Technical Appendix

In this appendix I present maps of the study cities that show the location of Home Owner's Loan Corporation (HOLC) Residential Security rating categories provided by the Mapping Inequality project (Nelson et al., 2018). The shaded polygons in Figures A1 through A3 represent varying levels of investment risk informed in part by racial and ethnic bias: A is "Best"; B, "Still Desirable"; C, "Definitely Declining"; and D, "Hazardous" (Jackson, 1980). This appendix also provides further details on how I derived estimates of land surface temperature from Landsat 8 image bands for each of the three cities considered. Table A1 reports the date and time of acquisition for each of the six satellite images used in this study. In addition to cloud cover percentage across the entire 170 × 185 km (106 × 115 mi) scene, the recorded maximum, minimum, and mean temperatures at the local airport for each image acquisition date are also given.

Table A1. Landsat 8 imagery characteristics.

City	Date	Time	Cloud cover (%)	Airport max temp (hist. mean)	Airport min temp (hist. mean)	Airport mean temp (hist. mean)
Baltimore, MD	8/22/2017	3:46 p.m.	0.72	92 °F (85 °F)	70 °F (65 °F)	81 °F (75 °F)
	7/8/2018	3:45 p.m.	0.06	83 °F (87 °F)	56 °F (67 °F)	70 °F (77 °F)
Dallas, TX	8/29/2018	5:01 p.m.	1.29	99 °F (96 °F)	79 °F (75 °F)	89 °F (85 °F)
	6/13/2019	5:01 p.m.	2.61	88 °F (91 °F)	64 °F (71 °F)	76 °F (81 °F)
Kansas City, MO	7/25/2017	5:00 p.m.	0.02	95 °F (89 °F)	71 °F (69 °F)	83 °F (79 °F)
	8/19/2017	4:54 p.m.	0.01	91 °F (87 °F)	65 °F (67 °F)	78 °F (77 °F)

Source: USGS EarthExplorer, Mesonet API

I intentionally chose the images for each city to capture different temperature conditions to assess whether the observed patterns in land surface temperature (LST) distribution across the city are stable on days that are more and less hot. As shown in Figures A1 through A3, formerly redlined areas of the generally exhibited higher mean LST for both images considered.

