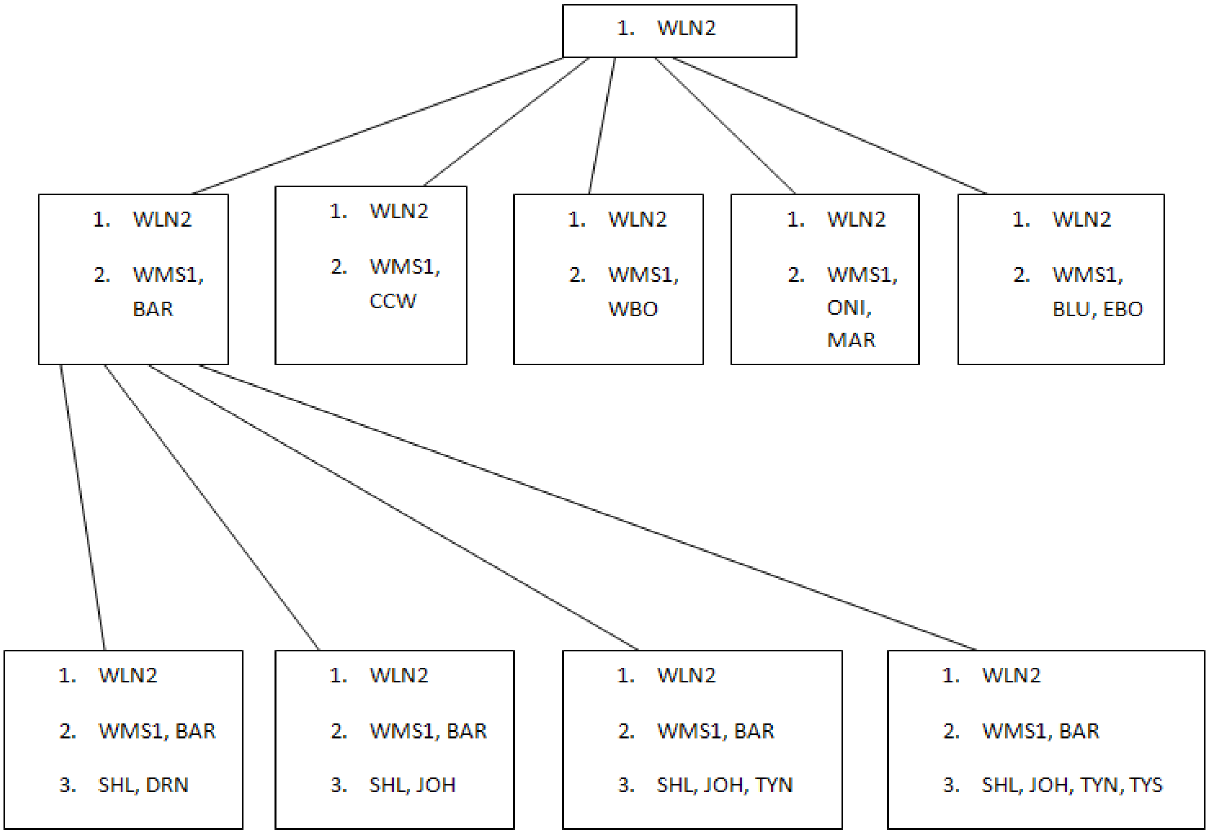

Figure 11: Another Step in the Decision Tree

Because the second and third branches are a subset of the fourth branch, those two branches can be eliminated from future possible configurations. Since the fourth branch used the most watersheds in its district, it was chosen in this report for continued examination. Again, ideally, both the first and fourth branch should be continued for evaluation. This process was continued until the ten districts were determined.

Watersheds with less than 1,000 people were initially excluded from the analysis. Based on the primary district delineation, these small areas were added to adjoining districts to yield combined districts which did not exceed the population limit and were as spatially compact as possible (Figure 12).

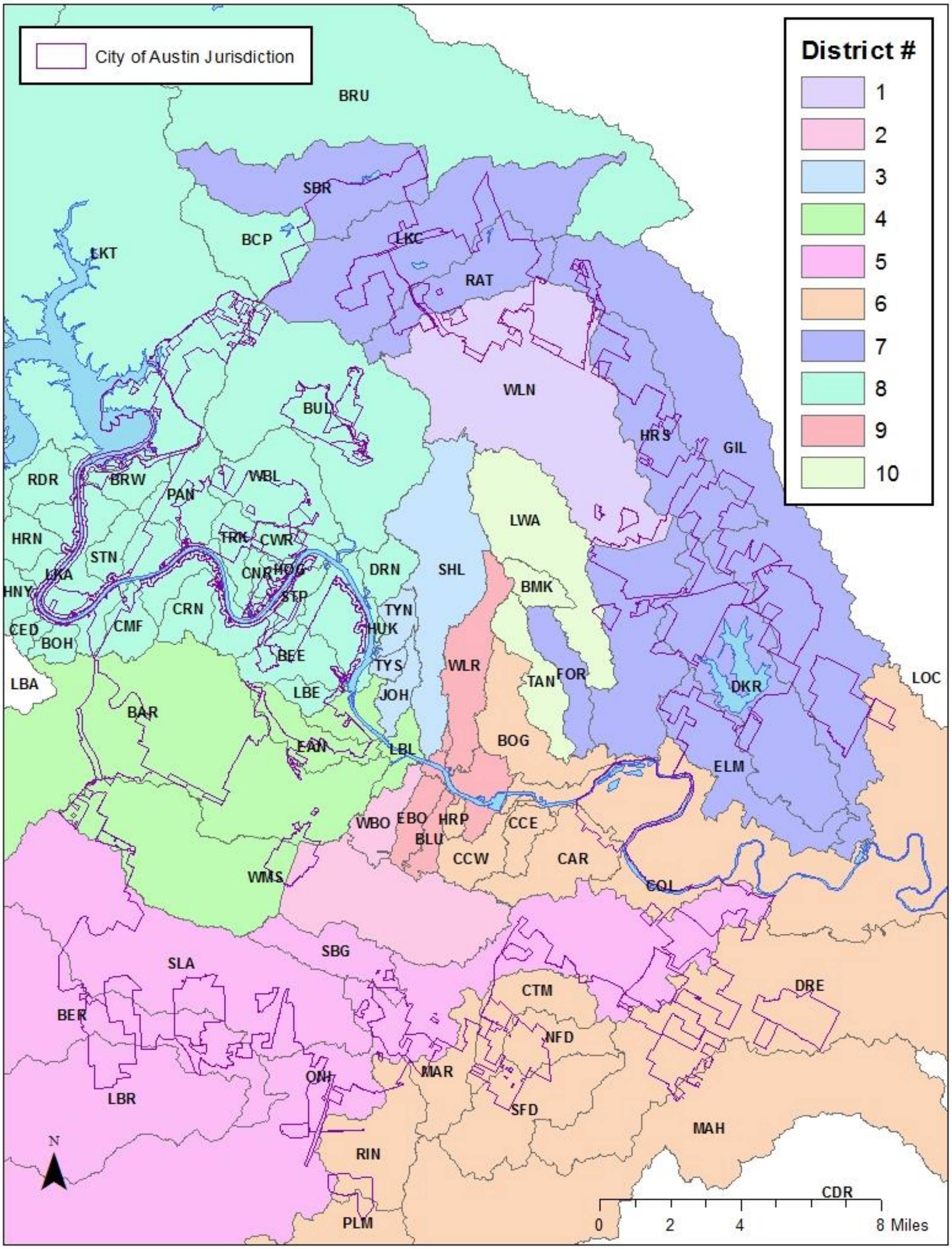

Figure 12. 10 voting districts delineated along watershed boundaries with City of Austin jurisdiction boundaries. Watersheds with the same color fall within the same voting district.

Table 1. Watersheds comprising the delineated districts.

District	Watersheds
1	Walnut (upstream half)
2	West Bouldin, Williamson (downstream half)
3	Johnson, Shoal, Taylor North, Taylor South
4	Barton, Eanes, Lady Bird Lake (western and central thirds), Williamson (upstream half)
5	Bear, Little Bear, Slaughter, South Boggy, Onion
6	Boggy, Carson, Colorado, Cottonmouth, Country Club East, Country Club West, Dry East, Harpers, Maha, Marble, North Fork Dry, South Fork Dry, Plum, Rinard,
7	Decker, Elm, Fort, Gilleland, Harris, Lake, Rattan, South Brushy, Walnut (downstream half)
8	Buttercup, Bee, Bohls, Brushy, Bear West, Bull, Cedar, Commons Ford, Connors, Cuernavaca, Coldwater, Dry North, Honey, Hog Hollow, Harrison, Hucks, Little Bee, Lake Austin, Lake Travis, Panther, Running Deer, Steiner, Stephens, Turkey, West Bull
9	Blunn, East Bouldin, Waller, Lady Bird Lake (eastern third)
10	Buttermilk, Little Walnut, Tannehill

Voting age population may be estimated for proposed district boundaries (Table 2). Overall, there is a 10.2% relative difference in the minimum and maximum voting age population within the districts relative to the average voting age population for all districts. Demographic information may be compared for any district with the citywide totals. Relative to citywide (within the voting area) total population, there are 7.8% African-American, 34.3% Hispanic-American, and 6.2% Asian-American residents according to 2012 U.S. Census estimates.