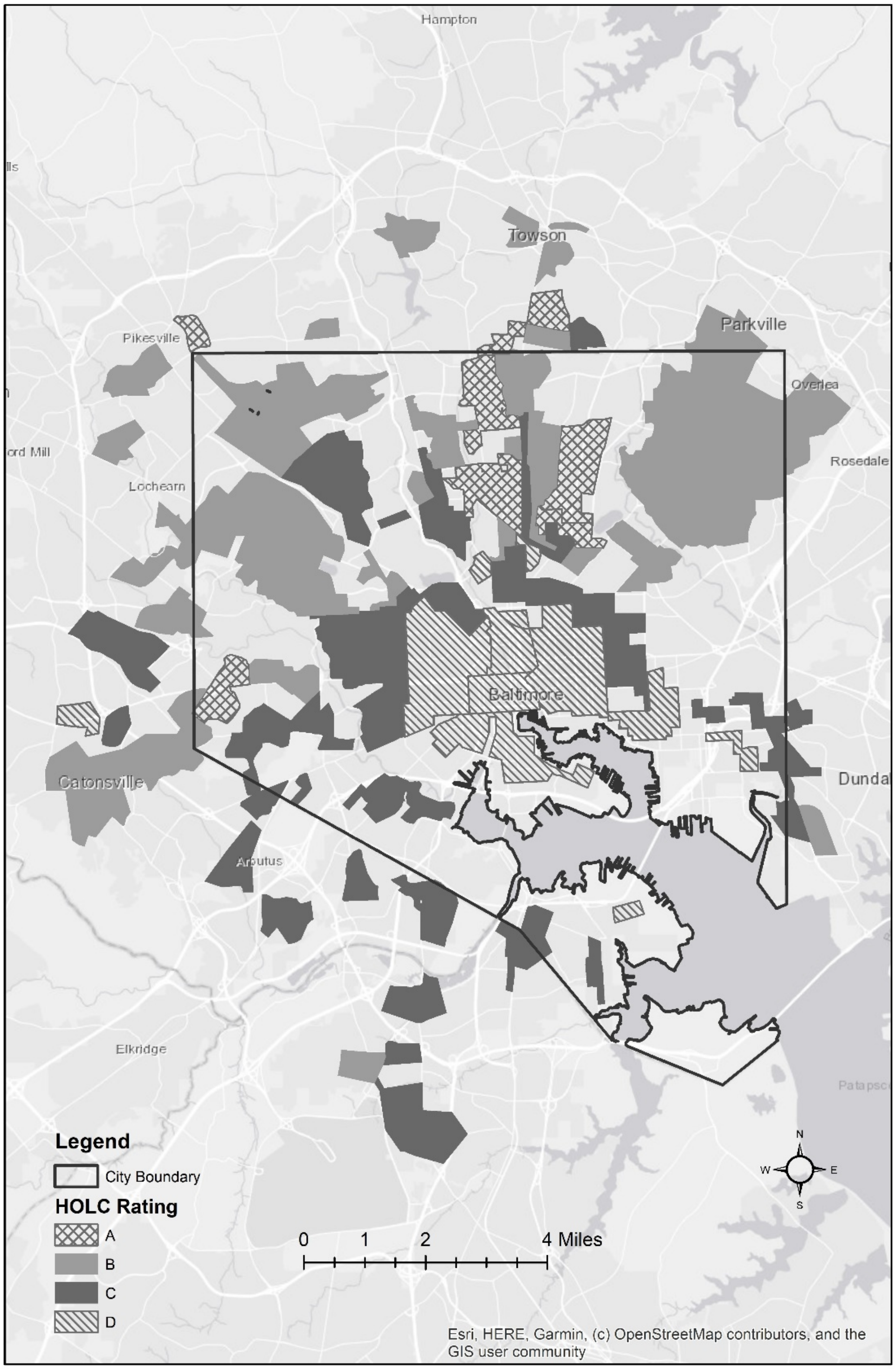

Figure A1. Baltimore boundary with HOLC classes. Source: U.S. Census Bureau, University of Richmond Mapping Inequality project.