Table 2: Final District Delineation Outcome of One Path along the Decision Tree. VAP=voting age population, Total Pop=total population, # HU=number of housing units, COV=coefficient of variation, RPD=relative percent difference.

District	VAP	Area (mi^2)	Total Pop	%Black	%Hispanic	%Asian	# HU	%Age 65+
1	62,790	26.3	77,639	10.4	25.0	11.4	38,977	6.8
2	61,151	16.1	80,858	5.6	54.8	1.3	34,465	6.8
3	63,615	16.8	73,179	2.1	12.5	7.8	38,019	10.2
4	60,431	34.6	76,081	2.2	17.5	7.0	37,440	7.7
5	64,145	47.0	87,498	4.9	38.6	4.6	34,258	6.1
6	59,192	35.4	78,056	12.9	55.7	2.9	32,642	5.2
7	61,669	54.5	83,874	16.4	32.5	8.6	34,952	6.5
8	59,820	59.2	77,408	1.9	9.0	11.2	36,053	10.7
9	62,394	12.4	70,919	5.0	33.0	6.4	35,004	5.2
10	65,534	17.2	92,314	13.3	62.8	2.7	36,074	5.6
average	*62,074*	*32*	*79,783*	*7*	*34*	*6*	*35,788*	*7*
COV	*0.032*	*0.532*	*0.082*	*0.715*	*0.552*	*0.549*	*0.054*	*0.277*
RPD	*10.2*	*146.2*	*26.8*	*195.2*	*157.5*	*158.2*	*17.7*	*78.5*

Discussion

The results given by the algorithm provide one possible configuration for a district map composed of watersheds. This configuration has two districts spanning large areas on the eastern and southern periphery of the city as needed to generate sufficient voting age population. Based on a qualitative assessment, most of the other districts appear relatively compact. Given the irregular watershed shapes, it seems natural that district maps based on watersheds could appear gerrymandered, and may not be the most compact of all possible outcomes. Two watersheds were subdivided prior to input into the algorithm to account for population totals near constraint limits necessary, and the Lady Bird Lake adjacent area was subdivided into 3 watershed units to allow for possible north-south joining of watersheds across the river. If additional watersheds were subdivided into smaller but logical units, particularly for watersheds with high voting age populations, additional and potentially more compact delineations could be produced by the algorithm.

Other district configurations are possible given the mild constraints of similar populations within each district. However, the number of those configurations becomes increasingly smaller with each constraint added. For example, racial determination was not considered as a constraint in each delineated district. Given racial composition or voting block constraints, it is unclear whether the district map configuration given in this report would comply with applicable regulations.

The adjacency matrix used in this analysis was based on the citywide watershed GIS layer, and did not account for watershed areas clipped by City of Austin voting area boundaries. This would be an important consideration in officially delineating districts to ensure contiguous districts.

This Graph Theory algorithm provides a deterministic solution based on a range of possible configurations. One configuration based on watershed boundaries was selected for this report, but other configurations based on arbitrary delineations are possible. This configuration was not intended to be an ideal solution, but was intended to present one method to initiate district apportionment using a less biased approach recognizing criticality of water resources to the state and City of Austin. As demonstrated here, given a small number of staff working with the algorithm, various configurations can be presented to policy makers and the public for discussion.

Furthermore, as described by the principle of watershed governance, configuration of voting districts along watershed lines using an objective procedure as detailed here could reduce political dispute over district boundary delineation. This practice would be consistent with existing City of Austin land development and water quality regulations that recognize existing and inherent physiographic differences between watersheds. Disturbance conditions and ecological goals vary between watersheds, as do desired patterns of development as recognized by the citywide Imagine Austin Comprehensive Plan. Watershed based district configuration could also align districts with the function of several major city utilities. The Austin Water Utility designs and maintains service basin areas for wastewater collection that align in part with watershed boundaries. The Watershed Protection Department assesses the environmental integrity of 50 watersheds citywide on a routine basis, and uses watershed-specific information to prioritize capital improvement projects that address water quality, flooding and erosion problems.

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