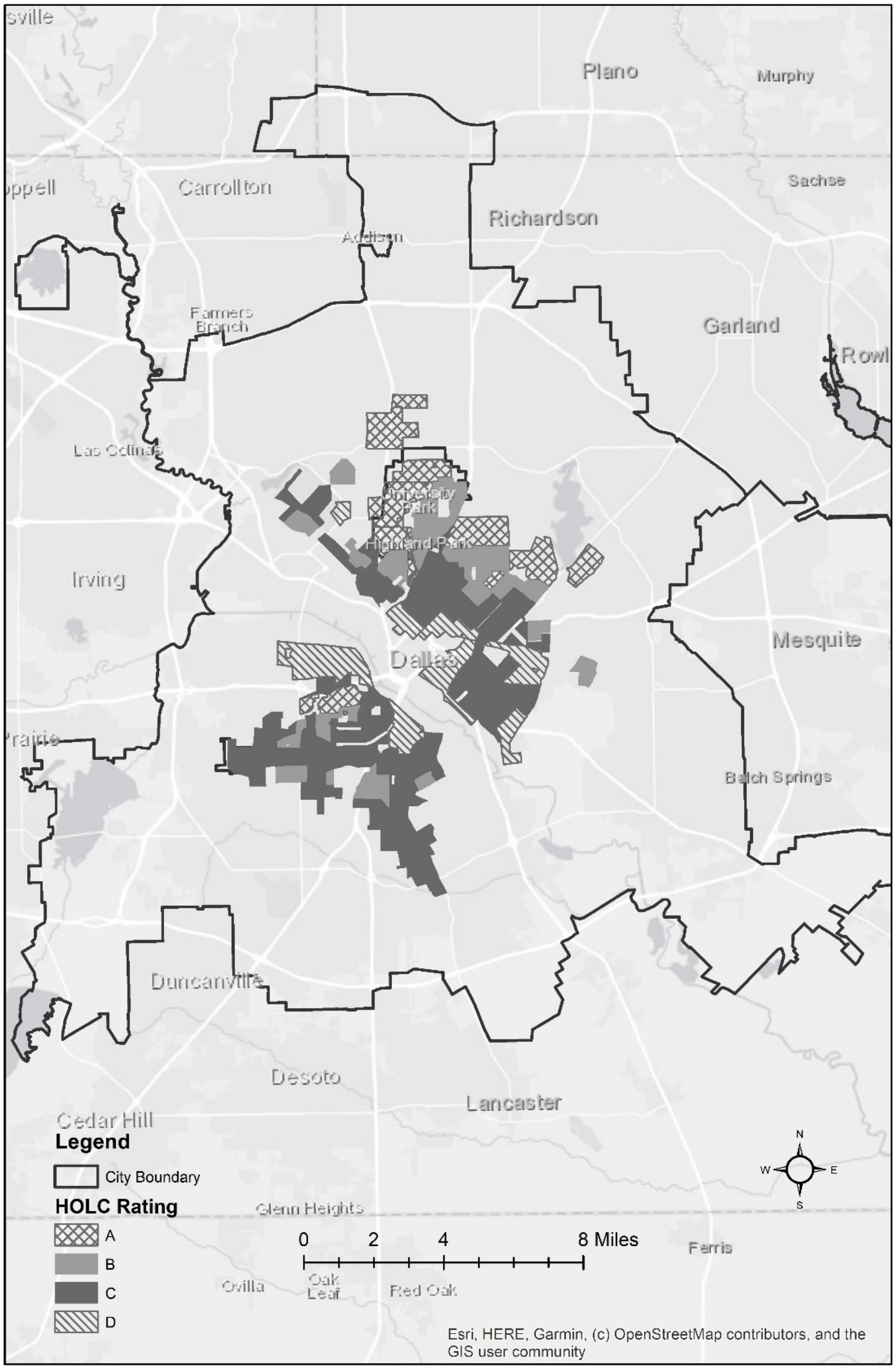

Figure A2. Dallas boundary with HOLC classes. Source: U.S. Census Bureau, University of Richmond Mapping Inequality project.

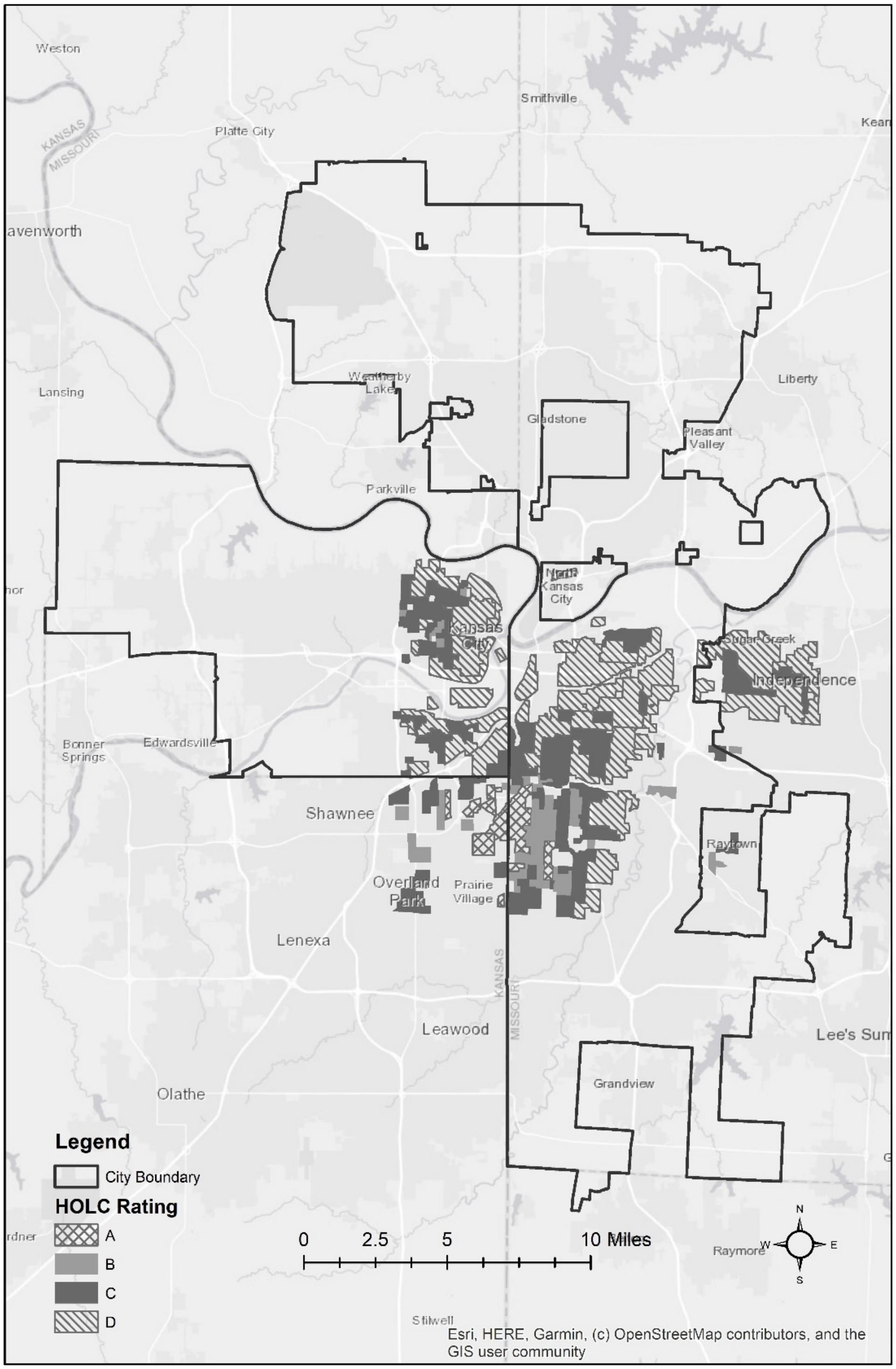

Figure A3. Kansas City boundary with HOLC classes. Source: U.S. Census Bureau, University of Richmond Mapping Inequality project.

Landsat images include two thermal bands collected at 100 m^2 spatial resolution, but these are resampled to 30 m^2 resolution to be consistent with the other bands before they were available to users. I used parameters from the image metadata to convert the digital numbers (raw data values) in Band 10 of each image used in this study to top of atmosphere (TOA) spectral radiance, then brightness temperature as described in greater detail in the *Landsat 8 Data Users Handbook* (Zanter, 2018). Normalized difference vegetation index (NDVI) is a unitless measure of vegetative cover that ranges between –1.0 and +1.0, with values closer to +1.0 suggesting more vegetation in a pixel consistent with forests or dense crop cover. The NDVI was calculated as the ratio of the difference in Band 5 (near-infrared) and Band 4 (red) to the sum of Band 5 and Band 4 as shown in Equation 1.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad [1]$$

Land surface emissivity is a measure of how much incoming radiation is reflected back out into the atmosphere, relative to a theoretical "blackbody" object that absorbs and emits all incoming radiation. The true emissivity value for an object or land cover lies between 0 and 1 (Jin & Liang, 2006) but "the composite emissivity values for urban mosaics are rarely known" (Kwarteng & Small, 2010). Land surface emissivity (LSE) was estimated from the proportion of vegetation in each pixel after Sobrino et al. (2004), where pixel-level variation in LSE is approximated by using the estimated proportion of vegetation[1] to modify what would otherwise be a static emissivity value (Van de Griend & Owe, 1993). Land surface emissivity (LSE) was estimated from the proportion of vegetation in each pixel after Sobrino et al. (2004).

$$LSE = (0.004 * PV) + 0.986 \qquad [2]$$

The proportion of vegetation (PV) in each pixel was estimated from NDVI as the squared ratio of pixel's NDVI value minus the minimum NDVI in image to the difference between the maximum and minimum NDVI values in the image (Carlson & Ripley, 1997). Finally, LST was estimated according to the single window method outlined by Jiménez-Muñoz et al. (2009).

$$LST = \frac{BT_{10}}{1 + \frac{0.00115 * BT_{10}}{1.4388} * \ln(LSE)} \qquad [3]$$

Here, BT_{10} is brightness temperature as measured at the sensor, *LSE* is land surface emissivity described above, the band-specific wavelength of emitted radiance is 0.00115, and 1.4388 is an atmospheric constant.

References

Carlson, T. N., & Ripley, D. A. (1997). On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, *62*(3), 241–252.

Jackson, K. T. (1980). Race, ethnicity, and real estate appraisal: The home owners loan corporation and the federal housing administration. *Journal of Urban History*, *6*(4), 419–452.

Jin, M., & Liang, S. (2006). An improved land surface emissivity parameter for land surface models using global remote sensing observations. *Journal of Climate*, *19*(12), 2867–2881.

Kwarteng, A., & Small, C. (2010). Remote sensing of urban environmental conditions. In T. Rashed & C. Juergens (Eds.), *Remote sensing of urban and suburban areas* (pp. 267–287). Dordrecht, The Netherlands: Springer.

Jiménez-Muñoz, J. C., Cristóbal, J., Sobrino, J. A., Sòria, G., Ninyerola, M., & Pons, X. (2009). Revision of the single-channel algorithm for land surface temperature retrieval from Landsat thermal-infrared data. *IEEE Transactions on Geoscience and Remote Sensing*, *47*(1), 339–349.

Nelson, R. K., Winling, L., Marciano, R., & Connolly, N. (2018). *Mapping inequality.* Retrieved from https://dsl.richmond.edu/panorama/redlining

Sobrino, J. A., Jiménez-Muñoz, J. C., & Paolini, L. (2004). Land surface temperature retrieval from LANDSAT TM 5. *Remote Sensing of Environment*, *90*(4), 434–440.

Van de Griend, A. A., & Owe, M. (1993). On the relationship between thermal emissivity and the normalized difference vegetation index for natural surfaces. *International Journal of Remote Sensing*, *14*(6), 1119–1131.

Zanter, K. (2018). *Landsat 8 (L8) data users handbook.* Sioux Falls, SD: U.S. Geological Survey. Retrieved from https://www.usgs.gov/land-resources/nli/landsat/landsat-8-data-users-handbook

Note

[1] Water and vegetation have emissivity values closer to 1.0, but even impervious surfaces and bare soils have emissivity values greater than 0.9.